

# **GEOARCHAEOLOGY OF ST. CATHERINES ISLAND, GEORGIA**

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## ABSTRACT

This edited volume addresses the geoarchaeology of St. Catherines Island (Georgia). The field of geoarchaeology has typically been defined as either *geology pursued within an archaeological framework* or (sometimes the reverse) *as archaeology framed with the help of geological methodology*. Either way, the formalized objectives of geoarchaeology define a broad range of pursuits, from placing archaeological sites into relative and absolute temporal context through the application of stratigraphic principles and absolute dating techniques, to understanding the natural processes of site formation, to reconstructing the landscapes that existed around a site or group of sites at the time of occupation.

The editors of this volume have generally followed the lead of G.R. Rapp and C.L. Hill (2006, *Geoarchaeology: The Earth-science Approach to Archaeological Interpretation*) by stressing the importance of multiple viewpoints and methodologies in applying geoscience techniques to evaluate the archaeological record. In the broadest sense, then, *Geoarchaeology of St. Catherines Island* applies multiple earth science concepts, techniques, or knowledge bases to the known archaeological record and the processes that created that record.

This volume consists of 16 papers presenting the newest research on the stratigraphic and geomorphological evolution of the St. Catherines Island landscape. Of particular interest are presentations addressing the relative timing and nature of sedimentation, paleobiology, sea level change, stream capture, hydrology, and erosional patterning evident on St. Catherines Island (and to some degree the rest of the Georgia Bight). These papers were initially presented at the Fourth Caldwell Conference, cosponsored by the American Museum of Natural History and the St. Catherines Island Foundation, held on St. Catherines Island (Georgia), March 27–29, 2009.

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ST. CATHERINES ISLAND, GEORGIA, MARCH 27–29, 2009

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## PREFACE

GALE A. BISHOP, HAROLD B. ROLLINS, AND DAVID HURST THOMAS

The Fourth Caldwell Conference was organized to bring together a small group of researchers interested in addressing questions relating to the archaeology, geoarchaeology, and paleobiology of the American Southeast. The topic of this symposium was *Geoarchaeology of St. Catherines Island and the Georgia Bight*. The various papers discuss the newest research relating to the stratigraphic and geomorphological evolution of the St. Catherines Island landscape. Of particular interest are presentations addressing the relative timing and nature of sedimentation, sea level change, stream capture, hydrology, and erosional patterning evident on St. Catherines Island and the Georgia Bight. The papers in this volume were presented at that conference, which was sponsored by the American Museum of Natural History and held on St. Catherines Island (Georgia), March 27–29, 2009.

David Hurst Thomas begins the volume with a consideration of *geoarchaeology* as played out on St. Catherines Island and the Georgia Bight.

After considering several widespread definitions of geoarchaeology, he defines three generations of “geoarchaeological” thought among American archaeologists. The pioneers relied heavily on the seminal organizing principles of geology—the concepts of *superposition* and *index fossil*. Thomas Jefferson was the first geoarchaeologist (at least in America) and Thomas argues that the legacy of first-generation geoarchaeology has conditioned archaeological practice until fairly recently, perhaps only two or three decades ago. The second generation of geoarchaeology (in which Thomas includes himself) spans the late 1970s through the present. Most of the archaeology of St. Catherines Island was conducted under this paradigm and Thomas suggests that these archaeologists transcended the purely temporal-spatial to explore more far-reaching objectives with a plethora of new methods and technologies. The third (contemporary) generation of geoarchaeology has the opportunity to build upon this foundation, elucidating and merging the natural



Participants in the Fourth Caldwell Conference, standing in front of the stratified paleosols exposed at Yellow Banks Bluff on the northeastern margin of St. Catherines Island, March 27–29, 2009: (left to right) Gale Bishop, Royce Hayes, Patty Stahlman, Anna Semon, Tim Chowns (in the back), Tony Martin (in the front), Frank Vento, Bud Rollins, Rachel Cajigas, Stan Riggs (seated in the front), Fred Rich, Brian Meyer, Kelly Vance, Bran Potter, Lori Pendleton, Bob Booth, Chester DePratter, Dave Thomas, Christina Friberg, and Guinness Mahar.

and cultural past in unprecedented ways. Thomas concludes chapter 1 with a six-pack of suggestions for third generation geoarchaeologists working on St. Catherines Island and her surrounding waters.

In chapter 2, Fredrick J. Rich, Anthony Vega, and Frank J. Vento review the evolution of Late Pleistocene climates and environments in the American Southeast, with special emphasis on St. Catherines Island and the Georgia Bight. They order their contribution in chronological fashion, beginning with discussions of the oldest-dated deposits, and proceeding to the time of first European contact.

The most ancient floras in this area date back more than 50,000 years, an artificial limit defined by the accuracy of radiocarbon technology. The Wisconsinan glacial phase of the Pleistocene Epoch peaked at approximately 18,000  $^{14}\text{C}$  yr B.P., when permanent ice covered most of North America north of the Ohio River and extended across the pole to cover much of Europe and Asia. Glacial maximum winds were primarily from the northwest and most of North America was within the cold, dry, circumpolar vortex leading to a boreal climatic regime for eastern North America. During this glacial maximum, sea levels fell as much as 170 m (550 ft) below current levels as vast stores of water were locked in the continental ice sheets.

During the last glacial maximum (18,000  $^{14}\text{C}$  yr B.P.), the average jet stream position migrated to approximately the Gulf Coast region and much of eastern North America was overlain by cold and dry polar air. For much of the American Southeast, jet stream amplifications were relatively unimportant as the region lay primarily within persistent cool, dry conditions. St. Catherines Island, and all the other barrier islands on the East Coast were far inland and must have been incorporated as parts of the coastal plain. Familiar southeastern plant taxa include *Pinus*, *Quercus*, *Carya* (probably pecan), and *Liquidambar* and there is quite a diversity of herbaceous plants, including grasses, sedges, ferns, and *Sphagnum*. Assuming that the flora of the Southeast remained fairly stable during the Late Glacial Maximum, and for the first few thousand years following glacial retreat, it would appear that the major environmental variable to affect the Georgia coastal plain was the presence or absence of the ocean itself.

Following two meltwater pulses, a period of ice mass stabilization, the Younger Dryas cold

interval ensued and lasted until about 11,500  $^{14}\text{C}$  yr B.P. While the cause of the Younger Dryas is still debated, it was likely centered on atmospheric and oceanic circulation changes induced by cold meltwaters from the retreating Laurentide Ice Sheet. The authors review the sparse palynological and paleobotanical evidence from the Southeast during the Younger Dryas, which ended as a new atmospheric/oceanic equilibrium and renewal of climatic amelioration began. Evidence indicates that the Younger Dryas ended as abruptly as it began.

The period 9000–8000  $^{14}\text{C}$  yr B.P. marked a continuation of cool-season zonal flow, but potentially higher warm-season evapotranspiration rates led to prominent drying throughout the American Southeast. Conditions abruptly changed during the Atlantic (8000–4500  $^{14}\text{C}$  yr B.P.) climatic episode, as wetter conditions prevailed. The subboreal, at 4500–3000  $^{14}\text{C}$  yr B.P., marks another abrupt transition to a drier climate regime. The dryness was likely induced by expansion of the Bermuda-Azores anticyclone, particularly during the warm season. By the Sub-Atlantic period (3000–2000  $^{14}\text{C}$  yr B.P.) the climate system transitioned to conditions similar to the present. This engendered more frequent and greater magnitude midlatitude cyclone migrations throughout the study region, resulting in an overall increase in moisture.

In chapter 3, Gale A. Bishop, Brian K. Meyer, R. Kelly Vance, and Fredrick J. Rich summarize the history of geological research on St. Catherines Island. Programs by the University of Pittsburgh, the American Museum of Natural History, Sewanee University, and Georgia Southern University developed relatively independently over the past two or three decades, primarily because of asynchronous living constraints on St. Catherines Island. But these programs have become more collaborative and synergistic over time, culminating in the highly collaborative research published as *Native American Landscapes of St. Catherines Island* (Thomas, 2008: esp. chaps. 3, 4, 5, and 29). This three-volume monograph summarized what was known about the geological foundation and origin of the island, and the history of colonization by the first St. Catherines islanders. Geoarchaeology to date has largely focused on the timing and the history of sea level change on St. Catherines Island (and along the Georgia Bight) and its eventual effect on human occupation of

St. Catherines Island. This chapter reviews that literature and traces the lines of thought about the geologic history of the Georgia Bight, with a particular focus on St. Catherines Island.

As sea level continues its inexorable rise due to global warming, other anthropogenic conditions (damming of upstream rivers and dredging of the Savannah ship channel) on the southeastern coast have combined to decrease the southward longshore sediment flow along the Atlantic Coast, significantly increasing erosion of St. Catherines Island, Georgia's most vulnerable sentinel island.

In chapter 4, Frank J. Vento and Patty A. Stahlman argue that paleosols as allogenic genetic units (now buried cumulic A horizons) document prolonged episodes of stability and afford excellent chronostratigraphic marker horizons recognizable throughout the eastern United States. On the other hand, autogenic genetic units (e.g., a sand horizon from a large flood or hurricane is a one-day event) are locally developed, the result of a circumscribed event that is constrained geographically and/or environmentally. Genetic units can also provide important information on the responses of near-shore marine and fluvial systems to Holocene climate change, and aid in archaeological site prediction. The driving mechanisms for prolonged changes in the sea levels and fluvial regimes in the eastern United States were ablation of the Laurentian ice sheet and changes in atmospheric circulation. Paleosols on stable/fixed barrier islands along the coast of Georgia appear to reflect these changes in eustatic sea level and atmospheric circulation.

Beginning in April of 2008, Vento and Stahlman began preliminary geomorphological investigations at St. Catherines Island, identifying and dating a series of now buried terrestrial paleosols at Yellow Banks Bluff, an extensive outcrop of Pleistocene sand on the eastern shore of St. Catherines Island. The uppermost paleosol has been dated to about 6440  $^{14}\text{C}$  yr B.P. Three lower buried A horizons have yielded dates of approximately 10,800, 13,600, and 22,800  $^{14}\text{C}$  yr B.P., while a probable cultural feature lying above these paleosols has yielded a date of 6270  $^{14}\text{C}$  yr B.P. These paleosols potentially provide important information on eustatic sea levels, climate change, and the occurrence of deeply buried prehistoric cultural resources.

In chapter 5, Anthony J. Martin and Andrew K. Rindsberg also discuss the outcrop at Yellow

Banks Bluff, previously interpreted as containing marine hardgrounds formed during a pre-Silver Bluff Pleistocene highstand. Their interpretation of the outcrop and its trace fossils favors storm-washover fans deposited behind dunes, and rejects a marine origin. Trace fossils within thin, dark-brown beds within the outcrop are identified as burrows made by fiddler crabs (*Uca* spp.), which formed on washover fans as poststorm colonization surfaces. This interpretation is based on the burrows' distinctive J-shaped forms and networks (*Psilonichnus* [ichnospecies] and *Thalassinoides* [isp.], respectively), as well as analogous colonization by fiddler crabs observed in modern washover fans on the island. Vertical root traces crosscut the Yellow Banks Bluff deposits in places; infaunal insects then burrowed root traces, as evidenced by pervasive and multiple generations of backfilled burrows (*Taenidium* isp.). At least a few root and insect traces within the outcrop, however, are modern, potentially complicating paleoenvironmental interpretations. In one exposure south of (and below) Yellow Banks Bluff, a black peaty mud containing pinecones and terrestrial wood represents a freshwater-swamp channel deposit, further corroborating a terrestrial context to laterally adjacent and crosscutting facies. Facies of Yellow Banks Bluff are thus interpreted as eolian (foredune) succeeded by washover fans and backdune meadows. Biogenically reworked tree-root traces and associated facies are similar to those interpreted in the Raccoon Bluff formation (Pleistocene) on Sapelo Island, hinting at possible paleoenvironmental and stratigraphic equivalence. In short, the sea level history of Yellow Banks Bluff facies indicates sea level only slightly higher than that at present. Martin and Rindsberg suggest that research should focus on further confirmation of age determinations, possible correlation of Yellow Banks Bluff with similar outcrops in the Georgia barrier islands, and interpretation of distinctive trace fossil assemblages that may be diagnostic of specific paleoenvironments.

In chapter 6, Fredrick J. Rich and Robert K. Booth discuss the Quaternary vegetation and depositional history of St. Catherines Island. Arguing that St. Catherines is one of the least disturbed of the barrier islands along the Georgia coastline, they summarize a suite of studies, conducted over the past several decades, on the geological development, current vegetation, and vegetational history. Maps and descriptions of the principal plant

communities currently on the island have been developed by several investigators and ethnobotanical studies reveal some information on the composition of plant communities prior to European disturbance. A longer-term perspective on the vegetation and developmental history of the island is provided by lithostratigraphic studies of pollen preserved in a range of depositional environments. Rich and Booth distill and summarize the palynological work performed on St. Catherines Island over the past decade. The distribution of sites is scattered, the ages of deposits are not systematically distributed, and the available records are discontinuous, so this compilation cannot be seen as the result of a comprehensive study. But the accumulation of data of different ages from many localities shows that the sediments of St. Catherines Island contain a wealth of palynological and paleoecological information that bears on our understanding of ancient terrestrial ecosystems of the Georgia coastal plain.

Rich and Booth conclude that, in very general terms, the core of St. Catherines Island is of Pleistocene age, though it is unclear just when the island first took form, or if it developed over a long period of time and intermittently. The oldest floras from that ill-defined period of island development appear to come from Yellow Banks Bluff and the greatest depths at Cracker Tom and the St. Catherines Shell Ring. Between about 6000 and 4000 years ago, the island began to flood, and the now-vanished feature known as Guale Island disappeared as a rising sea level brought the forces of erosion and longshore drift to the eastern margin of St. Catherines Island. The establishment of current hammock and marsh plant communities at the Cracker Tom locality occurred some time after 3200  $^{14}\text{C}$  yr B.P. The southern end of the island (south of the Cracker Tom locality) subsequently developed, and the flora that was encountered by Spanish explorers came to occupy the island. The rapidity of the physical and biological changes that occurred during that episode of island development probably cannot be overstated.

In chapter 7, Donald B. Potter, Jr., reports on recent shoreline erosion and vertical patterns evident on St. Catherines Island, a Holocene-Pleistocene barrier island with no artificial structures on the beach. Measurement of shoreline retreat on the east and north shores, begun in 1974 by Donald McClain, has been expanded over the past 20 years to include more than 30 stations. On the north shore a 1.0 to 1.5 m/yr southward

migration of the beach into a forested Holocene dune field has left dead standing pines below the high tide mark. Growth of a large bar at the northeastern tip of the island has provided protection from wave energy for Holocene beach sands and the northernmost Pleistocene bluff along the east shore of the island, where up to 20 m of lateral accretion has occurred below the 4 m high bluff. In contrast, the southern 0.5 km long stretch of this Pleistocene bluff has eroded at rates ranging from 1.6 m/yr to 2.7 m/yr since 1996.

South Beach has the highest rates of erosional retreat. Freshwater Flag Pond, 1.5 km long, was breached by 10.4 m of lateral erosion by storm waves in the winter of 1992–1993 and is now flooded daily at high tide. Breaching is underway at Beach Pond, the remaining fresh water pond along the eastern shore. Retreat between Beach and Flag ponds has averaged 1.6 m/yr for the past eight years. Estimates for longer periods of erosion, based on comparisons of aerial photographs and present shoreline positions, reveal erosion rates for the Flag Pond area of 2.3 m/yr from 1972 to 2008 and rates of 5.4 m/yr in the southernmost marsh at latitude 31° 33' 50".

In chapter 8, Harold B. Rollins, Kathi Beratan, and James E. Pottinger assess the effects of Hurricane Hugo in 1989 on the geomorphology of the northern end of St. Catherines Island. During the fall of 1995 and late spring of 1996, they made detailed field maps of beach ridges observed at two specific locations along preselected baselines (at North Beach and also Picnic Point). They also employed panchromatic and natural color aerial photographs, dating back to the 1950s and ranging in scale from 1:10,000 to 1:60,000; to minimize effects of differences in tidal cycles, these aerial photographs were standardized by locating the High Water Line (HWL) on each photograph. Photographs were georectified and corrected for distortion. Combining these methods, the authors demonstrate how this single storm event was correlated with the construction of a set of three beach ridges along the northern end of the island. Hurricane Hugo apparently triggered an interval of net import of sediment shoreward in this area, interrupting the normal ebb-dominant export of sediment to a more offshore marginal shoal. Perturbation of inlet dynamics appears noticeable over mesoscale intervals of time correlating with fluctuating intervals of violent and quiescent Atlantic coastal storm activity.

In chapter 9, Timothy M. Chowns examines

drainage changes in the Ossabaw, St. Catherines, and Sapelo sounds, and discusses their significance to island morphology and spit building on St. Catherines Island. He argues that the Holocene transgression has encouraged the straightening of river estuaries on the Georgia coast so that most flow directly into the ocean and form a right angle with the coast. Chowns hypothesizes that many of these estuaries were formerly diverted to the south by the development of spits, probably during a minor regression between about 4300 and 3600 cal B.P. He argues that by decreasing the volume of the tidal prism, and releasing sand to the longshore transport system, stillstand (or minor regression) favors wave over tidal processes. By contrast, the modern transgression has increased the volume of the tidal prism and trapped sediment upstream in the estuaries, thus initiating the present tide-dominated system that prevails at the head of the Georgia Bight.

Chowns suggests that the modern inlet at Ossabaw Sound is of recent origin, formed by the breaching of Silver Bluff and Holocene beach ridges by storm avulsion. St. Catherines Sound and Sapelo Sound are possible locations of earlier breaches. The breaching of Sapelo Sound may have decapitated a spit at the southern end of St. Catherines Island to form Blackbeard Island and left an abandoned channel beneath Blackbeard Marsh. Similarly, the breaching of St. Catherines Sound may have dissected a spit at the southern end of Ossabaw Island to form "Guale Island" with an abandoned channel beneath "Guale Marsh." With the infilling of Blackbeard and "Guale" marshes, Blackbeard Island became part of Sapelo Island and Guale Island became part of St. Catherines.

A conservative interpretation ascribes these changes to the local switching of distributaries between adjacent existing inlets, while a more radical interpretation suggests that the breaches may have formed as the result of flooding and segmentation of the lower Ogeechee valley. In this case the Ogeechee may have occupied the low country between the Princess Anne and Silver Bluff beach ridges as an original tributary of the Altamaha. In either case avulsion is most likely to have occurred as a consequence of storm flooding in the back-barrier marshes.

Chowns suggests that to test these hypotheses and to provide a time line, it is necessary to establish absolute dates for the proposed changes. To this end, he has begun a program of  $^{14}\text{C}$  and

luminescence dating of the inlet breaching and the redistribution of sand onto St. Catherines Spit. The approximate ages of beach ridges on St. Catherines Island are known from archaeological sites but these might be refined with luminescence dates from quartz sands from the old dune lines. In this way, he could establish a correlation between changes in inlet position and the formation of different sets of beach ridges. Perhaps there is a connection to settlement patterns and cultural changes on the islands.

In chapter 10, Gale A. Bishop, David Hurst Thomas, Matthew C. Sanger, Brian K. Meyer, R. Kelly Vance, Robert K. Booth, Fredrick J. Rich, Donald B. Potter, and Timothy Keith-Lucas discuss the various vibracores and vibracore transects that have been drilled on St. Catherines Island to date. Stratigraphic relationships and  $^{14}\text{C}$  dates constrain the Central Core of St. Catherines as at least Pleistocene in age, and basal strata of fern peats indicate that sea level had risen to -4.0 m by approximately 6020  $^{14}\text{C}$  B.P., surrounding the island with brackish water and cutting it off from the mainland.

The Cracker Tom Transect penetrates the Holocene accretional terrains on the Atlantic front of the island, and extends into the underlying Pleistocene, thereby connecting Back Creek Village to the ancient geomorphology along the front side of St. Catherines Island. The St. Catherines Shell Ring Transect penetrates through marsh mud and oyster bioherms into the Pleistocene substrate and connects St. Catherines Shell Ring into the ancient geomorphology of the back side of St. Catherines Island. In both transects, basal peat was penetrated at total depth of vibracoring and dated with  $^{14}\text{C}$  methods. The peat beds were dominated by *Woodwardia* fern spore and detritus, providing the oldest dates on St. Catherines Island ( $47,620 \pm 2500$   $^{14}\text{C}$  B.P. at Cracker Tom Bridge and  $39,110 \pm 660$   $^{14}\text{C}$  B.P. at the St. Catherines Shell Ring). Oyster shell from a marsh mud at St. Catherines Shell Ring also provided an old date ( $> 44,800$   $^{14}\text{C}$  B.P.). Overlying the terrestrial peat deposits in the Cracker Tom Transect, evidence of aerial exposure, charcoal, and shell was found, providing much younger dates of  $6020 \pm 50$   $^{14}\text{C}$  B.P. and  $4060 \pm 50$   $^{14}\text{C}$  B.P., respectively, documenting the return of marine conditions shortly before colonization of St. Catherines Island by its earliest known human population.

Vibracoring also provides a mechanism to

rapidly provide ground truth to geophysical anomalies with minimal detriment to the site while maximizing return of stratigraphic, archaeological, and sedimentological data within its confining context. Vibracoring of the St. Catherines Shell Ring and the McQueen Shell Ring, followed by archaeological testing and  $^{14}\text{C}$  dating, confirm the earliest known cultural event at the St. Catherines Shell Ring at 2540–2290 cal B.C.

In chapter 11, R. Kelly Vance, Gale A. Bishop, Fredrick J. Rich, Brian K. Meyer, and Eleanor J. Camann report results from a Ground Penetrating Radar (GPR) survey running more than 20 km in length. The reflection profiling (using 100 MHz and 250 MHz antennae) indicates a gross island suprastructure consisting of at least 6–8 m of sand-dominated strata that thin westward to 2–5 m. The sand-dominated succession overlies one or two persistent basal reflectors of a lower facies that may represent clay rich or saltwater-saturated sediments characterized by horizontal, subparallel radar elements. The middle sand-dominated facies (Pleistocene?) is widespread and characterized by sigmoidal radar elements produced by prograding (regressive) beach deposits. The middle beach facies appears to have been truncated (at least locally) and overlain by overwash and eolian deposits that filled local marshes forming an upper facies that grades upward into largely horizontal elements overprinted by pedogenic processes and humate cementation. Investigations near South Pasture reveal an apparent unconformity marked by an irregular contact between sand and an underlying dense, blue-gray clay at ~2.7 m depth. Sag structures have been discovered in the northern, middle, and southern portions of the island in regions that coincide with the distribution of Mandarin-Rutledge soils within the Central Depression. Profiling indicates subsidence of 2–5 m in these structures with subsequent accumulation of sediment within these basins. These features may have been generated by subsidence along minor faults or through fault-joint focused dissolution of carbonates at depth with consequent sag of overlying strata. The faults and joints were probably essential conduits for artesian springs that fed former freshwater wetlands of the Central Depression.

In chapter 12, Robert S. Prezant, Harold B. Rollins, and Ronald B. Toll present the results of their two year study of postsettlement dispersal and repopulation of adult *Mercenaria mer-*

*cenaria* in fringing marsh and tidal creek habitats at Engineers Point West and Long Creek. During a single low-tide interval (August 1989) a series of quadrats were established at Engineers Point West using a laser level and elevations were recorded; 12 hours later each quadrat was totally defaunated of clams. Approximately 100 of the collected clams were marked, measured, and weighed, and then replaced randomly within each quadrat. During subsequent visits, in January 1990, October 1990, and February 1991, each quadrat was remapped, and all clams within the quadrats were harvested, measured, weighed, and aged (via annual growth ring counts). Recruits were sequentially numbered and replaced in each quadrat, along with those of the original and subsequent collections. Isopleth maps were prepared for each quadrat, documenting net changes in erosion and aggradation. To assess reproductive maturity, 20 clams were randomly collected from areas adjacent to the quadrats and their gonads examined by standard histological procedures. Concurrently, another mark/recapture study was carried out on one of the point bars in Long Creek, on the eastern side of St. Catherines Island.

Prezant and colleagues conclude that rapid population replacement by adult clams following loss of adults within quadrats demands an explanatory model involving wholesale movement of otherwise sedentary adult bivalves. They determined that clams were transported in a saltational manner associated with specific hydrodynamic events such as episodic storms, perhaps in combination with the effects of ebb-tidal flow. Stochastic models of adult repopulation might explain the commonly observed lack of a range of year classes in clam population age class structure of coastal Georgia quahog populations. Moreover, the fate of postsettlement juvenile and adult bivalves under varying physical conditions has significant meaning for the paradigm of “supply-side” ecology, which predicts that larval recruitment would produce a series of age (size) classes reflecting the variable success of adult reproductive events. While certainly the dominant controlling factor for sessile biota, the numerous reports of recruitment patterns for several other sedentary (but not permanently attached) marine organisms document irregular or unpredictable settlement patterns that cannot be explained by small (planktonic) propagules.

This study of hard clam dispersal on St. Cath-

erines Island addresses one of the major gaps in our knowledge involving the role of passive dispersal of fully grown adults. In particular, these stochastically redistributed and reproductively mature bivalves can help support and sustain locally dispersed metapopulations. The relative roles of larval recruitment, postsettlement juvenile dispersal, differential survival, and adult movement (both passive and active) have yet to be assessed under varying hydrodynamic situations.

In chapter 13, Gale A. Bishop, Fredric L. Pirkle, Brian K. Meyer, and William Pirkle report the results of studies documenting recent nesting behavior of loggerhead sea turtles on St. Catherines Island. They argue that these behaviors provide a model for the suite of sedimentary structures produced by nesting sea turtles, and an analog for trace fossils in ancient near-shore marine sedimentary rocks, including: (1) large crawlways produced by mature female turtles, (2) small-scale crawlways made by hatchlings, (3) distinctive disrupted sediments of the nest, and (4) depredated nests. They suggest that this study of loggerhead and leatherback sea turtle nests provides the background to understand deterioration of sea turtle habitat that reflects the recent erosion of St. Catherines Island and establishes the background information necessary to understand the harvesting of sea turtle eggs and hunting of sea turtles by precontact Native Americans.

Chapter 13 also describes nest types on St. Catherines Island that range from simple to complex; are both unobstructed and obstructed; and situated in backbeach, dune, washover fan, and forebeach habitats. Nests consist of disrupted elliptical surface layers filling a broad, shallow covering pit approximately 20–30 cm deep, overlying a smaller body pit, and both overlying a vertical-walled, urn-shaped egg chamber. Subsequent erosional or predatory events may modify or obliterate the sediments and entrained nest structures, making them easy to overlook or misinterpret if seen in the fossil record. The authors also discuss fossilized nesting structures discovered in the Cretaceous Fox Hills Sandstone of Colorado, including two egg chambers, a body pit, a crawlway, and associated backbeach sedimentary structures that exhibit structures, proportions, and attributes of modern sea turtle nests documented on St. Catherines Island.

In chapter 14, Gale A. Bishop and Brian K. Meyer discuss the deterioration of sea turtle habi-

tat on St. Catherines Island. Accelerating changes in sea turtle nesting habitat became apparent in the early to mid-1990s on St. Catherines Island with breaching of Flag Pond, enhanced scarping and development of washover fans, and shoreline retreat along most of the beach. These factors affected the loggerhead sea turtle nesting habitat resulting in increasing relocation of in situ nests into higher quality habitat in 1995. This trend is documented by qualitative assessment of the entire beachfront in 1998 and quantified annually beginning in 1999 using a new Rapid Habitat Assessment tool.

The repetitive Rapid Habitat Assessment was designed to score habitat efficacy on a scale of 0 to 10 (poor to good) along the beachfront using a GPS grid with a spacing of 0.001 degrees (~110 m). Rapid Habitat Assessment data show a beachwide decrease in habitat quality over the last decade with rapid deterioration along approximately 85% of St. Catherines beaches resulting in low-quality sea turtle nesting habitat. Clutches of eggs moved from doomed nests and at-risk nests have increased hatching productivity from an estimated 5% to an actual success of 72% when they are relocated into sea turtle nurseries having slightly higher elevation in a more protected natural habitat.

Bishop and Meyer argue that deterioration of sea turtle nesting habitat provides an independent measure of beach erosion attributed to (1) sea level rise, (2) sand deprivation due to removal of sand from the longshore system caused by regional sediment impoundment in dammed rivers and dredging and removal of sand from the Savannah Ship Channel, and (3) lack of proximal sources of fluvial sand at St. Catherines Island. Deteriorating nesting conditions at St. Catherines Island may be a predictor of future conditions expected to spread up and down the coast of the Georgia Bight.

In chapter 15, Gale A. Bishop, David Hurst Thomas, and Brian K. Meyer employ contemporary data from St. Catherines Island to model the hunting and harvesting of sea turtles (and their eggs) along the Georgia Bight. They note that indigenous peoples around the world have harvested (and continue to harvest) sea turtle meat and eggs as nutritional resources, use sea turtle skeletal elements as useful tools and ornaments, and incorporated sea turtles into their mythologies and traditions. Gathering of sea turtle eggs provides a low-cost, high-benefit source of sea-

sonal nutrition to many societies in the past and in historical time.

Nesting loggerhead sea turtles likely provided a significant seasonal nutritional resource to pre-contact and postcontact indigenous occupants of Georgia's barrier islands. St. Catherines Island has existed in several iterations for over 40,000 years as a barrier island, but has been occupied by indigenous Native Americans for only the last 5000 years or so.

Although the archaeological visibility of harvesting sea turtle eggs is limited, it is logical to speculate that indigenous inhabitants harvested eggs and meat of loggerhead sea turtles that nest on St. Catherines barrier island beaches from May to September in Georgia. Hunting sea turtles and gathering sea turtle eggs represent high benefit to expenditure seasonal activities that resulted in acquisition of important protein resources during the summer and early fall months. The paucity of archaeological evidence may be explained as taphonomic biases due to food preparation at remote beach sites and by the lack of preservability of eggshells in summer camps.

In the final chapter, Harold B. Rollins and David Hurst Thomas examine interrelationships among many ecological, geomorphological, and sedimentological factors that define what they term the "zone of optimal shellfish harvesting" (ZOOSH) available to prehistoric Native American populations of St. Catherines Island. They argue that prehistoric foraging strategies were constrained by these interactions. They also discuss how such strategies should be framed in the context of relative sea level change. Expansion and contraction of the ZOOSH of St. Catherines Island was influenced by a complex of ecological and geomorphological interactions. The ecological dimensions included between-habitat and within-habitat specificity of shellfish taxa, stochasticity of shellfish resource distribution, and interspecific interactions, such as predation, competition, and trophic cascading. Geomorphological factors included inlet migration and sediment supply, antecedent topography, changes in tide versus wave dominance, relative rates of sea level rise or fall, the asymmetrical effects of sea level rise versus fall, gradual versus episodic change, proximity to hinterland resources, climate change, and prehistoric anthropogenic factors, among others. Temporal changes in the ZOOSH of St. Catherines Island may be summarized as follows:

(1) 5300–4300 cal B.P.—following the Ho-

locene transgression now eroded Guale Island formed adjacent to the eastern margin of the Pleistocene Silver Bluff shoreline. A short-lived lagoonal embayment was replaced by an extensive interisland marsh (Guale Marsh) and over an interval of a few centuries to a few millennia the ZOOSH changed from shoreface to open lagoon to intertidal marsh with bountiful, if somewhat unpredictable, oyster and clam resources. Geographic compression of maritime forest and marsh resources contributed to a high diversity of shore-parallel terrestrial and marine resources and enabled operation of a central-place foraging strategy.

(2) 4300–3600 cal B.P.—a relatively rapid 2 m drop in sea level led to destruction of marshland on both western and eastern sides of St. Catherines Island and wave dominance supplanted tidal dominance. Guale Island eroded and the marshland ZOOSH was significantly degraded, or disappeared. The shoreface ZOOSH became increasingly isolated from human settlements and the central-place foraging strategy was no longer operational.

(3) 3600 cal B.P. to recent—sea level rose slowly, transgressing over remnants of Guale Island. The tidal prism was reestablished but Guale Marsh had diminished presence, and the Guale Marsh ZOOSH never achieved its former stature and did not play a prominent role as a source of marine resources in post-St. Simon cultures.

The volume also contains two appendices relating directly to the geoarchaeology of St. Catherines Island: (1) a compendium of all available (>350) radiocarbon dates from both natural and "cultural" contents and (2) a detailed listing of the vibracore, artesian wells, and measured section record to date from the island.

#### A WORD ABOUT RADIOCARBON DATING

Throughout this volume, we report and discuss radiocarbon evidence according to the standards established by the journal *Radiocarbon* in their "Instructions for Authors" (promulgated 22 August, 2005, and updated 28 August, 2006). The standard reference on the calculations and terminology follow Stuiver and Polach (1977). Whenever possible, calibrated dates are reported using the latest available international calibration curve (currently INTCAL04 and MARINE04); if a computer program was used to

calibrate dates, authors have included the name and version number of the program in reporting calibrated ages.

#### UNCALIBRATED AGES: B.P.

In this volume, “B.P.” is understood to signify “conventional radiocarbon years before A.D. 1950.” Ordinarily, then, uncalibrated radiocarbon dates are reported in this form:

Beta-21408:  $3470 \pm 80$  B.P.

where Beta-21408 is the laboratory number for the sample and  $3470 \pm 80$  B.P. is the uncalibrated age of the sample (with 3470 being the age in radiocarbon years before 1950, and 80 is the laboratory’s estimate of error at the  $1\sigma$  [one standard deviation level]). Because “B.P.” is conventionally understood to mean “years before 1950,” the form “yr B.P.” is usually redundant. But in some cases, we employ the expression “ $^{14}\text{C}$  yr B.P.” to distinguish conventional ages from those corrected to calendar estimates.

Because we now understand that the distribution of “radiocarbon years” is not linear, all  $^{14}\text{C}$  dates reported in this volume will be “calibrated” (as below); but for the “heritage literature,” meaning 1990s and earlier (when calibration protocols were not fully solidified), authors are encouraged to report “previously cited as XXX B.P.” whenever appropriate.

#### CALIBRATED AGES: CAL B.C., CAL A.D., CAL B.P.

The symbol “cal” is used to express calibrated radiocarbon ages (with “cal” understood to mean “calibrated,” not “calendar”). Such “calendar ages” are absolute dates, whether known or inferred, but a “calibrated date” is an estimate grounded in statistical probability, and is therefore properly expressed as one or more ranges of calendar years, accompanied by an appropriate confidence interval.

In this volume, authors are encouraged to use either “cal B.P.” or “cal B.C./cal A.D.” (or both). Similarly, the use of  $1\sigma$  and/or  $2\sigma$  confidence intervals are left to the author’s discretion.

#### RESERVOIR CORRECTIONS

In the early development of radiocarbon dating methods, investigators concluded that when living samples of freshwater organisms produced apparent  $^{14}\text{C}$  ages of up to 1600 years (Taylor, 1987: 34), the materials had been contaminated by carbonates derived from bedrock limestone. As a result,  $^{14}\text{C}$  determinations for marine sam-

ples will always appear “older” than  $^{14}\text{C}$  dates on contemporary terrestrial samples. This difficulty can be overcome by computing correction factors based on such apparent age differences, which enables archaeologists to compare shell samples with  $^{14}\text{C}$  ages of contemporary terrestrial samples. Using samples of *Crassostrea virginica* of known age, Thomas (2008: chap. 13) derived a reservoir correction specific to St. Catherines Island and surrounding waters. For all marine samples discussed in this volume, we employed the Marine04 curve, which takes into account the “global” ocean effects (Hughen et al., 2004); to accommodate estimated local effects on St. Catherines Island, we input the regional difference of  $\Delta R = -134 \pm 26$ .

#### ROUNDING CONVENTIONS

We also employ the rounding conventions advocated by Stuiver and Polach (1977: 362). That is, for all radiocarbon determinations, we supply one more digit than can be accurately accounted for; in reporting estimated ages and statistical uncertainties, figures like  $8234 \pm 256$  or  $42,786 \pm 2322$  are rounded, respectively, to  $8230 \pm 260$  and  $42,800 \pm 2300$ . When the uncertainty is less than 100 years, rounding off to the nearest multiple of 10 will be followed between 50 and 100 years.

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## NOTES

1. Chapters 13, 14, and 15 present new research on the loggerhead sea turtle population that nests on the beaches of St. Catherines Island. At first glance, this might seem to be an unusual contribution to *Geoarchaeology of St. Catherines Island, Georgia*. But we feel that the process of monitoring beaches for 130–140 days per year for 19 consecutive

years—as Gale Bishop and his colleagues have done—provided an unprecedented opportunity to observe daily, monthly, annual, and decadal changes in these beach fronts. This opportunity is particularly timely because during this interval, global climate change altered sea levels, creating extensive barrier island erosion along the Atlantic seaboard during the initial stages of a modern marine transgression. The biogeographic upshot is that roughly 70% of the sea turtle nests on St. Catherines Island had to be located to better habitat during the last decade.

Two of these contributions directly address the *Geoarchaeology of St. Catherines Island, Georgia*. By documenting how the eroding seashore has impacted sea turtle nesting habitat, chapter 14 provides an alternative and independent methodology of documenting erosion rate and marine transgression on St. Catherines Island—by examining the rate of deteriorating sea turtle nesting habitat as a proxy of on-going climate change. Similarly, chapter 15 projects what the expected sea turtle utilization record ought to be, then reports the conflicting archaeological evidence showing something different. These findings raise significant questions about the nature of sea turtle utilization and its geoarchaeological visibility. Why should sea turtle exploitation appear so minimal on St. Catherines Island (and the other Georgia islands), but show up so significantly in the Caribbean, Mesoamerica, and many other parts of the world? To situate these two discussions, chapter 13 draws together—for the first time—a comprehensive body of detailed scientific information on the previously scattered, incomplete, descriptive morphology of loggerhead sea turtles nests in the Georgia Bight. In the tradition of interdisciplinary approaches to natural history, we think this preamble is essential to undergird the interpretations reflected in chapters 14 and 15. This approach also extends this geoarchaeological record into deep time by identifying the only other sea turtle nesting structures described thus far, on the western shoreline of the 70 million-year-old Cretaceous Western Interior Seaway southeast of Denver, Colorado.

We feel that this holistic treatment of historical science is appropriate to this volume because it draws together diverse information from (now) fragmented scientific disciplines (Somerville, 1834) into a “natural history” to celebrate the integrative process of scientific discovery (Gould, 1989) inherent in the mission of the American Museum of Natural History: “to discover, interpret, and disseminate—through scientific research and education—knowledge about human cultures, the natural world, and the universe.” (<http://www.amnh.org/about/mission.php>)



## CHAPTER 1

### WHY THIS ARCHAEOLOGIST CARES ABOUT GEOARCHAEOLOGY: SOME PASTS AND FUTURES OF ST. CATHERINES ISLAND

DAVID HURST THOMAS

The Fourth Caldwell Conference is all about geoarchaeology, as played out on St. Catherine's Island and the Georgia Bight. I have been fortunate enough to work on such things for a while and will use this space to reflect, to summarize, and to suggest. The first section of this chapter considers the self-definitions of *geoarchaeology* by several major scholars, some of whom seem to privilege the present at the expense of forebears. To broaden the historical perspective, I suggest that we view "geoarchaeological" thought, at least from a North American perspective, in terms of three generations. The pioneers relied heavily on the seminal organizing principles of geology—the concepts of *superposition* and *index fossil*. Thomas Jefferson was the first geoarchaeologist (at least in North America) and I will argue that such first-generation geoarchaeology has dominated archaeological practice until fairly recently (until perhaps two or three decades ago). The second generation of geoarchaeology, my own, spans the late 1970s through the present. Most of the archaeology of St. Catherine's Island was prosecuted under this paradigm and I believe that we transcended the purely temporal-spatial to explore far-reaching objectives, wrapping our research in a plethora of new methods and technologies. The third generation of geoarchaeology—defined by me, I suppose, as pretty-much current—has the chance to build upon this foundation, then scope out the natural and cultural past in unprecedented ways. This chapter develops a six-pack of suggestions for those third-generation geoarchaeologists lucky enough to be working on St. Catherine's Island and her surrounding waters.

#### WHAT IS GEOARCHAEOLOGY, ANYWAY?

In my view, the framework of geoarchaeology was defined by *Geoarchaeology: An International Journal*, first published in January 1986. According to its publication guidelines, this eponymous journal would be dedicated to "exploring the methodological and theoretical interface between archaeology and geology."

How appropriate is it, then, that this pivotal paper would be published by Bud Rollins, our friend, colleague, and coeditor of this volume (Rollins, Richardson, and Sandweiss, 1986)? In this ground-breaking paper, "The Birth of El Niño"—published in the very first issue of *Geoarchaeology*—Rollins and his coauthors marshaled a variety of evidence from geological, archaeological, and oceanographic sources to explore the revolutionary hypothesis that, about 5000 years ago, a major structural change took place in the eastern Pacific water mass, triggering the present-day arid coastal climatic conditions along the northern and central Peruvian coastline, forcing coastal foragers to shift away from land-based seasonal subsistence in the grasslands and forests, and instead exploit the diverse cold water maritime resources that now appeared. True to the editorial guidelines of *Geoarchaeology*, Rollins and his collaborators did indeed explore the methodological and theoretical frontiers to articulate the interface between archaeology and geology.

Many others have offered more formalized definitions of the field. Karl Butzer (1982: 5) penned perhaps the most widely quoted definition of *geoarchaeology* as simply "geology that



Fig. 1.1. The location of St. Catherines Island, Georgia.

is pursued with an archaeological bias or application.” Gifford and Rapp (1985: 15) reversed the focus, viewing geoarchaeology as “archaeology pursued with the help of geological methodology.” Others preferred a more specific agenda, detailing the formalized objectives of geoarchaeology (esp. Waters, 1992: 7–13; Renfrew, 1976):

(1) to place sites and their contexts in a relative and absolute temporal context through the application of stratigraphic principles and absolute dating techniques (Renfrew, 1976);

(2) to understand the natural processes of site formation (Renfrew, 1976; Schiffer, 1972, 1976, 1987); and

(3) to reconstruct the landscape that existed around a site or group of sites at the time of occupation, typically separating the living (biological realms, plant and animal resources, plant macrofossils, pollen, phytoliths, zooarchaeology, and so forth) from the nonliving (the platform on which all biological organisms evolved, lived, and interacted through time).

Rapp and Hill (2006: 1) have more recently stressed the importance of multiple viewpoints in geoarchaeology (particularly during the past quarter-century), arguing that the term should “designate a variety of types of research that use geoscience techniques in the evaluation of the

archaeological record.” They also suggest that “perhaps [in] its broadest sense ... *geoarchaeology* refers to the application of any earth-science concept, technique, or knowledge base to the study of artifacts and the processes involved in the creation of the archaeological record. Geoarchaeology thus becomes ‘the geoscience tradition within archaeology ... [that] deals with earth history within the time frame of human history’ or that ‘implies archaeological research using the methods and concepts of the earth sciences’” (Rapp and Hill, 2006: 1–2, citing Gladfelter, 1981; Butzer, 1982).

### FIRST GENERATION GEOARCHAEOLOGY: TWO SEMINAL PRINCIPLES

Garrison has observed that geoarchaeology has evolved primarily as a “method-oriented” enterprise—without a general body of theory to govern its conduct (2003: 2). I agree with that assessment, but also believe that the practice of geoarchaeology has experienced some significant generational shifts in objectives and methodology.

During geoarchaeology’s initial generation—which lasted two centuries—archaeologists found the discipline of geology to be a productive mine of assumptions, techniques, and even some important theory. It was geologists, after all, who first pulled together the two major principles of stratigraphy—the paired concepts of *superposition* and *index fossils* that have been critical in our understanding of how the archaeological record is put together (Thomas, 1998b: 205–206, 224–227; Kelly and Thomas, 2010: 102–103, 125).

Perhaps more to the point, these two geological principles have guided our long-term investigation of the human presence on St. Catherines Island. Let us pause a moment, then, to review this initial contribution and to see how first generation geoarchaeology has been invaluable to St. Catherines Island archaeology.

#### STENO’S LAW OF SUPERPOSITION

The *law of superposition*, initially formulated by Nicolaus Steno in the mid-17th century, would seem to be geology’s most important principle. Steno’s law, simply stated, holds that in any pile of sedimentary rocks (undisturbed by folding or overturning), the strata on the bottom must have been deposited first. On a broader scale, Steno’s principle, almost preposterously simple, holds

that—all else being equal—older deposits tend to be buried beneath younger ones. Steno also conceptualized two other “stratigraphic laws”—the law of original horizontality (layers of sedimentary rock are deposited in roughly horizontal positions) and the law of lateral continuity (layers of sedimentary rock are laterally continuous until they intersect the edge of a basin or pinch out to zero thickness), both also important to the deciphering of layers of sediment. Steno’s three laws of stratigraphy form the foundation of stratigraphic theory and the interpretation of nearly all sedimentary layering. For more than four centuries, these canons have facilitated the correlation of cliffs, stream valleys, drill cores—and archaeological sites.<sup>1</sup>

#### THOMAS JEFFERSON: THIRD PRESIDENT AND FIRST GEOMORPHOLOGIST?

The overriding concern for early geologists like Steno was verticality—how sedimentary beds stacked up on one another in their stratigraphic sequences. Thomas Jefferson is not only the father of American archaeology (Thomas, 1979: 25–30, 167), but I would also argue that he was likewise the first geoarchaeologist (at least in the Americas; see Wheeler, 1954: 58; Thomas, 2005). Jefferson’s firsthand excavations and observations on a mound (or barrow), located along the Rivanna River near Charlottesville (Virginia), enabled the third American president to reconstruct the various mound construction stages and to suggest its probable use as a burial feature—all based on his innovative application of basic stratigraphic principles.<sup>2</sup>

Thanks to his geological forebears, Jefferson got it right. And, as it turns out, stratigraphic techniques for analyzing archaeological and geological sites have changed very little since his day. The technology is, of course, vastly improved, but the bedrock philosophy that guided Thomas Jefferson is basically unchanged, as our own excavations at McLeod Mound amply illustrate.

EARLY GEOARCHAEOLOGY ON ST. CATHERINES ISLAND: Not long after I began doing archaeology on St. Catherines Island, Mr. John Toby Woods (then island superintendent) showed us a seven-mound mortuary complex centered on Cunningham Field, each located in the southern part of the Pleistocene island core (Thomas and Larsen, 1979; see fig. 1.2).

We called the northernmost of these McLeod Mound (9Li47; AMNH-105) because of its prox-

imity to the antebellum boundary ditch constraining McLeod Field. Between November 1975 and May 1976, our crews excavated approximately 100 m<sup>3</sup> of McLeod Mound fill (roughly 40% of the site). When the digging was completed, we

recorded a 20 m long profile and recorded the major depositional units (fig. 1.3). This stratigraphic profile and measured section provided the primary data necessary to understand the construction sequence at McLeod

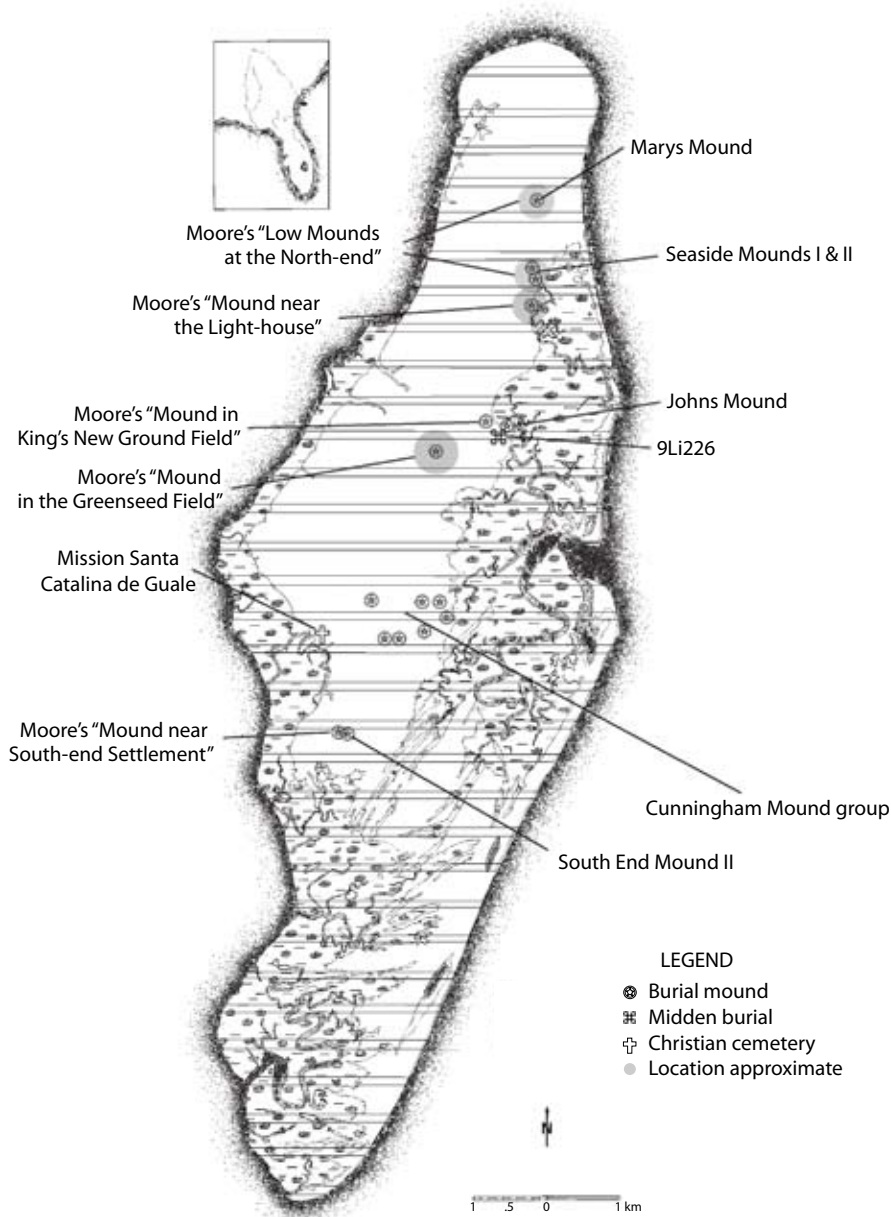


Fig. 1.2. The location of known aboriginal mortuary sites on St. Catherine's Island (after Thomas, 2008: fig. 24.1). The horizontal lines demarcate the 100 m wide survey transects.

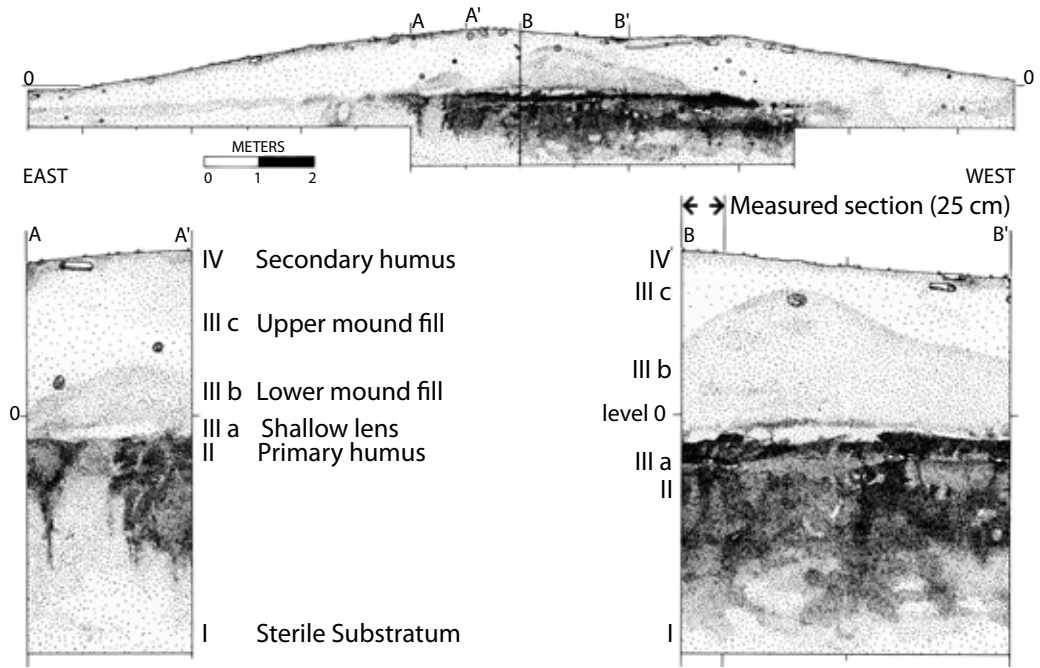


Fig. 1.3. Measured stratigraphic section of McLeod Mound, St. Catherines Island (after Thomas and Larsen, 1979: fig. 9).

Mound. We would hope that any competent field archaeologist studying the McLeod Mound would have produced comparable data, but then came the matter of interpretation. We believe that although most archaeologists should generate about the same data, interpreting these data is not at all mechanical and would differ with each researcher. The job at hand was to translate the observable stratigraphic phenomena into the natural and cultural processes that created this stratification, and here's where the geological law of superposition came in handy. Steno's laws hold that the older deposits should lie near the bottom of the stratigraphic profile, should be horizontal, and be laterally continuous, so we construct a stratigraphic picture from the bottom up:

(1) Unit I is a sterile yellow sand, and by coring off site, we recognize that the late Pleistocene yellow sands of the Silver Bluff submergence extend throughout the area and predate human occupation of the area.

(2) Soil cores indicate that unit I is generally capped by a rich organic paleosol and this primary humus could be recognized as the black hori-

zontal stain across the McLeod profile, formed after the deposition of unit I, but prior to any human activity at the site. Two  $^{14}\text{C}$  determinations processed on charcoal from this surface indicate ages of  $3250 \pm 60$  cal B.P. (1680–1410 cal B.C., UCLA-1997E) and  $2660 \pm 60$  cal B.P. (970–560 cal B.C.; UGA-1557). Although the earlier date falls in the St. Simons period, we found no fiber-tempered ceramics at McLeod Mound and thought that perhaps this date was processed on older charcoal lying on the ground surface.

(3) Sometime in the past, several pits had been dug into this primary humus, including a large, 6 m deep central pit, which was excavated, then filled and covered with a ring of potsherds, oyster shells, and clam shells. The central pit was then expanded to the north, and five individuals (all adult females) were buried within. Two  $^{14}\text{C}$  dates are available on the hard clams from the shell feature within this central tomb:  $2760 \pm 70$  cal B.P. (850–460 B.C.; UGA-1554) and  $2290 \pm 80$  cal B.P. (340 cal B.C.–cal A.D. 80; UGA-1555).<sup>3</sup> These dates are significantly different at the 95% level. Assuming that the most recent clams were

harvested shortly before their inclusion in the central tomb, these dates place this construction during the Refuge-Deptford periods.

(4) A small sand mound was then erected over the central tomb. We have a single charcoal date with an age of  $1840 \pm 70$  cal B.P. (cal A.D. 20–380; UGA-1256). It seems likely that this charcoal resulted from another burning of the primary humus and was subsequently included in the mound fill.

(5) A secondary humus zone formed over the top of the entire mound. This unit IV humus is much lighter than the soil in unit II because of the limited time available for soil formation and also because it was not burned to clear the vegetation.

This construction sequence is inferred entirely from the stratigraphic column and profile (figs. 1.3 and 1.4). Almost identical sequences were noted at eight additional mounds excavated elsewhere on St. Catherines Island (Thomas and Larsen, 1979).

The law of superposition provides the key to unlocking stratigraphic sequences like this, provided that the initial descriptions are accurate. Over four decades, we have conducted strati-

graphic excavations at roughly 200 habitation sites and more than a dozen mortuary localities on St. Catherines Island (as summarized in Thomas, 2008). We successfully located the lost Mission Santa Catalina de Guale and spent 15 years digging there (Thomas, 1987; Blair, Pendleton, and Francis, 2009; Reitz et al., 2010 and various works in prep.). We are currently conducting archaeological excavations at two Late Archaic shell rings (Thomas, 2010; Sanger and Thomas, 2010) and numerous major late prehistoric occupational sites.

When it comes to stratigraphic association, nothing in our interpretations differs much from those made in 1784 by Thomas Jefferson, except that modern excavations are conducted more systematically and precisely and we can employ radiometric dating methods to assign ages that constrain the stratigraphic history. I believe that Jefferson would have interpreted the McLeod Mound stratigraphy the way I did, had he worked from figure 1.3.

#### THE INDEX FOSSIL CONCEPT

By distinguishing older from younger strata, Steno’s law of superposition helped facilitate correlation of various geological (and archaeological) exposures. But such correlation has its limits. It is impossible, for instance, to correlate geological exposures at the Grand Canyon directly with the White Cliffs of Dover in England. Fortunately, our ever resourceful geological colleagues thought up a second principle, *the index fossil concept*, that assisted worldwide geological correlations and proved especially important in archaeological applications.

In the early 19th century, a surveyor named William Smith began collecting data from geological strata throughout England as he engineered canals for transporting coal at the beginning of the Industrial Revolution; as he constructed the first geological map, he became enraptured with the fossils that turned up in various canals and vertical exposures. As he grew to understand the regional geology, Smith recognized that different exposures of the same stratum contained comparable fossils. Smith eventually became so knowledgeable that when somebody showed him a fossil, he could guess the stratum from which it had come (hence the nickname “Strata” Smith).

Smith’s French contemporaries made similar discoveries. While mapping the fossil-rich strata surrounding Paris, Georges Cuvier and Alexan-

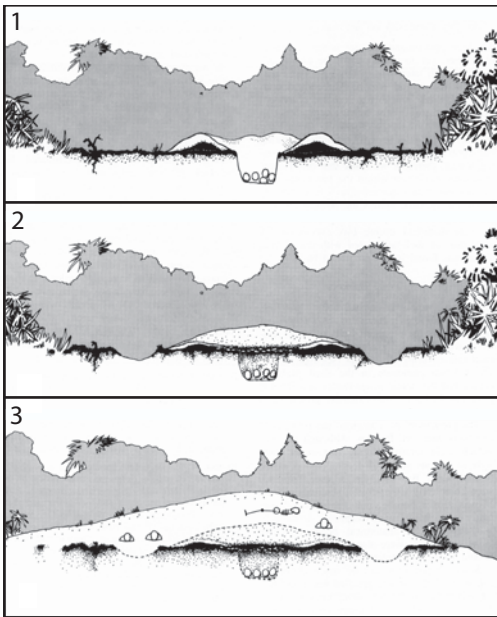


Fig. 1.4. Inferred stages of mound construction at McLeod Mound (after Thomas and Larsen, 1979: 10).

dre Brongniart also discovered that certain fossils were restricted to specific geological formations. After applying the law of superposition to arrange the strata of the Paris Basin in the proper chronological sequence, they organized their fossil collections into the appropriate stratigraphic order. French fossil assemblages, it turned out, varied systematically according to the age of the parent strata. When Cuvier and Brongniart compared their fossils with modern species, they discovered, as expected, that fossils characterizing later strata more closely resembled modern forms than did those of more ancient strata.

This is the *index fossil concept*: Rocks containing similar fossil assemblages must be of similar age. Obviously there are exceptions to both the index fossil concept and the law of superposition, but these principles enabled geologists around the globe to correlate their stratigraphic sections into master chronologies.

#### DIAGNOSTIC ARTIFACTS, ARCHAEOLOGY'S VERSION OF INDEX FOSSILS

Geologists proposed the laws of stratigraphy rather early in the game (Steno, 1669). But the derivative index fossil concept would not become a viable tool for archaeology until much later (during the early 19th century) because it took some innovative experimentation to learn how to convert human artifacts into useful tools for dating archaeological sites.

Nels Nelson, a curator at the American Museum of Natural History, is generally credited with the first systematic application of the index fossil concept in stratigraphic archaeology in the Americas (Nelson, 1914, 1916; see also Browman and Givens, 1996). After targeting an artifact-rich trash heap in the Galisteo Basin of New Mexico, Nelson separated the deposit into 1 ft arbitrary levels, effectively creating a stratigraphic column even in the absence of visual stratigraphy. Reasoning from the law of superposition, he knew that the oldest artifacts should lie at the bottom of the column.

He then searched through each level to find time markers in the form of diagnostic pottery types. Pottery was a natural choice because potsherds were the most common cultural debris and Nelson knew that ceramic styles varied considerably across the American Southwest. More than 2000 sherds turned up in the 10 ft test section at San Cristobal. First grouping the sherds into obvious stylistic categories, Nelson

then plotted their distribution according to depth below the surface.<sup>4</sup>

This is the index fossil concept in action. Just as geologists learned to distinguish certain extinct lifeforms as characteristic of various rock strata, so too could archaeologists use diagnostic artifact forms to characterize (and hence date) strata across archaeological sites. Exactly the same application of geoarchaeological principles supported the development of the ceramic sequence we currently use on St. Catherines Island.

Archaeology and geology also share similar concepts inherent in the use of faunal zones (as detailed above in terms of index fossils). These shared concepts include condensed zones (where index isochrons become compressed through thin lithosomes), stratigraphic reworking (where older materials are exhumed and redeposited in younger contexts), and stratigraphic leak (where younger materials find their way into or beneath older layers). Interestingly, the concept of a condensed zone independently surfaced in the context of a chapter in this volume (see chap. 10) describing the “condensation” of time lines (as determined from <sup>14</sup>C dates on geological and archaeological materials in a transect of the St. Catherines Shell Ring). This effect, largely due to the island being above base level and susceptible to erosion, forces our 5000 years of archaeological history into a thin layer, approximately 50–100 cm thick, whereas the material deposited during the same interval, but below base level, accumulated some 500 cm of thickness. Stratigraphic reworking—as an admixture of “systemic” and “behavioral” contexts—has always bedeviled archaeologists because humans have always been great “recyclers,” taking useful materials from the past (shell middens) and reusing them in a younger context (their “now”), bringing older artifacts into younger contexts (e.g., Thomas, 1988b; see esp. Schiffer, 1972, 1987). Similarly, we have recognized the implications of “stratigraphic leak,” as postholes, burial pits, and other excavations (fig. 1.4) cut down through older layers and are backfilled by younger materials (and consequently lead to stratigraphic reworking on a local scale). More recently, as geoarchaeological processes such as “stratigraphic reworking” and “stratigraphic leak” have become integrated into the broader, more comprehensive theoretical framework of “site formation processes,” archaeologists can appreciate the importance of understanding, simply stated, that “*there is no simple*

*correspondence between the distribution of artifacts in a site and human behavior*" (Kelly and Thomas, 2010: 117).

**THE ABORIGINAL CERAMIC SEQUENCE OF ST. CATHERINES ISLAND:** It is fitting that the origins of the northern Georgia coastal ceramic chronology can be traced to the extensive W.P.A. excavations in Chatham County—as synthesized by Joseph Caldwell and his colleague, Antonio Waring (1939a, 1939b; Caldwell and McCann, 1941; Caldwell, 1958; see also DePratter, 1991: 157; Williams, 2005: 181). Since this pioneering research, several investigators (including several students of Caldwell) have modified the ceramic sequence, (including Waring, 1968a, 1968b; Caldwell, 1970, 1971; Steed, 1970; DePratter, 1976a, 1978, 1984; Pearson, 1977, 1979; DePratter and Howard, 1980; see also Sears and Griffin, 1950; Larson, 1958, 1978; Milanich, 1973, 1977; South, 1973; Stoltman, 1974; Cook, 1975; Martinez, 1975; Braley, 1990; Williams and Thompson, 1999; Williams, 2005).

We have classified all of the aboriginal ceramics recovered from our St. Catherines Island excavations according to northern Georgia coastal chronology (DePratter, 1979a: table 30, as updated in DePratter, 1991: table 1; Guerrero and Thomas, 2008: 372–403: table 15.2). DePratter (1979a, 1991) grouped the various ceramic types into a chronological sequence of archaeological periods and phases for the northern Georgia coast (Guerrero and Thomas, 2008: figs. 14.1 and 14.2). Temper, surface decoration, rim form, and vessel form vary “asynchronously” (DePratter, 1979a: 122), meaning that whereas some types (such as Refuge Plain and Refuge Simple Stamped) persisted for more than a millennium, other types (particularly those defined by fine-grained distinctions in surface decoration, such as incising or net marking) are considerably more restricted in time. This systematic variability has been synthesized into a chronological sequence of seven major cultural periods, subdivided into nearly two dozen archaeological phases.

We then compared the ceramic evidence with the  $^{14}\text{C}$  chronology developed for St. Catherines Island (Thomas, 2008: chap. 15), an exercise fully anticipated by DePratter himself (DePratter and Howard, 1980: 33; DePratter, 1991: 157). At this point, a total of 186 radiocarbon dates were available to us from “cultural” samples derived from St. Catherines Island contexts, but only 110 of these dates could be reasonably associated with

a diagnostic aboriginal ceramic assemblage.

Table 1.1 compares the radiocarbon-derived St. Catherines Island chronology with DePratter’s (1979a, 1991) northern Georgia coast chronology, derived largely from stratigraphic association. To the left is DePratter’s original chronology (expressed in [uncalibrated] yr A.D./B.C.). The middle column converts DePratter’s initial estimates into “calibrated” years A.D./B.C. (using the CALIB conversion program, as discussed below). The right-hand column summarizes the St. Catherines Island chronology (also expressed in calibrated years A.D./B.C.). For convenience in meshing the archaeological and noncultural radiocarbon evidence presented in this volume, table 1.1 reconfigures the St. Catherines Island cultural chronology in terms of  $2\sigma$  cal A.D./B.C. and cal B.P. estimates, accompanied by their raw radiocarbon ages (expressed in  $^{14}\text{C}$  yr B.P. estimates).

We feel that our St. Catherines Island results overwhelmingly confirm the previous research on the ceramic chronology for Georgia’s north coast (taking into account the fine-grained specifics that should vary from island to island). Despite the rarity of absolute dating available at the time, DePratter’s (1979a, 1991) chronological estimates fully anticipated the barrage of  $^{14}\text{C}$  dates now available from research conducted on St. Catherines Island. Most of the proposed revisions involve a temporal shift of a century or two and the maximum discrepancy is less than 400 years. Considering that the chronologies cover a temporal span of nearly 5000 years, this comprises less than a 10% change.

These results are a tribute to those who have worked to evolve the ceramic chronology of the northern Georgia coast—particularly Joseph Caldwell, Antonio Waring, and Chester DePratter. We feel privileged to follow in their footsteps and fully anticipate that additional revisions and refinements will be necessary.

#### HORIZONTAL STRATIGRAPHY

Stratigraphy also has an obvious horizontal dimension and geologists have extensively explored the nature of that diversity within a single stratum. The oil-rich Permian Basin of west Texas, for instance, is known to have formed, in part, as stream deposits and elsewhere as back-reef and quiet-water lagoons. Archaeologists are also quite aware of “flat stratigraphy,” and this is why temporal variability can sometimes be expressed horizontally. Without putting too fine a point on

it, it is important to understand the parallels between horizontal archaeological stratigraphy and the geological application of Walther’s law in which temporally migrating facies can construct a similar “horizontality,” but actually reflect different environments of deposition. A snapshot view of the Permian Basin of Texas, for example, would display all environments from stream to quiet water lagoon, and would only provide the horizontal stratigraphy as these facies migrate temporally (Harold Rollins, personal commun.). The important point is this: the dynamic that makes a “horizontal stratigraphy” is the process

of temporal migration that makes the horizontal component happen.

The classic research on horizontal stratigraphy in archaeology took place at Cape Krusenstern, a beach formation northeast of Nome, Alaska, where the archaeological sequence spans at least 5000 years. Aerial photographs demonstrated that the cape is not a single beach at all, but instead 100 secondary dune ridges that merge to create a peninsula extending far into the Chukchi Sea. The principle of horizontal stratigraphy is not complex: On any series of uneroded beach surfaces, the younger stratum will be seaward,

TABLE 1.1  
(modified from Thomas, 2008, table 15.3)  
**Comparison of the Northern Georgia Coast (DePratter, 1979: table 30,  
as modified by DePratter, 1991: table 1) and the St. Catherines Island Chronologies  
(as defined in Thomas, 2008: chap. 15)**

Phases	Northern Georgia coast chronology age (uncalibrated)	Northern Georgia coast chronology age (calibrated)	St. Catherines Island chronology age (calibrated)
	A.D. 1700 <sup>a</sup>	—	A.D. 1700 <sup>b</sup>
Altamaha			
	A.D. 1580	—	A.D. 1580 <sup>b</sup>
Irene			
	A.D. 1325	A.D. 1310–1390	A.D. 1300
Savannah			Savannah phase deleted
	A.D. 1200	A.D. 1280	A.D. 1300
St. Catherines			
	A.D. 1000	A.D. 1050–1150	A.D. 800
Wilmington			
	A.D. 500	A.D. 630	A.D. 350
Deptford			
	400 B.C.	400 B.C.	350 B.C.
Refuge			
	1100 B.C.	1360 B.C.	1000 B.C.
St. Simons			
	2200 B.C.	2750–2860 B.C.	3000 B.C.

<sup>a</sup>Beginning and ending age estimates for the Altamaha period in the northern Georgia coast chronology are based on historical documentation, not <sup>14</sup>C dating.

<sup>b</sup>Uncalibrated.

the older inland. Beginning at the Chukchi Sea, archaeologists counted 114 such relict beach terraces, most of them covered by a protective rind of grassy sod, and they were able to assign a relative date to each (Giddings, 1961, 1966; see also Mason and Ludwig, 1990). As a result, the horizontal stratigraphy evident on the beach ridges of Cape Krusenstern holds promise as an ideal laboratory for future geological studies of shifting sea levels and sea currents. Here is one case in which archaeologists can begin to pay back their enormous debt to the geological profession, because archaeological sites provide excellent, fine-scale chronological control for geological research.<sup>5</sup>

The principle of horizontal (archaeological) stratigraphy was first applied to the Georgia Bight by archaeologist Chester DePratter and his geological colleague James Howard, who employed the northern Georgia ceramic sequence to document rates of accretion and erosion along the Georgia Bight (see Hoyt and Hails, 1967; Hoyt and Henry, 1971; Bigham, 1973; DePratter and Howard, 1977; Griffin and Henry, 1984; see table 1.1).

Unlike Giddings's work at Krusenstern, the challenge facing DePratter and Howard was more geological in nature: How did the Georgia Sea Islands originate, how did they grow, and exactly how are they being modified by ongoing erosion? Both deposition and erosion have operated on numerous beach dunes along the margins of these barrier islands. Geologists had long wished to document how these islands change, but lacked a reliable method to systematically date (absolutely) the beach lines, although relative dating has been done for some time.

DePratter's northern Georgia ceramic chronology reinforced the fact that aboriginal people have lived, in great numbers, on the barrier islands. Given the significant change in ceramic styles over this interval, DePratter and Howard could apply the index fossil concept, demonstrating that archaeological sites could be dated with some accuracy from the potsherds contained in the shell middens (even in the absence of <sup>14</sup>C dating). The two independent processes—accreting shorelines and changing pottery styles—provided a way to measure the changing shape of the Georgia Sea Islands because the distribution of aboriginal pottery can date the antiquity of sand dunes.

In a pilot study on Tybee Island (near Savannah), DePratter and Howard (1977) demonstrated how this method works. Fiber-tempered St. Simons pottery (the oldest type in the sequence, and

also the most ancient ceramics in North America [see table 1.1]) is found on Tybee Island only miles inland from the modern shoreline. Since DePratter and Howard knew that St. Simons pottery (an index fossil) is older than about 3000 yr B.P., they concluded that the shoreline must have been about 3 mi inland at the time; St. Simons pottery cannot be found any closer to the modern shoreline because the seaward beaches had not yet formed. Because Deptford period ceramics occur up to 2 mi shoreward of the present beach line, the 2500 yr B.P. shoreline must have been about 2 mi inland from the current beach. During the Wilmington–St. Catherines phases (about 1000 years ago), the shoreline was about a mile inland, and the pottery of the late prehistoric Irene phase is found much closer to the present beach. If these accretionary geological processes continue, of course, future geoarchaeologists will be able to date the early 21st-century shoreline from the Coke bottles and aluminum beer cans that litter today's beaches.

DePratter and Howard (1977) clearly demonstrated the potential for horizontal stratigraphic studies to contribute to our understanding of the linkage of geology and archaeology along the Georgia Bight. In my view, this research set the stage for an entire second generation of geoarchaeological research on the Georgia coast, including our own efforts on St. Catherines Island (see also Walker, Stapor, and Marquardt, 1995; López and Rink, 2008: 50).

## SECOND GENERATION GEOARCHAEOLOGY AND BEYOND

After addressing the basics of defining stratigraphic associations and time markers, we spent three decades pursuing so-called “second generation” geoarchaeology on St. Catherines Island. We have recently synthesized much of this research—except for the findings at Mission Santa Catalina de Guala—in a three-part volume on the aboriginal landscape of St. Catherines Island (Thomas, 2008). This research was highly interdisciplinary, involving teamwork at every level and the title page credits 25 “contributors.” We built heavily on all manner of geoarchaeological research, including the use of vibracores to reconstruct the geological evolution of St. Catherines Island (Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008; Thomas, Rollins, and DePratter, 2008), analysis of palynological records to recon-

struct past vegetation patterns (Booth and Rich, 1999; Booth, Rich, and Bishop, 1999; Booth et al., 1999), projection of sea level change during the middle and late Holocene (as summarized in Thomas, 2008: 42–48), and the examination of historic and geomorphic records reflecting the hydrology of St. Catherines Island (Hayes and Thomas, 2008). Using modern control samples of the American oyster (*Crassostrea virginica*; see Blair and Thomas, 2008; Thomas, 2008: 345–362), we calculated a reservoir correction factor for comparing marine and terrestrial  $^{14}\text{C}$  dates and employed nitrogen and carbon isotopes to reconstruct diet from human bone (Schoeninger et al., 1990; Hutchinson et al., 1998; Larsen et al., 2001; Schoeninger and Thomas, 2008). Building upon the earlier work of Morris and Rollins (1977), we examined the growth banding of shells (so-called *sclerochronology*; per Hudson et al., 1976; Quitmyer et al., 1997) to reconstruct patterns of harvest in *Mercenaria* (O'Brien and Thomas, 2008; Russo and Saunders, 2008), then turned to oxygen isotope analysis to reconstruct sea water temperature as a proxy for season-of-capture in *Mercenaria* to test our growth banding results (Andrus and Crowe, 2008). Detailed examination of vertebrate zooarchaeological remains permitted reconstruction of climatic and hunting patterns on St. Catherines Island (Reitz, 2008; Reitz and Dukes, 2008) and working with the bald cypress tree-ring records permitted more detailed charting of paleoclimatic change along the Georgia Bight (Blanton and Thomas, 2008).

Despite what has been learned from these second generation, multidisciplinary, geoarchaeological investigations, there is much more to test and considerably more to understand. In the remainder of this chapter, I summarize the current thinking regarding six of the most important archaeological questions raised in these studies. To the degree possible, we deconstruct our own research and raise several questions and/or hypotheses—research agendas that we hope will inform and intrigue the next generation of geoarchaeological inquiry on St. Catherines Island and the Georgia Bight.

#### FIRST QUESTION: HOW DID CHANGING SEA LEVELS AND LANDFORMS IMPACT ANCIENT ST. CATHERINES ISLANDERS?

This section briefly reviews the collaborative geoarchaeological research that informs current

thinking about the changing geomorphology of St. Catherines Island (including the appearance and disappearance of a phantom island, Guale), shifting late Holocene sea levels, and the impact of these models on our understanding of human foraging adaptations over the past 5000 years on St. Catherines Island. Then we look toward the future to suggest how future geoarchaeological research might refine these understandings and provide testable hypotheses to further develop our comprehension of the natural and cultural landscapes of St. Catherines Island.

#### CURRENT THINKING

We can examine the relationship of human populations to their natural landscape in four specific areas: human demography (as played out in “horizontal stratigraphy”), the “Guale Island hypothesis,” sea level change, and the nature of aboriginal foraging and farming on the changing St. Catherines landscape.

**HORIZONTAL STRATIGRAPHY ON ST. CATHERINES ISLAND:** Various contributors to Thomas (2008) have synthesized our thoughts on the changing shape of St. Catherines Island, combining the available stratigraphic and geomorphological evidence from St. Catherines with the distribution of archaeological ceramics recovered from the more than 200 sites known from the island. They reconstructed the shape of St. Catherines Island at key points in time and subsequent investigators used these geomorphic models to frame the archaeological evidence in more human terms (Thomas, 2008: chaps. 30–32).

Attempting to understand the interrelationships between St. Catherines Island’s archaeological sites and environmental history depends upon accurate reconstruction of the geomorphic configuration of the island during the past several millennia. Whereas the major evidence dealing with the geological evolution of St. Catherines Island was summarized by Bishop et al. (2007, fig. 70) and Linsley, Bishop, and Rollins (2008), the discussion by Thomas, Rollins, and DePratter (2008) developed more fine-grained geomorphic models that facilitate understanding of the distribution of archaeological remains (including a consideration of the 41 “noncultural”  $^{14}\text{C}$  dates available at the time) to help interpret the geomorphic evolution of St. Catherines Island. They supplemented the archaeological and geomorphological evidence by considering

the available historical maps. Beginning with the important 18th-century maps of William Gerard DeBrahm, they could further document the evolution of modern St. Catherines Island by superimposing a succession of topographical and hydrographical maps.

**THE GUALE ISLAND HYPOTHESIS:** Rising sea level during the early Holocene culminated in a rapid transgression of a sequence of barrier islands that eventually welded (“docked”) against the relict late Pleistocene strandlines about 3700 cal B.C. (5000  $^{14}\text{C}$  yr B.P.). With the sea level approximating the modern stand, a new hooklike “Guale Island” formed offshore to the northeast of St. Catherines Island (Bishop, 1989; Linsley, 1993; Bishop et al., 2007: 41; Linsley, Bishop, and Rollins, 2008).

This extension effectively buffered the shoreline and protected a large interisland marshland extending from Picnic Bluff, past Seaside Inlet to the King New Ground dock area. Guale Island may have been similar in size and shape to the seaward components of such island doublets as Sapelo–Blackbeard (see chap. 3).

The relict marsh system exposed along North and Middle beaches is evidence that the interisland marsh existed by at least 2400 cal B.C. (4200 cal B.P.). Tidal creeks meandering through “Guale Marsh” provided access to the rich shellfishery and produced a mosaic of meandering bends and levees along the creek beds. Guale Island was eventually inundated and eroded, spread as a broad shoal by rising sea level, leading to the eventual development of the shorelines present along North and Middle beaches today.

**LATE HOLOCENE SEA LEVEL CHANGE ON THE GEORGIA BIGHT:** Thomas (2008: chap. 4) summarized the available evidence on sea level change across the Georgia Bight (see also Thompson and Turck, 2009; Rollins and Thomas, chap. 16, this volume). We believe that modern St. Catherines Island formed shortly after 3000–2650 cal B.C. when sea level rose sufficiently to isolate the Pleistocene core from the mainland. During the St. Simons period, Guale Marsh extended southward to (and including) Middle Beach, as indicated by exposures of relict marsh muds between Seaside and McQueen inlets (West, Rollins, and Busch, 1990; see also chap. 3, this volume).

The best available evidence indicates that sea level peaked, then began to drop during the first half of the St. Simons period (DePratter, 1975, 1977b; DePratter and Howard, 1977, 1980, 1981;

Brooks et al., 1986; Gayes et al., 1992; see also Thomas, 2008: chap. 4, fig. 32.1). From a localized highstand at 2300 cal B.C. (roughly 130 cm below MHW [mean high water]), sea level dropped about 2 m (at a rate of 50 cm/century). Such lowered sea level likely modified the sedimentary dynamics of the Georgia Sea Islands, affecting the back island marshes most dramatically (including the western margin of St. Catherines Island) by draining expanses of low marsh and causing some degree of downward erosion (incisement) of larger tidal creek channels. Some degree of progradation of Guale Island and seaward expanse of Guale Marsh might have occurred.

During the Refuge–Deptford periods, Guale Island survived along the northeastern margin of St. Catherines Island and additional beach ridges accumulated along the southeastern shoreline, extending beyond the modern Cracker Tom Hammock and arching northward past the contemporary McQueen Inlet (Linsley, 1993; Thomas, Rollins, and DePratter, 2008: figs. 29.1, 32.3). Although still buffered from the Atlantic Ocean by Guale Island, Guale Marsh expanded markedly to the southwest, extending into McQueen Inlet and perhaps as far south as the Middle Settlement/Cemetery Road area. Numerous beach ridges also formed along the island’s northern end and, except for a remnant spur of island core to the northwest, the western shoreline approximated its modern configuration.

Beginning about 1600 cal B.C. and continuing throughout Refuge–Deptford times, sea level began rising slowly (at a rate of 10 cm/century), from a low water mark of roughly 3 m below MHW. Marshland resources along the eastern margin of St. Catherines Island diminished (due to the eventual inundation, erosion, and southward transport of sediment comprising Guale Island and disappearance of Guale Marsh), and estuarine marshlands reappeared along the entire western margin of the island.

**THE ABORIGINAL FORAGERS AND FARMERS OF ST. CATHERINES ISLAND:** This is a story of shifting physical and intellectual landscapes, from the dynamics of coastal geomorphology to the differing paradigms that archaeologists and geoarchaeologists carried with them to St. Catherines Island. We have employed the general paradigm of human behavioral ecology, describing the specific models employed, addressing the assumptions involved with each approach, and summarizing

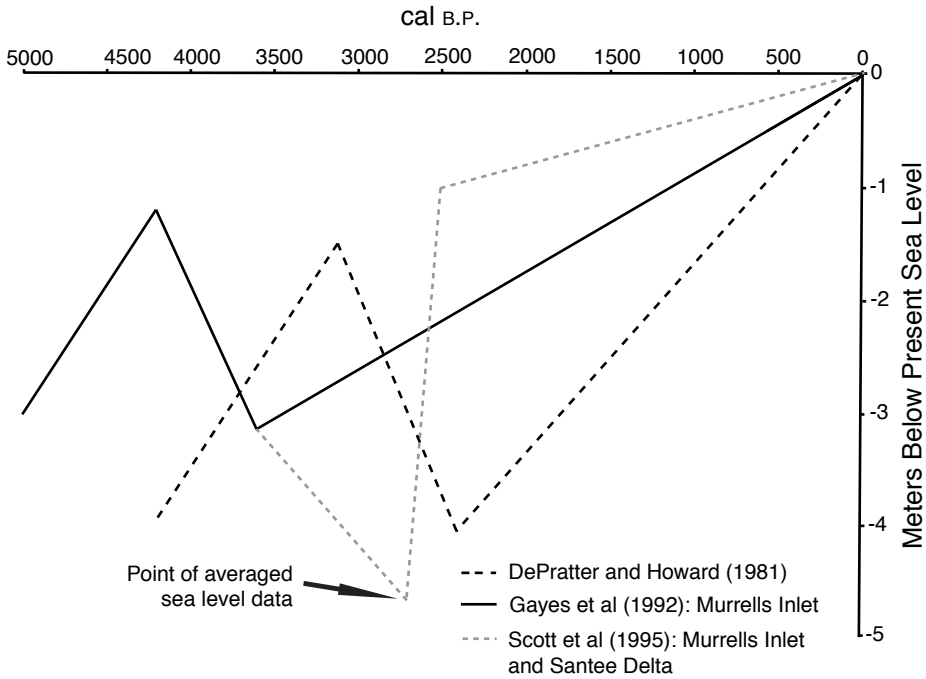


Fig. 1.5. Sea level curves for the Georgia Bight, adopted from Colquhoun and Brooks (1986), DePratter and Howard (1981), and Gayes et al. (1992; after Thompson and Turck, 2009: fig. 9).

the results of the extensive optimal foraging experiments that we conducted across the diverse habitats of St. Catherines Island. We developed a series of specific, testable hypotheses regarding the subsistence and settlement practices of these aboriginal foragers and farmers, then framed an archaeological research design to test these hypotheses (Thomas, 2008). Specifically, we used the *diet-breadth (or prey choice) model* to address the issue of which foods an efficient forager should harvest from all those available on St. Catherines Island. Diet-breadth models predict that foragers will optimize the time spent capturing prey, and employ the simplifying assumptions that all resources are randomly distributed (without patches) and that “capture/handling” and “search” times represent the sum total of all time spent foraging. We also applied the *patch choice model*, which, combined with the central limit theorem, predicts that foraging effort will correlate directly with efficiency rank order, meaning that foragers should spend more time working the higher-ranked patches and less time in patches

with lower energetic potential. Finally, we also drew upon the *central place foraging* model to investigate the time/energy spent processing resources at temporary camps before transport to a residential base. For several years, we also conducted a series of optimal foraging experiments, specifically addressing procurement and return rates for key marine and terrestrial resources that would have been available to aboriginal foragers (Thomas, 2008: chaps. 7–10).

Several demographic trends emerged from this longitudinal examination of St. Catherines Island archaeology (Thomas, 2008: chaps. 32–35). The biogeography of the island is such that foragers could systematically search and exploit resources in any patch on the island and return home each night. This conclusion is based on a strictly terrestrial modeling of effective foraging radius. Use of watercraft (which we think was extensive during all time periods) would have vastly extended the effective foraging radius, enabling foragers to return to their home base virtually at will.

During the late Holocene transgression, the landscape available to St. Catherines Island foragers blossomed, with high-ranking marine patches developing in close proximity to long-standing terrestrial patches, thereby minimizing transport costs from centrally placed residential bases. During the initial occupation of St. Catherines Island, Late Archaic foragers (3000 cal B.C.–1000 cal B.C.) established central-place settlements exclusively on first-tier habitats located on the Pleistocene island core, exploiting the diverse and proximal marine and terrestrial resources of the island.

But when the sea level dropped dramatically, as we believe it did during the Late Archaic, the estuarine oyster beds along the western margin of St. Catherines Island must have been heavily impacted. If patches of oyster beds survived at all, they did so at significantly diminished levels; any Late Archaic foragers exploiting this vastly reduced and more remotely situated shellfishery would have created archaeological sites that are today either eroded away or buried beneath 2 m of more recently deposited salt marsh sediments. These same fluctuating environmental constraints created a vastly different ecological setting on the oceanfront side of St. Catherines Island. A new barrier island formed offshore, protecting a vast, new saltwater marsh and providing foragers with an alternative source of salt-marsh resources. The formation and subsequent disappearance of Guale Island and Guale Marsh likewise had a major impact on the behavior of St. Catherines Island foragers and the archaeological record they left behind.

When the sea level returned to previous levels, human foragers came back to St. Catherines Island in increasing numbers. As human population increased, so did the progressive utilization of fragmented, second-tier habitats, suggesting a significant intensification in provisioning strategies. A variety of proxy measures demonstrate that the aboriginal population of the island expanded exponentially from the earliest human footprint (about 3000 cal B.C.) to the abandonment of Mission Santa Catalina de Guale (in A.D. 1680).

The common scenario of increasing sedentism through time probably does not hold for the 5000-year-old record on St. Catherines Island. Seasonality indicators, settlement pattern distributions, and intensification of occupation proxies indicate that St. Catherines islanders employed predominantly a collector mobility strategy of lo-

gistical movement from the Late Archaic until the Spanish *reducción* policy aggregated the aboriginal population at Mission Santa Catalina de Guale.

#### HOLOCENE SEA LEVEL CHANGE:

##### FALLACIES OF MISPLACED CONCRETENESS?<sup>6</sup>

William Marquardt (2010) has recently critiqued the perspectives on sea level change set out above, questioning the conclusions and procedures of Thomas (2008). When originally published in the Proceedings of the Third Caldwell Conference (Thomas and Sanger, 2010), Marquardt's (2010) critique was presented without comment or rebuttal. But we feel that these alternative views deserve a comprehensive discussion and the following section is designed to further that dialogue. Marquardt (2010: 255) emphasizes (correctly, in my view) that archaeologists must fully appreciate the potential abrupt climate change (and requisite cultural responses), monitored at a century (or even decadal) scale. He likewise criticizes "some geologists, who traditionally worked at much broader temporal scales than archaeologists, tend to publish uncalibrated and uncorrected radiocarbon dates, or to be unclear about whether or not their dates had been calibrated." Marquardt is clearly correct in this case as well: Because the <sup>14</sup>C time scale is not actually linear, a number of geological, archaeological, and paleoinvestigators (e.g., Bartlein et al., 1995; Grayson and Meltzer, 2002: 380; Thomas, 2008: chap. 13; Thomas and Sanger, 2010) have warned that the use of uncalibrated radiocarbon ages can create quite misleading impressions of the relationships between events dated this way.

Marquardt is particularly critical of my own research results on St. Catherines Island (esp. Thomas, 2008, chap. 4; Thomas, 2010; Sanger and Thomas, 2010). He mistrusts my reliance on the sea level reconstruction of Gayes et al. (1992) and Scott, Gayes, and Collins (1995) "which provides, in my opinion, inadequate resolution to account for subtle changes in St. Catherines Island's resources that [Thomas] wishes to address." Marquardt (2010: 264) promotes instead the research results of William Tanner (1992, 1993, 1995) as providing a superior perspective from which to understand the geoarchaeological and archaeological records of St. Catherines Island.

[Tanner's ] nuanced 7500 year sea level record is derived from extensive research on low-energy beach ridges in Jerup,

northern Denmark ... [also] useful are the comparisons recently provided by Balsillie and Donoghue (2004: 20, figs. 10 and 11). These researchers compile all published, dated, landward sea level data from both geological and archaeological sources for the northern Gulf of Mexico ... They then compare this new curve with the highly resolved isotopic record of Siddall et al. (2003) from the Red Sea. They also present a graphed comparison of the Red Sea curve with Tanner's (1990, 1991) records from St. Vincent Island, Florida, and from his (1993) Jerup record from Denmark (their fig. 11). The comparisons show general accord, demonstrating sea level teleconnections (that is,

a eustatic signal) even beyond the greater North Atlantic region, just as is increasingly the case with paleoclimate records. The Siddall et al. (2003) and Balsillie and Donoghue (2004) studies represent major advances in the realm of sea level research and, along with the underappreciated 1990s work of Tanner (in both Florida and Denmark), they offer much promise for southeastern archaeology... The initial reaction of many southeastern U.S. archaeologists might be, "Denmark? How could a Danish record be relevant to what is going on in my area?" My confidence in the Tanner record is based on the observations that (1) multiple Holocene records based on independent data

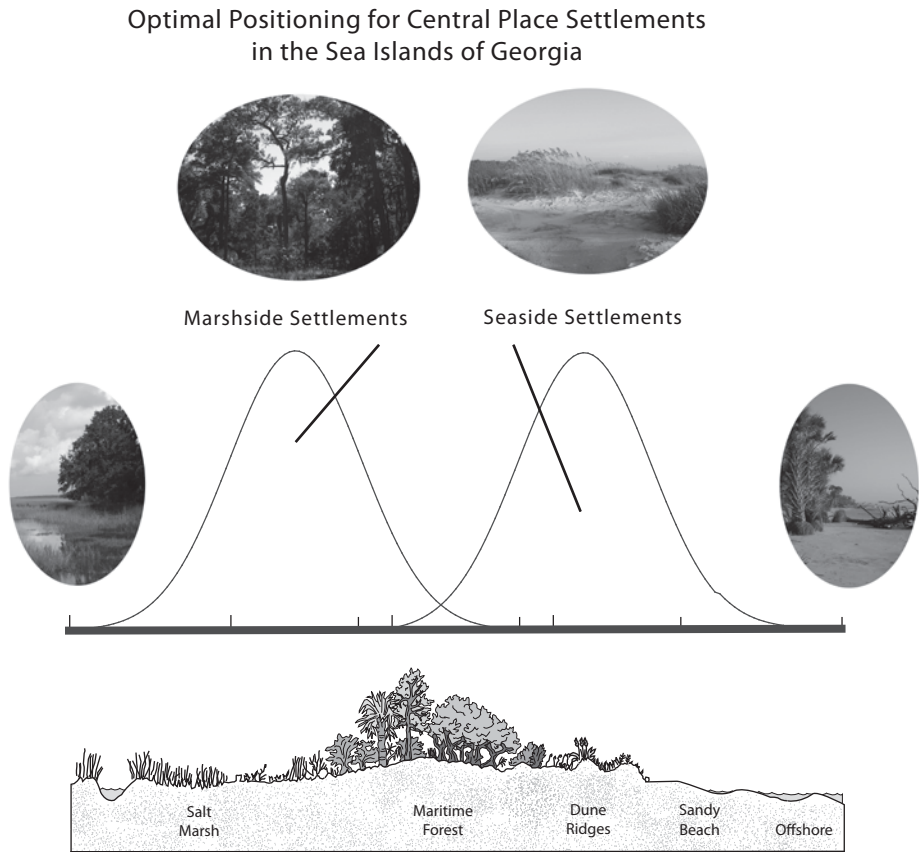


Fig. 1.6. Probabilistic distribution of optimal central places in the Sea Islands off coastal Georgia (after Thomas, 2008: fig. 11.10).

of many different kinds are in remarkable accord with Tanner's, including data from the North Atlantic region, which includes the southeastern U.S. ... and (2) Tanner's own 2000 year Gulf of Mexico sea level record (Tanner, 1993: 228, 2000: 93) is not only consistent with his Danish data but also with what we know of environmental and cultural changes on the Florida Gulf coast" (Marquardt, 2010: 255).<sup>7</sup>

Marquardt (2010: fig. 14.3; see fig. 1.7, this volume) then employed his rendering of the Tanner curve to critique the St. Catherines Island research, specifically our use of the locally derived "peat-based sea level record of Gayes et al. (1992: 159), a hockey sticklike affair that provides none of the nuances archaeologists need to interpret their much finer-grained data," (2010: 256, 258).<sup>8</sup>

Based on the "finer-grained data" in Tanner's global curve, Marquardt (2010) framed a series of "alternative hypotheses" for St. Catherines Island archaeology:

these two ring sites are not purposeful constructions, but instead domestic middens that owe their temporal placement to distinct episodes of sea level regressions within the Middle Holocene period, namely the "anomalous"

ca. 6400 cal B.P. deposit, the "ring middens" ca. 4550–4250 cal B.P. sediments, and the central features that date to ca. 4350–4250 cal B.P. Availability of reliable resources in a time of cool and dry climate may explain their particular place on the landscape (2010: 258).

Arraying the distribution of <sup>14</sup>C date probabilities from St. Catherines Island (after Thomas, 2010: fig. 8.12) against an excerpt from Tanner's sea level record, Marquardt noted that "ample dates are available for the period 4450–3300 cal B.P., but none are known for the 3300–2300 cal B.P. interval [fig. 14.2] shows that the first of these two periods is characterized by exceptionally low sea level ... the St. Catherines Island and McQueen shell ring middens (ca. 4850–4450 cal B.P.) were occupied during a sea level regression ... during part of this time." To make Tanner's curve "more intuitive and readable for archaeological purposes" Marquardt smoothed Tanner's raw data using a five-sample moving average, then averaged individual pairs of the resulting data in order to reduce the width of the graph. The result (Marquardt, 2010: 14.2) portrays relative sea level at a periodicity of 100 years, from 7550 to 50 cal B.P. (5600 cal B.C.–cal A.D. 1950) and specifically, during "2850–2550 cal B.P., marshside settlement may have been impractical due to inundation from a pronounced sea level transgression" (Marquardt, 2010: 264). These

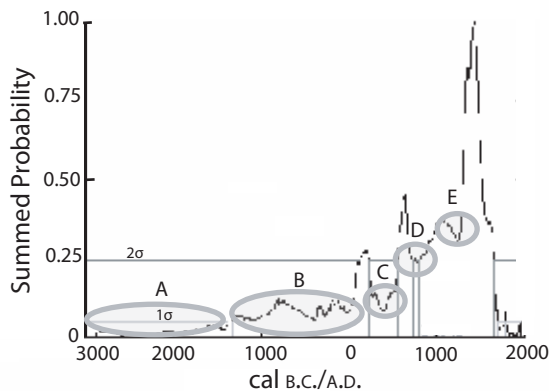


Fig. 1.7. The probability distribution of "cultural" radiocarbon dates ( $N = 116$ ) available from St. Catherines Island processed before January 1, 2005 (after Thomas, 2008b: fig. 16.11). Multiple dates have been run since this in the attempt to fill the obvious "gaps" (indicated by gray ellipses) evident in this distribution.

are remarkable conclusions, if true. This perspective contrasts dramatically with my own interpretations and hypotheses, which (as explained above) are based on the best available, locally derived sea level information from the central Georgia Bight.

Marquardt (2010: 271) concluded his critique this way: "Rather than waiting for geologists to produce the elusive perfect sea level model, archaeologists can themselves contribute to fine-tuning of the best available models (e.g., Balsillie and Donoghue, 2004) and of those few records (Tanner, 1991, 1993; Siddall et al., 2003) that can also serve as models."

I find Marquardt's (2010) application of the Tanner curve to the Georgia shoreline to be problematic, for a number of empirical and epistemological reasons, as elaborated below.

With all of the new science on the table, it is sad to see people revert to something like Tanner's curves ... His work was good, but the science was built on his work and many others, along with new techniques and understanding ... In my humble opinion, there is no gold standard in sea level and Tanner's work is definitely not the curve to tie things to (Stanley R. Riggs, personal commun.).

#### CONTEMPORARY APPROACHES TO SEA LEVEL CHANGE

High-quality data on relative sea level are currently available from the midlatitudes demonstrating considerable spatial and temporal variations among eustatic, isostatic, and local factors during the Holocene (e.g., Morris et al., 2002; Sella et al., 2007; Horton, 2007: 3070; Simms et al., 2008; Church et al., 2008; Horton and Shennan, 2009), but none of these more recent studies is cited in Marquardt (2010). Many of these modern studies focus on the incipient increase/decrease in the rate of sea level change, and its potential impact on coastal systems. Variability in coastal environments—specific sedimentary records reflecting localized responses to past environmental forces (Milliken, Anderson, and Rodriguez, 2008: 43)—can be attributed variously to rising sea level, climate change, flooding of antecedent, relict topography, and/or sediment supply variations. It is this balance among sea level, primary production, and rates of sediment accretion that regulates the relationship between the sediment surface and

the tidal framework, and therefore conditions the long-term stability—and even survival—of coastal wetlands (Morris et al., 2002).

Along continental margins with limited sand supplies—including the Atlantic coastline of the United States—the shorefaces are not simply thick piles of sand. The western Atlantic margin instead consists of a series of crustal highs and adjacent sediment basins, with variable accumulations of sand perched upon a preexisting and highly dissected geological framework (Lambeck and Chappell, 2001). "Holocene sea-level rise has produced a modern transgressive barrier island, estuarine, and fluvial sequence of coastal sediments that are being deposited uncomfortably over irregularly preserved remnants of pre-existing stratigraphic sequences of many sediment and rock units of variable ages, origins, and compositions" (Riggs, Cleary, and Snyder, 1995: 231). The higher portions of the shoreface maintain thin sediment covers over crystalline rock, with little (sometimes none) of the Pleistocene record preserved, and only a few meters of Holocene sediments in the modern coastal system. These sediment basins have been slightly subsiding for over millions of years, into the present day. These basins contain relatively thick sequences of Pleistocene sediment—up to 100 m—overlain by a substantial Holocene record. This complex pattern can only have evolved from very different patterns of relative sea level change that are tectonically driven.

Each barrier beach and shoreface is thus a composite of the complex interplay between its geological pedigree and the physical dynamics of the coastal system that conditions the current morphology, composition of the beach sediments, and the rates of shoreline growth or recession.

**THE WESTERN ATLANTIC COASTLINE:** From New Hampshire to Florida, the western Atlantic shoreline is characterized by a broad continental shelf that displays a significant interplay between postglacial isostatic recovery, forebulge collapse, and hydroisostatic load (Horton, 2007: 3066).

Some time ago, Clark, Farrell, and Pelletier (1978) suggested that sea level observations should be continually rising throughout the Holocene and a newly validated database confirms this to be the case along the entire U.S. Atlantic coast during the late Holocene, with no evidence of former sea levels above present during this time period (Engelhart et al., 2009). But these same investigators note a large vertical scatter in relative

sea levels—more than 4 m at 4 ka B.P.—because the entire coastline has been subjected to spatially variable subsidence from Glacial Isostatic Adjustments (GIA) resulting from the demise of the Laurentide ice sheet (Peltier, 1994, 1999).

Considerable ongoing research attempts to understand the dynamics and role of the glacial forebulge, as the Atlantic margin evolves from glacial to interglacial to glacial episodes, defining the associated geometry “with a level of resolution unmatched in any other currently available method” (Engelhardt et al., 2009: 1115). The geological data constrain the form of ongoing forebulge collapse along the U.S. Atlantic coast, with high rates of subsidence extending into Virginia and the Carolinas (Sella et al., 2007; Snay et al., 2007; Horton, 2007). To be sure, the northern part of the Atlantic margin was greatly depressed under the ice, and with the remainder differentially impacted southward. As the ice retreated, the northeastern segment rose so rapidly that the late Pleistocene shorelines are now hundreds of feet above MSL; southward from the ice front, there was a differential land response. Superimposed upon this general “teeter-tottering” north-south gradient is a series of smaller forebulges that further complicates issues of relative sea level patterning (Peltier, 2002). These processes are significant enough that eustatic sea level curves based upon tropical coral reefs for marine isotope stages (MIS) 5c, 5a, and 3 show “global sea level” at tens of meters below present MSL. But along the mid-Atlantic margin, these same shorelines are found several meters above present MSL. This can only be explained by regional variability and the interplay among the factors discussed above.

An enormous research effort over the past two decades has focused on the North Carolina shoreline, generating both (1) data and models relating to physical and biological responses to shifting sea level and (2) management policies to mitigate potential negative impacts on wetlands and other coastal resources from sea level rise (see Poulter et al., 2009 and the references therein). Of particular relevance here is the highly sensitive sea level database for North Carolina (Horton et al., 2009), marshalling 54 sea level index points directly related to a past tide level and another 33 data points providing limits on maximum-minimum elevations of relative sea level. The database is particularly rich for the post-4000 cal B.P. period. Horton et al. (2009) stress the similari-

ties and parallels to their North Carolina sea level curve to similar high-resolution studies along the mid-Atlantic coast of the United States, especially in New Jersey and Delaware (Nikitina et al., 2000).

Of especial relevance to the geoarchaeology of St. Catherines Island, a problem arises when one attempts to extend these high-resolution results southward into the Georgia Bight. Horton (2007: 3068) emphasizes the paucity of reliable data on relative sea level from South Carolina to Florida. This gap in high-resolution data is particularly critical because the Georgia Bight spans the interface between Zones II and III in the Clark, Farrell, and Peltier (1978) classification of differential sea level responses around the globe. Zone II extends along the western Atlantic seaboard from New England to the northern part of the Georgia Bight (the southern Carolina/Georgia margin or so); this region is characterized by a continual submergence because of the collapsing forebulge. But the contiguous Zone III (from the South Carolina/Georgia borders southward) is characterized by a “time-dependent submergence followed by a slight emergence commencing several thousand years subsequent to the melting event” (Clark, Farrell, and Peltier, 1978: 272). These authors also note that the sea level curve for the eastern continental shelf indicates that “the highest beach, 0.52 m above present sea level, was formed at 75 [ $^{14}\text{C}$  yr] B.P. (Clark, Farrell, and Peltier, 1978: 274, fig. 9A). *St. Catherines Island, we must note, lies almost precisely on this data-poor interface between sea level Zones II and III.*” Horton et al. (2009: 1730) continue that along the U.S. Atlantic coast south of North Carolina: “... studies have suggested the presence of a Mid Holocene highstand, which is contrary to our observational data. In South Carolina, an oscillating RSL history during the Holocene has been proposed (e.g., Gayes et al., 1992; Scott, Gayes, and Collins, 1995). Relative sea level rose from 3 m at 5200–4600 cal B.P. to –1 m by 4300 cal B.P.” Most studies from the Florida Keys show continual rise of RSL during the Holocene with no indication of an emergence (e.g., Robbin, 1984; Toscano and Lundberg, 1998). Toscano and Lundberg (1998) suggested that RSL rose from –13.5 to –7 m between 8900 and 5000 cal B.P. (see also Toscano and MacIntyre, 2003), but Froede (2002) suggested that late Holocene sea level was at least 0.5 m higher than at present in Key Biscayne, Florida.

Engelhart et al. (2009) have also presented a quality-controlled database of 212 basal sea level index points spanning the past 4 kyr cal B.P. for 19 locations from Maine to South Carolina, noting that “the southern North Carolina and South Carolina sites all show similar records of RSLR” (Engelhart et al., 2009: 1116). *Significantly, these same investigators stress the “absence of index points from Georgia and Florida.”*

#### SEA LEVEL RESEARCH IN THE GULF OF MEXICO

To better understand the context of regional variability in sea levels across the American Southeast, it is instructive to examine the history of investigation and particularly the most recent research findings for the Gulf of Mexico.

Absolute dating first facilitated the dating of Holocene sea level change more than four decades ago (Shepard, 1964) and the results for the Gulf Coast have been hotly debated ever since (see Morton, Paine, and Blum, 2000; Blum et al., 2001; Törnqvist et al., 2004a, 2004b; Donnelly and Giosan, 2008, for reviews of this controversy regarding Gulf Coast sea level research). Törnqvist et al. (2004a) commented on the “mutual conflict” among relative sea level curves for the U.S. Gulf Coast during the Holocene, noting that opinion remains divided about the nature of postglacial rise in sea level. Whereas some sea level curves demonstrate a smooth rise in relative sea level during the Holocene, others are characterized by a conspicuous “stair-step” pattern with prolonged (millennial-scale) still stands alternating with rapid (meter scale) rises.

Initial work on subaerial beach ridges suggested a complex record of sea level change along the Gulf Coast (e.g., Curray, 1960; Rehkemper, 1969; Nelson and Bray, 1970; Frazier, 1974; Stapor, 1975; Stapor, Mathews, and Lindfors-Kearns, 1991; Pirazzoli, 1991; Tanner, 1992; Tanner et al., 1989; Walker, Stapor, and Marquardt, 1995; Donoghue, Stapor, and Tanner, 1998). Researchers favoring such an “episodic” perspective have defined distinct periods of rapid increases in the rate of sea level rise, particularly during the early Holocene, centered at 15, 11, 8, 8.2, 7, 2.5, and 1.2 ka  $^{14}\text{C}$  B.P. (e.g., Rehkemper, 1969; Nelson and Bray, 1970; Penland et al., 1988; Thomas and Anderson, 1994, fig. 1; Donoghue, Stapor, and Tanner, 1998). Several investigators found decelerating sea level rise after the early Holocene (Toscano and Macintyre, 2003; Törnqvist et

al., 2002), with small rapid rises occurring during the overall late Holocene deceleration and with a rapid rise about 1700 years ago (Goodbred, Wright, and Hine, 1998). Rodriguez et al. (2004) likewise suggested that rates of shoreline retreat along the Texas coast were episodic during the Holocene.

Significantly, the most recent research clarifies the nature of the dramatic changes that took place in Gulf Coast estuaries over the past 10,000 years. Investigators examining submerged samples have reconstructed a record of gradual sea level rise during the Holocene (esp. Wright et al., 2005; Törnqvist et al., 2006; Milliken, Anderson, and Rodriguez, 2008). Specifically, Törnqvist et al. (2004a, 2006) report an extensive sampling program in the Mississippi Delta. They derive a high-quality database of chronological evidence from regressive mainland and island barriers and standplains on the northern and eastern Gulf Coast. They caution that reconstruction of sea level from barrier lithosomes is potentially complicated by temporarily and locally elevated wave runup levels, subsidence, and other factors. Törnqvist et al. (2004a, 2006) note that despite current consensus, strandplain progradation can also accompany slowing rising sea levels; progradation has not always been restricted to relatively stable or falling Gulf levels, but can also accompany slowly rising sea levels. They highlight the role of tectonic subsidence with respect to relative sea level rise, coastal erosion, and wetland loss, using the term “tectonic” in a broad sense, to encompass long-term thermal subsidence as well as subsidence induced by sediment loading, growth faulting, and compacting of pre-Holocene strata (Törnqvist et al., 2006: 697).

Milliken, Anderson, and Rodriguez (2008) derived a comparable, composite Holocene sea level curve for the northern Gulf of Mexico using basal peat and swash-zone deposits derived from meticulous facies analysis. They determined variations in the age of the  $^{14}\text{C}$  reservoir across this region and applied site-specific reservoir corrections to the sample ages, thereby increasing the accuracy of the derived sea level curve. Milliken, Anderson, and Rodriguez (2008: 1) found a rapid and possibly episodic rise during the early Holocene, followed by a slower, more continuous rise during the middle and late Holocene, concluding “that a middle Holocene highstand for the U.S. Gulf Coast is

highly unlikely, and that the entire area is still responding glacio-isostatically, by means of forebulge collapse, to the melting of the Laurentide Ice Sheet.”

The Milliken, Anderson, and Rodriguez (2008) curve for the Texas coastline closely matches the Törnqvist et al. (2006) curve for the Louisiana area. Although the Mississippi Delta curve could be criticized for having been constructed in an area where subsidence was known to be high and variable, Törnqvist et al. (2006) attempted to account for the degree of subsidence. According to Milliken, Anderson, and Rodriguez (2008: 1), the new composite regional curve “unequivocally” plots sea level –10 to –3 m below present levels from 800 cal B.P. to 4000 cal B.P., thereby precluding a mid-Holocene highstand above present sea level in the northern Gulf of Mexico. Furthermore, the combined records for the Gulf Coast are remarkably similar to the sea level curves (discussed above) for the mid-Atlantic margin, and existing models do not suggest any major difference between the two regions. Although there is a fair amount of regional variation, this is probably caused by subsidence—emphasizing the importance of understanding the specific record of subsidence in any particular area of interest.

**CONTINUING CONTROVERSIES OVER EPISODIC SEA LEVEL RISE AND BEACH RIDGE CHRONOLOGIES:** As the two previous sections have clearly demonstrated, the newest, mostly highly refined studies show no evidence for episodic or higher-than-present sea levels during the middle and late Holocene in the Gulf of Mexico or the mid-Atlantic. But this argument persists in the current literature, and this dispute is quite relevant to the geoarchaeology of St. Catherines Island.

Particularly in light of Marquardt’s (2010) critique of St. Catherines Island geoarchaeology, we will address the research of William Tanner and his associates. Tanner (1992) identified a low position of sea level at 4500–3000 <sup>14</sup>C B.P., a time period with a total apparent absence of beach ridges and he asked whether sea level could have been higher before, then lower, then higher again. Using a beach-sand grain-size parameter (kurtosis) as an inverted index reflecting surf-zone wave energy levels (Marquardt, 2010: fig. 14.3), Tanner (1992: 297) employed the following assumption: “sea level change is generally taken to indicate climate change, and may be more nearly global than what we per-

ceive to be climate change.”

Specifically, Tanner (1990, 1992) studied beach sand and ridge sequences in the extreme northern part of Denmark, near the town of Jerup, then expanded the focus to comparable beach ridge systems in Germany, north of Maracaibo (Venezuela), Caracas (Venezuela), Dog Island (Florida), and St. Vincent Island (Florida). He subsequently expanded this approach to a sample of roughly 50 beach ridge systems—“more than a thousand individual ridges”—from several states in the United States, from Canada, Mexico, Honduras, Venezuela, Brazil, Germany, and Denmark (Tanner, 1995).

Attempting to identify the processes responsible for “making the ridge,” Tanner (1995) rejected the notion that the ridges could have been formed as a nearshore bar. Citing Stapor (1975; Stapor, Mathews, and Lindfors-Kearns, 1988), he also rejected the hypothesis that the ridges were the result of catastrophic storms, maintaining that it was “not tenable.” With regard to “actual storm ridges,” he asserted that “not a single sandy beach ridge, of more than a thousand that have been studied to date, has the characteristics of known hurricane deposits” (Tanner, 1995: 154).

Instead, Tanner (1995) concluded that the granulometry and sedimentary structures of beach ridges and swales are indicative of normal fair-weather processes, in which a small fall in sea level generates swales and a small rise in sea level creates beach ridges. Settling on sea level change as the sole cause of the global continuities he observed that

the sea-level history that has been obtained in northern Denmark duplicates the history from various other areas, as far back as the record goes in each place ... the concept of a small couplet of sea-level changes, to explain the origin of a beach ridge and swale pair, has been developed and presented orally over a period of many years, and has been stated clearly in print (Tanner, 1995: 155, 159).

Tanner’s basic conclusion remained unchanged throughout: “All of the data now available from beach ridge plains provide the same general results ... therefore, the beach ridge work is not primarily concerned with local or short-term effects. Instead, these data from three continents must show sea level changes, even though

those changes have been relatively small” (Tanner, 1992: 302).

Building on the previous work of Tanner and Stapor (1972), Stapor, Mathews, and Lindfors-Kearns (1991) examined a series of geomorphic beach ridges along the central west Florida barrier system. Using beach ridge height and youngest shell dates, they suggested that sea level was higher than present at 2000  $^{14}\text{C}$  B.P. then falling at 1500  $^{14}\text{C}$  B.P. Walker, Stapor, and Marquardt (1995) employed archaeological evidence to support this higher-than-present sea level at 1750–1450 cal B.P. Blum et al. (2003) report optically stimulated luminescence (OSL) dates that suggest a sea level highstand along the Alabama coastline between 6700 and 4000 cal B.P., and again about 3500–2500 cal B.P. Similarly, Morton, Paine, and Blum (2000) proposed several higher-than-present sea level events at 5500–1200 cal B.P. along the Texas coast. The notion of highstands in relative sea level Holocene remains “a highly controversial issue,” as reflected in several vigorous discussions (e.g., Otvos, 1999, 2001; Rodriguez et al., 2004). Some more recent research on the beach ridge complexes in the northern Gulf of Mexico has revitalized some this earlier discussion of rapidly fluctuating sea levels and higher-than-present highstands. Morton, Paine, and Blum (2000) and Blum et al. (2001, 2003, 2008; Blum and Carter, 2000) have argued for a mid-Holocene highstand and fall in sea level since 6.5 ka. Blum et al. (2002) suggest that a late Holocene RSL fall might reflect true glacio-eustatic change, associated with the readvance and thickening of the Antarctic and Greenland ice sheets.

One case in point is St. Vincent Island (Florida), a critical locale for beach ridge research and the subject of much recent interest. Stapor (1975), Tanner (1988, 1992, 1995), and Tanner et al. (1989) had previously argued that this beach ridge plain indicated that “these water-laid semi-parallel to parallel landforms with elevations up to 4 m above mean sea level were controlled by a succession of sea-level fluctuations during the last 6500 years.” Otvos (2002: 102) has critiqued the evidence of a Gulf of Mexico marine highstand at elevations above present high tide levels (esp. Stapor, Mathews, and Lindfors-Kearns, 1991; Stapor, 1975; Donoghue and Tanner, 1992), arguing that the meaning of diagnostic sedimentological and morphological indicators (and their limitations and utility in reconstructing past sea levels) was not adequately addressed.

Tanner and Stapor (1973, 1975) had previously dated the earliest beach ridge set (A, B, and C) to 6500–4000  $^{14}\text{C}$  yr B.P., with later ridge sets (D, E, F, and G) formed between 3000 and 1000  $^{14}\text{C}$  yr B.P. and the remaining ridges formed later. But subsequent dating using archaeological associations (Miller et al., 1981; White, 2003) suggest that the Tanner et al. (1989) dates are too old; Miller and colleagues revised these estimates for the oldest ridges to 3000 to 4000 years. Otvos (2005) employed OSL dates on these same ridge sets, reporting an age range between  $6930 \pm 790$  and  $3950 \pm 530$  years ago for the oldest ridges, and much more recent age ranges for more recent ridge sets. López and Rink (2008: 52) comment that “even though in general Otvos (2005) OSL ages are decreasing from north to south, the values do not portray realistically the time between ridge formations”—perhaps due to differential sample depths.

López and Rink (2008) have generated “new reliable absolute ages on the beach ridge sequence” based on OSL dating of quartz sand grains from St. Vincent Island. These OSL samples were deliberately secured to mimic locations previously employed by Tanner (1992), who had used previously available topographical, geomorphological, radiocarbon, and sedimentological analysis to reconstruct the evolution of this strand-plain, with the oldest beach ridges on St. Vincent Island providing much younger OSL ages (between  $2733 \pm 404$  and  $2859 \pm 340$  years); the later beach ridges dating much later as well. López and Rink (2008: 49) conclude that their data provide “new reliable absolute ages on the beach ridge sequence on St. Vincent Island,” considerably revising the previous estimates of Stapor (1975), Tanner (1988, 1992, 1995), and Tanner et al. (1989).

A similar debate has taken place in the Sanibel Island group of southwestern Florida, where Stapor, Mathews, and Lindfors-Kearns (1987) associated the elevation of ridge summits with oscillating sea levels and/or wave energy conditions. Otvos (2005: 158) has argued that the contemporaneous sea level was approximately 0.5–1.0 m below present and he “strongly suggests that these variations resulted from uneven sediment supply, wave, and current energy conditions, rather than substantial longer-term regional sea-level oscillations” (Otvos, 2005: 158).

Several investigators support the general proposition that beach ridges can serve as accurate sea

level indicators (Stapor, Mathews, and Lindfors-Kearns, 1987; Donoghue and Tanner, 1992; Morton, Paine, and Blum, 2000; Blum et al., 2002; Blum et al., 2003). But other studies provide conflicting evidence (e.g., Rodriguez and Meyer, 2006), stressing the importance of understanding the dominant processes that control beach ridge formation and preservation. Otvos (2000) argues that whereas sea level can be reconstructed by examining the interface between intertidal and overlying eolian sediments (because this contact reflects a distinction between foreshore and wind-borne deposition), this interface is difficult to identify using granulometry and geomorphic structure. Wright et al. (2005: 634) conclude that “while other small variations of sea-level changes are possible within this overall context of decelerating rates of rise, the stratigraphic results of this study and the presence of relict dune morphologies near sea level ... suggest that relative sea level was never higher than present during the middle to late Holocene.”

Newly available GPR records appear to clearly define the contact between eolian facies and wave-constructed foreshore, but Rodriguez and Meyer (2006: 267) argue that this evidence is insufficient to reconstruct sea level. Specifically, Rodriguez and Meyer (2006) combined lidar and sediment coring with GRP profiling on the same beach ridge complex of the Morgan Peninsula (Alabama) where Blum et al. (2003, 2008) had previously argued for highstand. Rodriguez and Meyer (2006) find no evidence to support a higher-than-present sea level during middle to late Holocene; instead, they interpret the monotonic rise of the contact between foreshore and eolian deposits as evidence of a decreasing rate of sea level rise (Törnqvist et al., 2002) and an abundant sediment supply—not in response to sea level reaching stable current levels (Blum et al., 2002). Some research indicates that such sea level events might have been the result of other mechanisms, such as the flooding of flat antecedent topography (Rodriguez et al., 2004).

There is also considerable conflict between beach ridge-based sea level reconstructions and independent lines of evidence including coral and peat deposit chronologies (Scholl et al., 1969; Parkinson, 1989; Bard et al., 1996; Blanchon and Shaw, 1995; Toscano and Lumberg, 1998; Törnqvist et al., 2002, 2004; Rodriguez and Meyer, 2006; Milliken, Anderson, and Rodriguez, 2008). Using both corals and peats that

span the last 11,000 years, Toscano and Macintyre (2003: fig. 5) have constructed a western Atlantic Holocene sea level curve for the Florida Keys and Belize, presumed tectonically stable areas of the Caribbean, using both corals and peats that span last 11,000 years. These rates of sea level change are not indicative of extreme pulses of reef drowning and subsequent backstepping, and the attempt to correct this dataset with a hypothetical tectonic subsidence rate produced inconsistent results: “We therefore conclude that a middle Holocene highstand for the U.S. Gulf Coast is highly unlikely, and that the entire area is still responding glacio-isostatically, by means of forebulge collapse, to the melting of the Laurentide Ice Sheet” Törnqvist et al. (2004a: 1026).

On the contrary, Blum et al. (2008: 675) argue that recent data of “cyclical uplift and subsidence refute recent interpretations of delta stability, and suggest that late Holocene relative sea-level curves from the [Mississippi] delta region are instead a record of subsidence of the pre-Holocene depocenter.”

Törnqvist et al. (2004a: 1027) note that whereas “the cause of a higher than present middle Holocene RSL is uncertain, [a] conceivable driving mechanism could include equatorial ocean siphoniness (the transfer of ocean water to offshore collapsing forebulge areas) ... or hydro-isostasy (a result of the transfer of viscous mantle material from the oceans to continents due to ocean-water loading) or perhaps a hydro-isostatic uplift of Mexico due to its proximity to ocean-water loads in the Gulf as well as the Pacific Ocean.”

Another problem is that the organic carbon and marine shell incorporated into the ridges are not always contemporaneous with the beach ridges themselves—and radiocarbon dating in such contexts must involve only those carbon samples that indicate minimal reworking before burial (e.g., Stapor, Mathews and Lindfors-Kearns, 1991; Rodriguez et al., 2004; Giosan et al., 2006). Although OSL dating has also been used on such beach ridges, the results involve analytical and geological uncertainties (Otvos, 2005) and require confirmation by complementary methods such as radiocarbon dating (Donnelly and Giosan, 2008: 752).

Donnelly and Giosan (2008) ask whether these beach ridge complexes are related to changes in “storminess.” That is, assuming that the evidence for gradual submergence is correct (Milliken,

Anderson, and Rodriguez, 2008 for the Texas coast; Törnqvist et al., 2006 for the Mississippi Delta, and Wright et al., 2005 for northwestern Florida) – then the beach ridges of St. Vincent Island and Edith Hammock were formed at a time when sea level was between –2 m and –0.5 m of its present elevation – well within reach of storm waves over the last 3000 years (Rodriguez and Meyer, 2006).

While it is true that direct impact of severe storms would indeed result in significant coastal erosion at the landfall (Rodriguez and Mayer, 2006), Donnelly and Giosan (2008) emphasize the general change in wave climatology involved in increased tropical cyclone regimes and point out that for each direct strike, many more tropical cyclones would traverse the Gulf of Mexico, thereby significantly increasing the overall wave action during hurricane seasons, and potentially increasing the frequency of constructional swells (Otvos, 1995, 2000). Komar and Allan (2008) have documented an increase in summer wave heights along the U.S. East Coast since the 1970s, which is associated with the increased tropical cyclonic activity in recent decades.

In other words: an increase in “fair-weather” swell frequency and height during periods of increased tropical storm activity provides an alternative hypothesis to explain how beach ridges could develop a few meters above their contemporaneous sea level (Donnelly and Giosan, 2008). If this hypothesis is correct, then it would largely resolve the nature of Holocene sea-level change in the Gulf of Mexico.

Blum et al. (2008: 675) offer one potential way to resolve these apparent contradictions by supporting the concept of a mid-Holocene highstand and suggesting that localized subsidence might explain the gradual submergence reflected in sea level data from the Mississippi delta (Törnqvist et al., 2006: fig. 1A). They suggest a further refinement in knowledge of the isostatic mechanisms in deltaic areas by factoring in the loading effects involved with incision of this deglacial valley, followed by infilling and delta growth. The proposed solution tendered by Blum et al. (2008), of course, would not seem to apply outside of the Mississippi Delta.

Testing this hypothesis would require considerable research to develop reliable proxies of wave energy to reconstruct past storminess, detailed and accurate mapping of beach ridge complex, detailed geomorphological study of

variations in local sediment supply, and a more detailed understanding of beach ridge morphodynamics (Donnelly and Giosan, 2008: 752).

Noting the considerable debate that continues over the age and meaning of these beach ridges and strand-plains, López and Rink (2008: 51) conclude that “to date, there is no widely accepted beach ridge building model.” With that caution in mind, we must view the sum total of the sea level research summarized above as reflecting a paradox, namely that the beach ridge evidence still seems to conflict with the increasing and tightly constrained evidence of gradual submergence (Donnelly and Giosan, 2008: 751).

**RELEVANCE TO THE GEOARCHAEOLOGY OF ST. CATHERINES ISLAND:** Over the past three decades, several geoarchaeologists studying St. Catherines Island—initially working independently, but more recently, pooling their efforts—have developed a collective perspective on the origins of beach ridges and their relationship to marine sea level and storm events.

This position is contrary to the hypothesis of Tanner and his associates (1991, 1993, 2000)—that such beach ridges developed as marine processes—arguing instead that the observable beach complexes evident on St. Catherines Island are instead constructional features caused by wind blowing across broad beaches and dropping their sediment load at the vegetation margin of the backbeach. Observational evidence on St. Catherines Island demonstrates that beach ridges form as accretionary episodes by the building of transverse dunes initiated by wind shadows at the vegetation line marking the boundary between the backbeach and island (Bishop et al., 2007: fig. 57; see also [www.scistp.org](http://www.scistp.org), Bishop, Vance, and Meyer, 2007).

There is ample proof that these ridges are not formed by marine processes per se, but by wind transporting sand off the low-tide beach into backbeach wind shadows. The elevations of these multiple ridges are controlled by wind regime and direction, sand sediment size and cohesion, and how long the wind blew. Swales, however, probably really mark marine run-up processes during storms as ridges might well be flattened by surges of breaking waves. Then, after the storm, beach ridges would again form. Work on St. Catherines has led us to put much more faith in the boundaries between beach ridge complexes (Bishop et al., 2007: fig. 38) as

they are thought to mark major breaks in sedimentation and/or erosional events.

Rollins, Beratan, and Pottinger (chap. 8, this volume; see also Pottinger, 1996) further consider the role of storm events in forming the beach ridges. These authors document the impact of Hurricane Hugo on the northern end of St. Catherines Island in 1989. Contrary to the interpretations of Stapor (1975), Tanner (1988, 1992, 1995), and Tanner et al. (1989), Rollins, Beratan, and Pottinger (chap. 8) basically support Oertel (1975a, 1977) in suggesting that a rather complex scenario is required to explain the mosaiclike pattern of truncated sets of beach ridges at the north end of St. Catherines Island (and analogous sea islands). Oertel hypothesized that historical change in the sedimentary dynamics associated with the inlets (sounds) and marginal ramp shoals bordering the inlets led to sequential aggradation and degradation of beach ridge sets. A surfeit of sand is liberated for longshore transport by the dominant ebb tidal flow through inlets, such as St. Catherines Sound. This results in the construction of large sand shoals at the mouths of the inlets. The shoal ramps are asymmetrically developed on both sides of the inlets.

The predominance of southward longshore drift, driven by northeastern winds and storms, distributes the sediment southward at the front margin of the ramp shoal, especially when the shoal is attached and acts as a shield for sediment transported out the inlet. Conversely, when the shoal is detached, a "funnel" is created with its mouth open to the south, trapping sediment moving northward by fair weather summer drift and flood tide transport. The overall effect is such that beach ridge aggradation occurs during intervals when the ramp-margin shoal is attached to the south of the inlet, and beach ridge truncation results when the shoal is detached and ebb flow can course close to shore and not be forced around the outer margin of the shoal.

The impact of Hurricane Hugo along Picnic Bluff seems to support Oertel's model well, but Rollins, Beratan, and Pottinger (chap. 8) also highlight the role of single storm events in triggering rapid construction of beach ridge sets. It is possible that these three beach ridges formed so rapidly because movement of sand was restricted between the bluff and the shoreface. Storm events, as such, likely represent an unexpected complement to Oertel's model. Employ-

ing historical aerial photographs (from the mid-1940s to 1990) Rollins, Beratan, and Pottinger tested this hypothesis and found significant changes in the position of the north-point marginal ramp shoal correlated with the development of beach ridges. Coastal storm records are strongly correlated with changes in the shoal sand body.

Rollins, Beratan, and Pottinger argue that the complex mosaic of beach ridges along the northern end of St. Catherines Island is the product of at least three hierarchical levels of causation. Single storm events can trigger beach ridge deposition on the scale of only a few years. Over decadal spans of time, rapid modification of the marginal ramp shoal system occurs during intervals of violent storm activity, but relative geomorphic stability occurs during quiescent periods. The northern tip of St. Catherines Island experienced the most rapid change during the stormy mid-1940s through the mid-1960s. The high-angle truncation of the multiple sets of beach ridge construction at the northern end probably is the product of a different type of sedimentary dynamic playing out over significantly longer spans of time (see also Kana, Hayter, and Work, 1999; Chowns, chap. 9).

With respect to sea level change around St. Catherines Island, we conclude the following:

(1) *Relative sea level can be regionally variable*: There is plenty of theoretical evidence to suggest that considerable variability in relative sea level can be expected, with important contributing factors being the underlying sediment and rock units, available sand supply, current shoreface morphology, composition of beach sediments, the rates of shoreline growth or recession, geographic relationship to forebulge collapse, and the rate of isostatic recovery.

(2) *The Texas and Louisiana sea level curves match*: Degree of subsidence is reasonably well known and minor along the Texas shoreline, and the curve (Milliken, Anderson, and Rodriguez, 2008) for this area is consistent with the curve from Louisiana (Törnqvist et al., 2006), a place where subsidence is known to be high and variable. This would seem to suggest that the two combined datasets yield a good curve reflecting the large-scale trends in the Gulf of Mexico. Furthermore, both curves rely on basal peats (for which no reservoir correction is required) and their value as sea level markers is widely accepted; these trends are compared

and contrasted with *Donax* shells taken from swash-zone deposits (for which the carbon reservoir has been constrained). Further, these complimentary studies from the northeastern Texas shoreline and the Mississippi Delta are comparable with recent evidence from the salt marshes along the Suwannee River (Florida: Wright et al. [2005: fig. 1A]).

(3) *The mid-Atlantic sea level curves match:* The North Carolina curve (Horton et al., 2009) is based on a rich, diverse and highly sensitive series of sea level index points and an additional set of data points that constrain maximum-minimum elevations of relative sea level. The North Carolina curve is entirely consistent with high-resolution studies in Delaware (Nikitina et al., 2000) and New Jersey.

(4) *The mid-Atlantic and northern Gulf sea level curves match:* There is plenty of highly sensitive sea level data from the western Atlantic coastline and the northern Gulf of Mexico to suggest a smooth and continual rise of relative sea level during the Holocene.

(5) *There are mutually conflicting interpretations of oscillating sea level during the Holocene:* With respect to the ongoing controversy regarding a possible mid-Holocene sea level highstand above the present level (Morton, Paine, and Blum, 2000; Blum et al., 2001; Törnqvist et al., 2004a), the new composite regional curve “unequivocally” plots sea level –10 to –3 m below the present level from 800 cal B.P. to 4000 cal B.P., thereby precluding a mid-Holocene highstand above present sea level in the northern Gulf of Mexico (Milliken, Anderson, and Rodriguez, 2008: 1). Conflicting evidence includes results from the Florida Panhandle and the Georgia Bight that suggests an oscillating or stair-step history and/or higher-than-present relative sea level change during the Holocene; data from subaerial beach ridge complexes and strandplains are particularly controversial, with several investigators questioning the value of such data for reconstructing past sea level.

(6) *High-quality constraining data on Holocene sea level change are entirely lacking for the interior Georgia Bight.* But we note that relevant data are available in the form of stratigraphic sequences deposited below sea level and now lifted above sea level (Pirkle et al., 2007) on the Georgia-Florida border. At Yellow Banks Bluff, on St. Catherines Island,

there is a washover fan (and terrace) burrowed by semiterrestrial fiddler crabs, today located approximately 1.5 m above high-tide level (see chaps. 4 and 5).

(7) *If the late Holocene highstand suggested by Gayes et al. (1992), Scott, Gayes, and Collins (1995), and Froede (2002) is accurate for the interior Georgia Bight and southeastern Florida, then (1) it conflicts with several recent high-precision studies showing gradual sea level rise in North Carolina, Delaware, and New Jersey and (2) it must be confirmed by new high-resolution data currently unavailable.*

#### SOME POTENTIAL NEW DIRECTIONS IN GEOARCHAEOLOGY

This review of sea level history, coupled with paleoenvironmental and paleodemographic scenarios sketched out above, requires several assumptions, cries out for new, more highly constrained data, and leaves many questions unanswered. Rollins and Thomas (chap. 16) develop this topic in much greater detail, discussing in particular the importance of the immediate proximity of marine and terrestrial resources to the central-place foraging models developed for St. Catherines Island. Even relatively small changes and/or the distribution of accretionary terrains can have major impacts on the residential and mobility strategies of human foragers living on St. Catherines Island. This is why we need to refine, in much greater detail, the exact nature of sea level change and more accurately reconstruct the geomorphic configuration of the island during the past several millennia. We need to establish the ages of boundaries of the accretional terrains on St. Catherines Island and tie migration of coastal sand bodies to the evolution of the island. We also must understand the history of shifting rivers, and infilling of spits and marshes. We need to refine age estimates of beach ridges, to document the evolution and disappearance of seaside marshes, to map the locations of estuaries and tidal systems that determined where foragers spent their time, and how far foraging activities took them from their mainland bases in the maritime forest. We must refine estimates of relatively minor sea level shifts and their projected impacts on habitats (both terrestrial and marine), document the shifting diminution of Silver Bluff (“island core”) sediments and the construction of Holocene-age

accretionary beach ridges (shifting the balance between first-tier and second-tier habitats), and document the relative stability of the various island scarps, which function as boundary mechanisms constraining how close human settlements can be built to nearby marshlands.

## SECOND QUESTION: HOW DOES THE RADIOCARBON RESERVOIR EFFECT VARY ACROSS TIME AND SPACE IN THE GEORGIA BIGHT?

The apparent radiocarbon ages of marine samples are several hundred years older than contemporaneous atmospheric  $^{14}\text{C}$  samples. Dissolved inorganic carbon in the upper ocean is influenced by the exchange with both the atmosphere and the radiocarbon-depleted deep ocean, with a  $^{14}\text{C}$  content intermediate between the two (Broecker, Ewing, and Heezen, 1960; Broecker and Olson, 1961; Berger, Taylor, and Libby, 1966; Taylor, 1987: 34). Reservoir effects—the incorporation of ancient carbonates in living organisms—are today attributed primarily to upwelling, in which water from deeper ocean contexts is periodically brought upward and mixed with surface ocean water. Marine shell species can also be heavily influenced by effects of estuaries, bayous, inland waterways, and bay environments. In such environments, living shell can also be seriously affected by the discharge of carbonate-rich freshwater, which causes variability in apparent ages of up to a millennium.

To date marine materials, it is essential to separate the  $^{14}\text{C}$  of the ocean surface from that of atmospheric  $\text{CO}_2$ . Regional patterns of  $\Delta R$  are controlled by diverse factors, including localized circulation patterns, the relative inflow off freshwater sources (presumably carrying older carbonates), spatial variations in upwelling, water mass mixing, and variable air–sea gas exchange.  $\Delta R$  values can likewise vary in marine mollusc samples due to species, habitat, and/or substrate (Dye, 1994; Forman and Polyak, 1997; Hogg, Higham, and Dahm, 1998; Reimer and Reimer, 2001). In areas where waters are continuously exchanged with open ocean water and vertically well mixed (with concentrated upwelling offshore), reservoir effects tend to increase. Estuarine processes and dilution by freshwater most likely reduce reservoir effects within tidal waters.

## CURRENT THINKING ABOUT RESERVOIR EFFECTS

Our earliest excavations on St. Catherines Island explored the Refuge–Deptford periods burial mound complex, and we generated 29 radiocarbon dates from these excavations. Although we mentioned “reservoir effects” in passing (Thomas and Larsen, 1979: 138), we basically dismissed the problem. But when we compared nearly a dozen paired charcoal–marine shell samples, we found a disparity of 300–400 years, even though the samples should date the same behavioral event (Thomas, 2008: table 13.1 and fig. 13.1). Clearly, for  $^{14}\text{C}$  dating of zooarchaeological marine shells to play a prominent role in understanding the cultural chronologies of St. Catherines Island, we needed to correct for the reservoir effects involved in these  $^{14}\text{C}$  determinations.

We began by dating a series of known-age prebomb molluscs from various museum collections (Thomas, 2008: 348–353); the sample consisted of nine molluscs, spanning several species and approximately 800 km of coastline, from Beaufort (North Carolina) to Cocoa Beach (Florida). Although relevant comparable values are still scarce, the mean  $\Delta R$  value for the Carolina–Florida subsample ( $106 \pm 26$  years) compares favorably with the other available regional average  $\Delta R$  values (available from the online Marine Reservoir Correction Database) for the Bahamas and Florida ( $36 \pm 14$  years), Long Island Sound, New York ( $165 \pm 78$ ), and the Gulf of Maine ( $38 \pm 40$  years). Because none of the available prebomb, known-age molluscs came from the Georgia coast, we looked for a better way to create the modern control sample.

Knowing (1) that a commercial oyster industry had once flourished in the waters surrounding St. Catherines Island during the late 19th century and (2) this industry ceased operation during the 1920s, we reasoned that their massive spoil heaps on St. Catherines Island could provide a new, more specifically localized source of modern control samples. Specifically, because virtually all of the shells within these factory middens derived from *Crassostrea virginica* that were harvested between about 1900 and 1920, we anticipated that such known-age molluscs might be a useful addition to the reservoir-effect study. We estimated the age of harvest for each sample to be A.D.  $1910 \pm 10$  years.

We processed numerous  $^{14}\text{C}$  determinations

on *Crassostrea virginica* collected from the oyster boiling factories of St. Catherines Island and found that these “modern” oyster shells produced an extraordinarily negative mean  $\Delta R$  value of  $-134 \pm 26$ —one of the most extreme values yet recorded (Thomas, 2008: 357–259). It is clear that the intertidal species *Crassostrea* found on St. Catherines Island were sampling a different  $^{14}\text{C}$  reservoir than the surface mixed layer commonly assumed for such marine samples (perhaps due to intense wave action or exposure during low tide that caused atmospheric mixing in shallow and estuarine waters). When we applied this reservoir correction to the 11 charcoal-marine shell pairs, we found that in each case the charcoal and marine shell dates overlap significantly, reinforcing the conclusion that the local reservoir factor satisfactorily resolves the discrepancy between atmospheric and marine samples on St. Catherines Island (Thomas, 2008: table 13.3, fig. 13.9).

#### SOME POTENTIAL NEW DIRECTIONS IN GEOARCHAEOLOGY

Although the St. Catherines Island reservoir correction does indeed seem to “correct” marine dates to comparable ages derived from terrestrial samples, we see several potential problems that could be addressed in subsequent geoarchaeological investigations.

**SPECIES-SPECIFIC EFFECTS:** It may be that the  $\Delta R$  values computed on *Crassostrea virginica* (oysters) from St. Catherines Island are not be directly transferable to, say, *Mercenaria mercenaria* (clams). In the paired marine-terrestrial samples (mentioned above) oyster shell–charcoal pairs had a mean differential of  $279 \pm 138$   $^{14}\text{C}$  yr B.P. ( $N = 8$ ), whereas the corresponding mean age differential for clam shell–charcoal pairs is  $430 \pm 26$   $^{14}\text{C}$  yr B.P. ( $N = 3$ ; Thomas, 2008: 358). While these results are not statistically significant, there is a possibility that *Mercenaria mercenaria* and *Crassostrea virginica* might require different reservoir corrections (see Goodfriend and Rollins, 1998; Hogg, Higham, and Dahm, 1998). To date, our lack of modern prebomb controls on *Mercenaria* populations from St. Catherines Island makes such a species-level calculation of  $\Delta R$  values impossible at this point.

**DIFFERENTIAL CARBONATE UPTAKE:** The extreme reservoir correction derived for St. Catherines Island samples might result from the

positioning of the island relative to carbonate sources draining from the Piedmont. Of all the Georgia barrier islands, St. Catherines is currently farthest from a major river: neither Sapelo Sound to the south nor St. Catherines Sound to the north communicates directly with a major freshwater source. Rather, the Medway, South Newport, and Sapelo rivers are salt marsh estuaries situated north of St. Catherines, Sapelo, and Little St. Simons islands, respectively, and are dominated by ebb tides, with very little freshwater inflow (Howard and Frey, 1975). Griffin and Henry (1984: 43) suggest that this isolation from major deltaic systems may account for the extreme rates of erosion observed on St. Catherines Island during the historic period. Even a cursory look at coastal geomorphology shows that St. Catherines Island lies near the southern extent of the destructive delta (a chenier or delta bulge) built by the Savannah and Ogeechee rivers to the north. Perhaps this diminished freshwater sourcing reduces the number of carbonates entering the marine catchment.

But the Ogeechee and Altamaha rivers have headwaters that extend far into the coastal plain and tributary systems that aggrade north of Ossabaw and Little St. Simons islands, respectively. Perhaps barrier island sources closer to these major rivers would contain a greater load of imported carbonates, thereby making their apparent age more extreme (and, of course, requiring a different reservoir correction).

We hypothesize that distance to major deltaic systems should influence the reservoir effect: the closer to the major freshwater source, the greater the carbonate load reflected in the  $\Delta R$ . To test the hypothesis of lateral, facieslike variability, we have already begun a small-scale sampling program on late 19th- and early 20th-century oyster factories along the Georgia Bight. The attempt is to find known-age oyster samples and derive independent  $\Delta R$  values to compare with the St. Catherines Island results. Work has already begun on samples from Sapelo Island and we hope to expand the project in the near future.

**DOES  $\Delta R$  REMAIN CONSTANT THROUGH TIME?** As a practical matter, we initially assumed that  $\Delta R$ , the global reservoir  $^{14}\text{C}$  age of the ocean’s surface water, has remained stable through time on St. Catherines Island (and there is some support for this assumption; e.g.,

Reimer et al., 2001). But other studies have found that marine  $\Delta R$  values have fluctuated through time, due primarily to changing patterns of ocean circulation or regional upwelling in which deeper, older water may cause  $\Delta R$  to vary temporally (e.g., Ingram and Southon, 1996; Kennett et al., 1997; Deo, Stone, and Stein, 2004).

The problem with our previous “test” is that most of the 11 paired samples derived from late prehistoric (Irene) contexts, with only two of the pairs coming from pre-Irene contexts; none of the  $^{14}\text{C}$  ages were older than 2000  $^{14}\text{C}$  yr B.P. (Thomas, 2008: table 13.1). To test the proposition that  $\Delta R$  values might change through time, we have begun collecting paired charcoal-marine shell dates during our excavations in the two contemporary Late Archaic shell rings on St. Catherines Island—the McQueen Shell Ring (9Li1648) and St. Catherines Shell Ring (9Li231)—two sites that were occupied approximately 2500–2300 cal B.C. (Sanger and Thomas, 2010). We are still collecting and processing paired samples, but preliminary results suggest that the St. Catherines Island reservoir correction (discussed above) seems to work on these more ancient samples as well.

“JUMPING INLETS, SPITS, AND ISLANDS”  
IMPLICATIONS<sup>9</sup>: An independent test of both the differential carbon uptake and the change-through-time hypotheses may be possible through the ongoing research of Chowns and his colleagues. Chowns (2002) and Chowns et al. (2008) argue that rising sea levels over the last few thousand years have caused a number of inlets along the Georgia coast to become straighter. This change in drainage pattern has caused some inlets (such as St. Simons Sound, Sapelo Sound, and Ossabaw Sound) to become broader, while others have narrowed (viz. St. Andrews and St. Catherines sounds; see also Chowns, chap. 9). Chowns et al. (2008) have demonstrated this “jumping inlet” pattern of stream capture for the Brunswick River, which, prior to about 1480 B.P., entered the Atlantic Ocean south of Jekyll Island. But rising sea level “encouraged the river” to follow a more direct route, and empty instead to the north of Jekyll. If similar patterns of relocation hold further to the north, then redirection of the Altamaha and Ogeechee rivers could significantly change the distribution of ancient carbonates from the various catchments on the Piedmont.

RECONSTRUCTING ESTUARINE DROUGHT CONDITIONS AND SHIFTING SALINITIES: Recent research at colonial Jamestown (VA) highlights the potential of studying estuarine drought conditions by coupling fine-grained archaeological and paleoclimatic investigation. By comparing bivalve geochemistry (particularly oxygen isotope data) between modern oyster with those discarded in early 17th-century wells, these investigators have successfully quantified estuarine salinity, seasonality of oyster collection, and annual shifts in drought conditions in the Chesapeake Bay ecosystem.

We think it is likely that shifting hydrologies over the past century have significantly impacted the American (or eastern) oyster, *Crassostrea virginica*, living in the intertidal estuaries, along saltwater rivers and tidal creeks that dissect the expansive *Spartina* marsh bordering St. Catherines Island. Within a given locality, oyster growth depends on bottom conditions, degree of salinity, water temperature, and tidal movement. A century ago, coastal Georgia was among the world’s leading oyster harvesters, rivaling the celebrated, oyster-rich waters of the Chesapeake (Thomas, 2008: chap. 7). By the 1880s, overharvesting and pollution threatened Georgia’s shellfishery. The headwaters of these oyster-bearing rivers were also once fed by freshwater aquifers, which dried up due to the lowering of water tables over the past century.

By comparing isotope levels in century-old factory middens derived from *Crassostrea* individuals (harvested between about 1900 and 1920) with zooarchaeological bivalves available from various archaeological sites, we should be able to address the effects of hydrological change and shifting salinity over the past five millennia. Not only could we collect oysters that lived under the previous (artesian) hydrological regimen, but we have recently discovered that occasional *Mercenaria* were also (accidentally) harvested at the oyster factories, providing another potential source of samples to explore this issue. For St. Catherines Island (and the rest of the Georgia coastline), we have detailed salinity measurements taken between October 1888 and February 1889 (Drake, 1891). We think a comparison of modern, century-old, and zooarchaeological samples could help define the nature of recent hydrological and salinity shifts during the entire human occupation of St. Catherines Island.

### THIRD QUESTION: WHAT IS THE RELATIONSHIP BETWEEN HYDROLOGY AND LACUSTRINE ADAPTATIONS ON ST. CATHERINES ISLAND?

#### CURRENT THINKING ABOUT HYDROLOGY AND LACUSTRINE ADAPTATIONS

The island's Pleistocene core consists of a high-standing, relatively level terrain, attributed to the Silver Bluff shoreline. It is currently unclear whether this island core consists of a single homogeneous unit of deposition or several, although it would seem that multiple events and processes are implicated because of the distinctive Central Depression running along the midline (Bishop et al., 2007: 40, fig. 6).

The Central Depression is clearly evident on the 1867 map of St. Catherines Sound, produced by the U.S. Coastal Survey. This long, nearly linear zone of freshwater swamp extends from present-day Wamassee Pond northward to the depression immediately to the east of the present animal enclosures (but for some reason, this map fails to track the low-lying swampy area to its northern extent, at modern Gator Pond). Working from this baseline evidence, we believe that the extent of the former Central Depression is mirrored in the distribution of the Mandarin-Rutledge soils, the very poorly drained remnant soils that developed in the shallow depressions and freshwater swamps along the midline of St. Catherines Island (Looper, 1982; Reitz et al., 2008: fig. 5.2).

Based on these soil distributions and the dendritic pattern of relict groundwater outflows that once drained into the marsh, Hayes and Thomas (2008) reconstructed a large freshwater lagoon, which they believe once dominated the central reaches of St. Catherines Island. They argue that during the aboriginal period, freshwater was always abundant on St. Catherines, available in numerous places, except during periods of extreme drought. The Central Depression was hydrologically powered by the Floridan Aquifer, one of America's most productive groundwater reservoirs, which extends from South Carolina to Florida and reaches inland as far as Alabama. Near Brunswick (Georgia), the sedimentary strata comprising the Floridan aquifer are deeply buried beneath more than 150 m of sand and clay, and reach 600 m thick. This sequence thins and climbs toward the surface near Savannah, where the carbonate strata are less than 150 m thick and lie 15–50 m below the surface. The deep confined

aquifer discharged artesian water to the ground's surface in many places, and elsewhere, a relatively shallow well could tap the surficial reservoir of nonartesian water (fig. 1.8).

This was the hydrological regime available to the first St. Catherines islanders. The discharge of this system remained in approximate equilibrium so long as the Upper Floridan aquifer was recharged by rainfall in the interior of the coastal plain, where it lay near the ground surface. These artesian conditions created natural seeps, with water flowing to the surface in springs and seeping into rivers, ponds, wetlands, and other surface-water bodies throughout most of coastal Georgia. At Brunswick, the artesian water pressure reached about 20 m above sea level, and 10 m above sea level at Savannah. Over the past century, groundwater pumping has significantly lowered the water level in the upper Floridan aquifer throughout the entire coastal area. By 1971, artesian pressure surface was <3 m above sea level in the St. Catherines area, and at (or below) sea level by 1984.<sup>10</sup>

It is difficult for the modern observer to appreciate the magnitude of the hydrological change over this past century. By looking closely at the historical sources and tracing out the surviving geomorphological evidence, we believe it is possible to reconstruct what St. Catherines Island looked like before the deep drilling so significantly changed the hydrology. Working from this baseline evidence, we now appreciate the importance of the Rutledge fine sands, the very poorly drained remnant soil that developed in the shallow depressions and bays of the former central meadow of St. Catherines Island (Looper, 1982; see also Thomas, 2008: chap. 1). Based on mapped soil distributions and the dendritic pattern of relict groundwater outflows that once drained into the marsh, Hayes and Thomas (2008: fig. 5.1) reconstructed a large freshwater lagoon they believe once dominated the central reaches of St. Catherines Island. They argue that during the aboriginal period, freshwater was always abundant on St. Catherines Island, available in plenty of places, except during periods of extreme drought: The deep aquifer pumped artesian water to the ground's surface in many places, and elsewhere, a relatively shallow well could tap the surficial reservoir of nonartesian water.

A systematic archaeological survey on St. Catherines demonstrated the high degree of fit between the overall settlement pattern and the

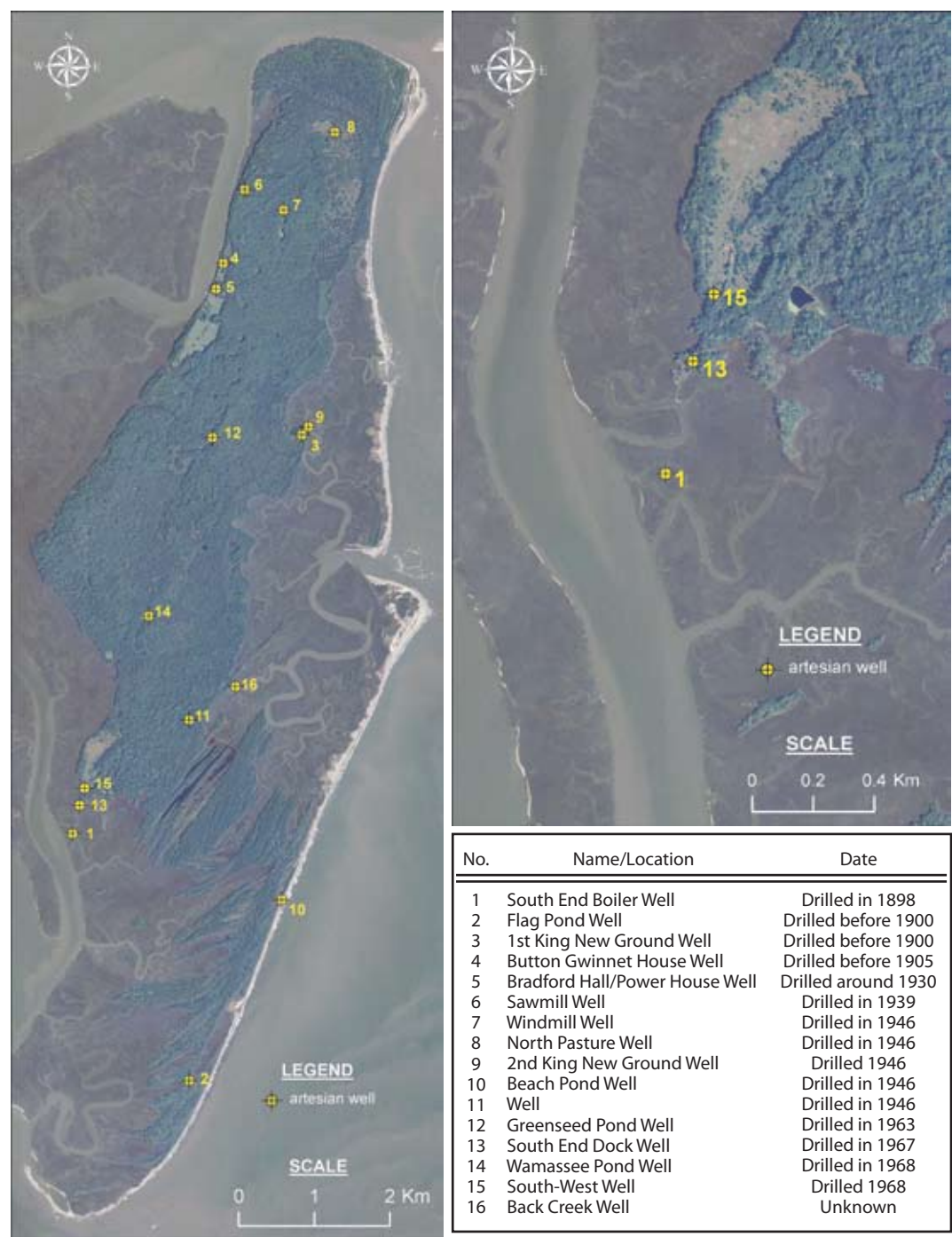


Fig. 1.8. The location and age of known artesian wells on St. Catherine's Island, with a detail of the South End Settlement (right).

theoretical expectations from central-place foraging theory (summarized in Thomas, 2008: chaps. 10 and 11). But the fit is not perfect. The presence of several lacustrine settlements along the Central Depression deviate notably from expectations grounded in human behavioral ecology (which posited that the major settlements should occur at the interface of the saltwater marsh and the maritime forest).

A cluster of three St. Simons period components found near the middle of the island is important because each site lacked marine shell of any kind and was detected only through the systematic shovel-testing program conducted as part of the islandwide transect survey. Each site lies along the margin of the Rutledge soil type that dominates the central north-south swale of the Pleistocene core. This poorly drained area of lowered elevation was doubtless flooded by freshwater ponds before the artesian water table was lowered a century ago. Apparently, these Late Archaic components accumulated as a lacustrine adaptation flanking the central freshwater ponds, likely exploiting freshwater resources such as turtles, migratory waterfowl, bulrush and cattails, and even freshwater fish.

We found comparable lacustrine settlements dating to the subsequent Refuge-Deptford periods, a series of small sites situated along the margins of the central freshwater marsh. Although marine shell was entirely absent at some sites, incremental analysis of the available *Mercenaria* shell suggests that the sites were occupied mostly during the wintertime. The subsequent Wilmington period continues this pattern, with relatively small and mostly wintertime occupations situated near the central freshwater swamp. Three similar lacustrine sites dating to the St. Catherines period were also mapped at Rice Field, Wamassee Pond, and Greenseed Field. Interestingly, this pattern virtually disappears during the late prehistoric period, with only a single Irene period site found in a lacustrine setting (along the margin of a small freshwater pond, far inland from the southern edge of Northwestern Marsh).

These lacustrine settlements are the most notable deviations from central place foraging expectations. They likely hosted a variety of subsistence activities such as lacustrine hunting (including ducks, freshwater turtles, and freshwater fish taxa), harvesting lacustrine wild plants (including cattail and bulrush), and plant-and-

harvest maize cultivation (a strategy for utilizing the low-lying slough areas characterized by Rutledge soils; previously lumped with swidden maize cultivation, which is better suited for the Pleistocene dune habitats).

From an archaeological perspective, we need to understand the nature of the Central Depression—its origin, its extent, and the degree to which this feature conditioned the hydrology of the island through time. Since sea level provides the hydrological baseline for surface and groundwater, any eustatic lowering of sea level will exert a significant influence on the freshwater hydrological regimen of the Georgia Bight (Colquhoun et al., 1981; Brooks et al. 1989: 91). We also need to know the locations of lagoon and slough deposits, with correlative studies of associated flora and fauna.

#### SOME POTENTIAL NEW DIRECTIONS IN GEOARCHAEOLOGY

Archaeological samples generated during the islandwide transect survey are quite inadequate for assessing the efficacy of the Pleistocene swale habitat to host a distinctive lacustrine settlement type. This opens an important new possibility for archaeological research on St. Catherines Island, namely an inland shoreline survey—basically walking the interface between the Rutledge/Echaw-Foxworth-Centenary soil series, much the way we walked out the marsh margins of the late Holocene beach ridges. Such a survey should rely on systematic shovel testing (because marine shell is sometimes absent at such sites, particularly those utilized during Late Archaic and Refuge time periods). This archaeological survey strategy should determine whether such site clusters are anomalous or represent a previously undetected lacustrine settlement type. One potential problem is that such “nonshell” sites, lacking in the calcium carbonates contributed by marine shells, will tend to have soil with acidic pH and correlatively poor preservation. The test excavation strategy should also seek out concentrations of charred plant and/or animal remains (perhaps through remote sensing techniques such as proton magnetometry).

**GEOLOGICAL ISSUES RELATED TO THE CENTRAL DEPRESSION:** From a broader, geoarchaeological perspective, we also need to know much more about the nature of the Central Depression of St. Catherines Island—its origin, its extent, and the degree to which this feature conditioned

the hydrology of the island through time.

Vance, Rich, and Bishop (and various students from Georgia Southern University) drilled 10 vibracores ranging from 2.5 to ~5 m depth in May 2008 to explore the shallow stratigraphy in the area of the Gator Pond sag structure identified on ground penetrating radar profiles (Vance et al., chap. 11). Questions under investigation include defining the "collapse" structure on the GPR profile, defining a possible boundary between older and younger Pleistocene terrains forming the island core, documenting the age and stratigraphy of heavy mineral sand markers in the island core as possible sea level indicators or storm deposits, documenting the palynological signature of the island stratigraphy by Rich and Booth (chap. 6; Booth, Rich, and Bishop, 1999, Booth et al., 1999), and defining sea level changes using ghost shrimp burrows (Bishop and Bishop, 1992), all tied into  $^{14}\text{C}$ , optical luminescence, and archaeological temporal frameworks.

The possibility of constructing a series of several east-west transects will allow us to test the hypothesized erosional terrace formed as part of Yellow Banks Bluff and document the timing of the erosional emarginations of King New Ground Scarp (see chap. 3: fig. 3.4). We can also further document the timing of the formation of St. Catherines Island and the migration of Guale Island, investigate the timing of precontact island geomorphology and human settlement, the distribution of precontact spring heads and freshwater ecology during late Pleistocene and the Holocene, and develop a history of succession of floras and faunas through time represented by the rapid Pleistocene glacial fluctuations by using palynological methods.

As the Central Depression is followed southward in this proposed research, we would have the opportunity to document the relationships between the Central Depression and a disconformity identified at South End Settlement by Vance's GPR surveys, as well as other subsurface structures shown on his GPR profiles (see fig. 11.6).

The eastern end of this proposed vibracore transect would be anchored to Yellow Banks Bluff, where approximately 5 m of Silver Bluff-age sand is exposed along nearly 1 km of the northeastern edge of St. Catherines Island (Bishop et al., 2007: 42–43, 49–50, figs. 9, 22–24). Vento and Stahlman (chap. 4) date the uppermost paleosol at Yellow Banks Bluff to 6440 yrs B.P. Three lower buried A horizons yielded dates of approximately

10,800, 13,600, and 22,800 yr B.P., while a probable cultural feature lying above these paleosols yielded a date of 6270 yr B.P. These paleosols will potentially provide important information on sea level and climate change, and they will possibly indicate the presence of deeply buried prehistoric archaeological sites; it is important to trace their distribution further into the island core.

Martin and Rindsberg (chap. 5) report that ichnological analysis of the same exposure favors an interpretation of storm-washover fans deposited behind dunes, questioning a previously suspected pre-Silver Bluff marine origin for the lowest of these deposits but nevertheless indicating that the lower Yellow Banks Bluff facies reflect a sea level somewhat higher than that at present. They indicate the need for further confirmation of age determinations and correlation of Yellow Banks Bluff deposits with other exposures on St. Catherines Island and elsewhere in the Georgia barrier islands.

Vance et al. (chap. 11) generated high-resolution GPR and vibracore profiles across portions of the Central Depression. They discovered sag structures in the northern, middle, and southern portions of the island in regions that coincide with the distribution of Mandarin-Rutledge soils. Profiling indicates subsidence of 2–5 m in these structures with concomitant accumulation of sediment within these basins. These subsidence features may have been generated along minor faults or fault-joint focused dissolution of carbonates at depth, with consequent sag of overlying strata. The faults and joints were essential conduits for artesian springs that fed the former freshwater wetlands of the Central Depression (figs. 11.9a and 11.12a). Such proposed research could also reveal important information relating to storm events that may have struck St. Catherines Island in the past (a possibility discussed in more detail below).

Combined with existing vibracore data, this new drilling program would generate a comprehensive genetic stratigraphic sequence for St. Catherines Island. Such a sequence could be extended to other islands along the Georgia Bight, developing a more comprehensive genetic framework that would aid in predictive archaeology and a better understanding eustatic sea level changes and paleoenvironments.

To summarize, this proposed investigation of the Central Depression could provide a critical research focal point as it links various aspects of

the island evolution including general geological structure, hydrology, and human history.

(1) The origin of the sag structures identified in GPR profiles should be confirmed with additional work. If the sag structures are produced by dissolution of carbonate rock at depth and these features were localized by joints or faults, they would be the most likely conduits for the artesian springs that fed the interior freshwater wetlands.

(2) Understanding the artesian access is also important for the future of the island hydrology. The same fractures and solution features that localized artesian springs could serve as avenues for saltwater intrusion if the artesian surface pressure continues to drop.

(3) These former central depression wetlands should preserve organic material and the climatic history. Wetland type and evolution may be determined through palynological investigation of the organic components. Radiocarbon dating is also possible for the younger portions of such deposits.

(4) These wetlands were utilized by St. Catherines islanders for 5000 years and perhaps, significantly, had the potential for preserving older sites due to their low, wet nature and decreased chance of destruction by erosion or tilling. Low areas generally continue to accumulate sediment and to bury and preserve geological, botanical-climatological, and anthropological/archaeological record in the island interior.

**ARCHAEOLOGICAL ISSUES RELATED TO THE CENTRAL DEPRESSION:** Hayes and Thomas (2008) summarized what is known about the hydrology of St. Catherines Island, and the results have important implications for the ancient aboriginal foragers. Early historical accounts speak about the relatively abundant, fresh, sweet water that was once available on Georgia's barrier islands. But those days are long past and to understand the nature of aboriginal life on St. Catherines Island, it necessary to evaluate the preindustrial hydrology and geoarchaeology of the Guale coast.

Systematic archaeological survey on St. Catherines demonstrates the high degree of fit between the overall settlement pattern and the theoretical expectations from central-place foraging theory (summarized in Thomas, 2008: chaps. 10 and 11). But the fit is not perfect. These lacustrine sites likely hosted a variety of subsistence activities such as lacustrine hunting (including ducks, freshwater turtles, crayfish, amphibians, and freshwater fish taxa), harvesting lacustrine

wild plants (including cattail and bulrush), and plant-and-harvest maize cultivation (a strategy for utilizing the low-lying slough areas characterized by Rutledge soils; previously lumped with swidden maize cultivation, which is better suited for the Pleistocene dune habitats).

#### FOURTH QUESTION: DOES THE DISCONTINUOUS CULTURAL RADIOCARBON RECORD ON ST. CATHERINES ISLAND REFLECT PUNCTUATED EQUILIBRIA?

Here we discuss the most obvious discontinuities in the 5000-year-long cultural record of St. Catherines Island. We consider how the cultural radiocarbon record was created and wonder whether the major "gaps" might have been caused by catastrophic hurricanes and storm surges in the past. We pose a series of testable hypotheses and explore the possibility that "paleotempestology" might provide a useful new geoarchaeological direction for St. Catherines Island.

#### CURRENT THINKING ABOUT OCCUPATIONAL CONTINUITY

Over the course of our archaeological investigations, we processed nearly 300 radiocarbon dates from St. Catherines Island. We followed a standardized procedure in processing all of the radiocarbon dates available so far (Thomas, 2008: table 13.4, chap. 15). We calibrated each date using the CALIB 5.0.1 Radiocarbon Calibration Program (as initially presented by Stuiver and Reimer, 1993 and updated by Stuiver, P.J. Reimer, and R.W. Reimer, 2005). For nonmarine samples, we used the IntCal104 curve (Reimer et al., 2004). For marine samples (as discussed above), we employed the Marine04 curve coupled with our own estimates of local effects (as discussed above).

When we plotted the cumulative probability distribution of culturally relevant  $^{14}\text{C}$  dates, we were struck by the nonrandom distribution of the radiocarbon record across the 5000 years of aboriginal occupation on St. Catherines Island (Thomas, 2008: 345–372; 435–474). Although some time periods showed several peaks of multiple, redundant radiocarbon dates, there were some major and obvious "gaps"—time spans for which  $^{14}\text{C}$  dates were rare (or even absent). And further, the most important "gaps" correspond precisely to the transitions between major cul-

tural periods.

The obvious question is this: *Does this cumulative radiocarbon record provide an acceptable proxy of long-term aboriginal dynamics?* And an equally obvious response is: *The distribution of "cultural" radiocarbon dates on St. Catherines Island probably reflects sampling bias rather than past cultural behavior.* With this issue in mind, we deconstructed our motivations for processing  $^{14}\text{C}$  dates and isolated two major strategies to account for our reliance on radiocarbon dating:

(1) To establish chronostratigraphic control during mortuary and midden excavations (effectively prosecuting a site-by-site application of the *law of superposition*), and/or

(2) To provide absolute chronological controls of the northern Georgia ceramic chronology (informing the *index fossil concept* to pin down the St. Catherines Island cultural sequence).

Because we pursued these two dating strategies to the exclusion of other sampling designs, the universe of all potential radiocarbon dates did not have an equal probability of selection (the hallmark of unbiased, randomized sampling). This is why we worried about the biases inherent in our long-term radiocarbon record. We were also aware of the stochastic distortions in the marine and terrestrial calibrations curves (McFagden et al., 1994: 221; Evin, Fortink, and Oberline, 1995; Thomas, 2008: 437–440). Because the radiocarbon time-scale is not strictly linear, the very process of calibrating a suite of radiocarbon dates to their true calendric ages introduces an intrinsic peak-and-valley configuration to the cumulative probability distribution (and this is even true for a continuous, uniformly sampled date series). In other words, some time spans are better than others for radiocarbon dating, and we worried whether calibration stochastic distortions could influence the peak-and-valley radiocarbon profiles.

This is why, in 2006, we processed more than four dozen additional radiocarbon determinations specifically targeting the obvious gaps in the cultural radiocarbon record. We have reported the results of this retesting in considerable detail (Thomas, 2008: chap. 16); for present purposes, let me highlight the following trends.

Despite the extensive resampling exercise, we could close (decisively) only one major gap in the cultural radiocarbon record, the "valley" about cal A.D. 800, at the boundary between Wilmington and St. Catherines periods. Three additional gaps remain, in one form or another,

and they cannot be dismissed as the product of sampling error:<sup>11</sup>

(1) **First gap (1350 cal B.C. through 350 cal B.C.):** During this 1000 year hiatus, virtually no marine shell middens were created on St. Catherines Island. We have previously argued that this anomalous gap in the  $^{14}\text{C}$  record was likely caused by the significant changes in sea level, a correlative diminution of marsh resources, and cultural abandonment of the island.

(2) **Second gap (cal A.D. 400):** After 350 cal B.C., marine shells began to accumulate again, in the tens of thousands in midden deposits scattered across the island, and they were made by people using ceramics very different from those before. But a significant gap appears in the cultural radiocarbon record, about cal A.D. 400, corresponding to the transition between the Deptford and Wilmington periods (see table 1.1). We believe that the proximate cause of this hiatus is (1) the general scarcity of shell midden deposition during this interval and (2) the clear-cut temporal break in mortuary activities between late Deptford and mid-Wilmington times. But the overall cessation of cultural activities and a clear-cut break in ceramic traditions remain to be explained.

(3) **Third gap (cal A.D. 1180–1280):** Another notable gap shows up at the common boundaries of the St. Catherines, Savannah, and Irene periods (table 1.1). Although stochastic calibration effects do appear to be operating here, these distortions cannot explain this apparent hiatus: these people made very different kinds of ceramics and their social structure was quite different, before and after the cal A.D. 1180–1280 gap.

I believe that we can dismiss both sampling error and internal stochastic distortions in the radiocarbon process. How should we explain these three apparent breaks in the cultural occupation of St. Catherines Island?

#### POTENTIAL NEW DIRECTIONS IN

##### GEOARCHAEOLOGY: PALEOTEMPESTOLOGY

Recently, I have been impressed with the potential of so-called "paleotempestology," a relatively new field that studies past hurricane activities by means of geological proxy measures (Liu, 2004; Liu and Fearn, 1993, 2000: 240). Several such proxies are potentially available for reconstructing past hurricane activity from the geological record, including overwash sediments in coastal lakes and marshes, microfossils (such as foraminifera, pollen, diatoms, dinofla-

gellates, and phytoliths) contained within these coastal sediments, wave- or flood-generated sedimentary structures or deposits ("tempestites" meaning storm deposits) in marine and/or lagoonal sediments, storm-generated beach ridges, oxygen isotopic ratios of hurricane precipitation recorded in shallow-water coals and speleotherms, and tree rings.

Although each proxy has demonstrable potential under appropriate localized conditions, Liu (2004: 15) argues that overwash deposits preserved in coastal lake and marsh sediments have proven to be the most useful way to reconstructing long-term patterns of hurricane landfalls. The "tempestology" model promoted by Liu (2004: 19–20) postulates that "we may expect stronger hurricanes, which usually generate higher storm surges, will likely produce thicker, more extensive overwash sand layers than those produced by weaker hurricanes" (Liu, 2004: 19–20). In a coastal lake setting, sediment cores can be expected to contain multiple lenses of overwash deposits sandwiched between "normal" organic lake sediments. Each of these sand layers, then, should provide a proxy record of a past hurricane strike in that locale. All else being equal, then, the horizontal extent and thickness of the overwash sand layer should be positively correlated with the intensity of the storm (assuming, of course, that the strike is a "direct hit").<sup>12</sup>

This research design tracks a modern hurricane of known intensity and geomorphic impact, then isolates its sedimentological "footprint" as a proxy. With this known historical signature in hand, the "tempestologist" then interprets the frequency, extent, thickness, and chronology of similar strata recovered in sediment cores to unravel the history of hurricane strikes in that locale.

**THE GULF COAST CHRONOLOGY:** This uniformitarian principle has been tested by Liu and Fearn (1993) on the near-shore sediments created by Category 3 Hurricane Frederick that devastated coastal Alabama in 1979. Along the central Gulf of Mexico, coastal lakes were subject to overwash processes when the storm surge overtopped their sandy barriers. Characteristic sand layers, deposited by these overwashes, can be identified in lake and marsh cores, providing proxy records of past hurricane landfalls spanning the last 5000 years (Liu, 2004: 13). These investigators conclude that few catastrophic hurricanes made landfall along the central Gulf

of Mexico coastline between 3230 cal B.C. and 1720 cal B.C. (5180 B.P.–3670 B.P.; reported as 4500 and 3400 <sup>14</sup>C yr B.P.) and again during the last millennium. But between 1720 cal B.C. and cal A.D. 1020 (3670–930 cal B.P. (reported as 3400 and 1000 <sup>14</sup>C yr B.P.)), the rate of major hurricanes making landfall increased by three to five times that recorded during the so-called "quiescent" periods.

Similarly, sediments generated by Hurricane Opal (a Category 3 storm that made landfall near Pensacola) were employed as a modern analog to interpret prehistoric sand layers recovered from deep-water cores of Western Lake, in the Florida Panhandle (Liu and Fearn, 2000: 238, 2002). Based on their examination of a 7000-year-long lake sediment record, Liu and Fearn (2000: 238) define similar "quiescent periods" and one major "hyperactive period" of marked increase in catastrophic hurricanes (Category 4–5 storms) striking the eastern Gulf Coast:

(1) **Quiescent period:** post-cal A.D. 1000 (930 cal B.P.; reported as post-1000 <sup>14</sup>C yr B.P.) only a single catastrophic hurricane made landfall.

(2) **Hyperactive period:** time of heightened hurricane activity between 1720 cal B.C. and cal A.D. 1020 (3670 ± 930 cal B.P.; reported as 3400–1000 <sup>14</sup>C yr B.P.) with an average of five catastrophic storms (Category 4–5) per 1000 years making landfall along the western Florida Gulf coast. This frequency is five times the rate during the "quiescent" periods immediately before and after.

(3) **Quiescent period:** between 3780 cal B.C. and 1720 cal B.C. (5730–3670 cal B.P.; reported as 5000–3400 <sup>14</sup>C yr B.P.) relatively few catastrophic hurricanes made landfall.

Liu (2004:13) suggests that the "hyperactive" period was likely due to a long-term shift in the position of the Bermuda High and the North American Oscillation.

**THE STORM SURGE HYPOTHESIS:** We know that catastrophic storms have struck the Georgia coast with some regularity. The Great Sea Island Storm, for instance, struck the Sea Islands, Savannah, and Charleston on August 27, 1893, killing perhaps 2000 people (Marscher and Marscher, 2004; see also Bishop et al., 2007: fig. 60). This Category 3 storm, with 120 mph winds and a storm surge of 16 ft, is considered to be one of the five most deadly hurricanes to have hit the United States during the historic period. A second, less well-documented hurricane

struck the Georgia Bight in 1897, apparently more heavily impacting St. Catherines Island and the southward barrier islands.

The impact of such a catastrophic storm on the barrier islands is not difficult to imagine. Striking without warning, the storm surge would have overwashed even the highest parts of these low-lying islands. It is conceivable that all terrestrial vertebrates would have perished, that seaward and estuarine marshes were destroyed, and that the maritime forest was flattened. Some marsh islands probably disappeared entirely. Beyond the direct storm damage, evidence suggests that major forest fires tend to follow intense hurricane landfalls. Not only do hurricanes dramatically increase the fuel accumulating on the forest floor, but a drier microclimate seems to follow as a result of increased insolation and higher wind speed under a more open forest canopy (Myers and van Lear, 1998). Even as the maritime vegetation grew back, there was increased likelihood of insect infestation by southern pine beetles and other taxa (Boucher, 1990).

With the Gulf Coast storm sequence in mind, we return to the cultural radiocarbon chronology of St. Catherines Island.

**(1) First gap (1350 cal B.C. through 350 cal B.C.):** We have previously argued that this anomalous gap in the  $^{14}\text{C}$  record was likely caused by sea level change and a decrease in available marsh resources (Thomas, 2008: chaps. 4; 32). But this millennium-long hiatus in cultural occupation on St. Catherines Island correlates almost exactly with the onset of Liu's (2004) "hyperactive period," when hurricane landfalls increased fivefold in the Gulf of Mexico. This "gap" also marks the end of the Late Archaic period throughout the American Southeast, and this "disappearance" was the subject of a previous Caldwell Conference (Thomas and Sanger, 2010).

**(2) Second gap (cal A.D. 400):** This occupation gap on St. Catherines Island divides the Deptford and Wilmington periods and takes place about six centuries before the end of the "hyperactive period" in the Gulf of Mexico.

**(3) Third gap (cal A.D. 1180–1280):** This notable gap separates the St. Catherines from the Irene periods, with the apparent absence of the Savannah period on St. Catherines Island (table 1.1). This gap is about two centuries after the end of the "hyperactive period" on the Gulf Coast.

It's obviously tempting to correlate the three

major gaps in the human occupation of St. Catherines Island with the most intense period of catastrophic hurricane activity during the late Holocene on the Gulf of Mexico coastline.

To date, we lack any direct evidence that the Gulf Coast sequence of late Holocene hurricane activity is duplicated along the Georgia Bight. Liu (2004: fig. 2.1) attempted to test this notion by taking piston cores from both Whitney Lake and Willow Pond on Cumberland Island; but these sequences were short, spanning less than a millennium, and did not provide the necessary time depth to reconstruct a local hurricane sequence in this area (Kam-biu Liu, personal commun.; see also Collins et al., 1999). The question becomes whether appropriate overwash marine or lagoon sediments exist on St. Catherines Island (or perhaps the adjacent mainland) to provide a localized record of past hurricane activity. Following the "tempestology" model (Liu, 2004: 19–20), would it be possible for investigators to find the sedimentological "footprint" of known-age hurricanes in the barrier islands, then interpret the frequency, extent, thickness, and chronology of similar strata recovered in sediment cores to unravel the history of hurricane strikes in that locale? This would provide an independent test of the cultural gaps noted from the radiocarbon record, and open the door to new lines of inquiry into the geoarchaeology and biodiversity of the past.

#### FIFTH QUESTION: WHAT HAPPENED TO WHITE-TAILED DEER OF THE GEORGIA BIGHT?

This section summarizes the late Holocene history of white-tailed deer in the greater St. Catherines Island area. Once rising sea level isolated a subpopulation of mainland deer onto the large composite barrier islands of the Georgia Bight, the island dwellers (1) became markedly smaller and (2) went locally extinct on most islands shortly after the Late Archaic period, but remained viable on St. Catherines and Ossabaw islands. We have previously argued that prehistoric hunting pressure might explain the differential rates of survival and extinction. But here, we pose a geoarchaeological alternative, that perhaps sea level change and/or catastrophic hurricane strikes during the so-called "Hyperactive Period" is explored below.

## CURRENT THINKING

WHY ARE WHITE-TAILED DEER SO SMALL ON ST. CATHERINES ISLAND? Modern white-tailed deer living on the Sea Islands are considerably smaller than their mainland counterparts, and their biomass has varied significantly through time (Purdue and Reitz, 1993; Thomas, 2008: chap. 8). At approximately 1600 cal B.C.—perhaps a millennium after St. Catherines Island had separated from the mainland landscape—the mean adult body weight of sea island deer is estimated at 72.5 kg (slightly larger than their mainland counterparts). But thereafter, the biomass of island deer populations shrank markedly, reaching an adult body size of only 37 kg for contemporary white-tailed deer populations in the Sea Islands. We believe that deer size in the Sea Islands reflects long-standing evolutionary and behavioral trends grounded in sea level changes during the Holocene. When rising seas separated the modern barrier islands from mainland habitats, terrestrial vertebrate populations were stranded on the major islands and to some extent, the marsh islands and hammocks as well. Specifically, terrestrial vertebrate populations living on barrier islands have restricted mobility and limited immigration, with open water barriers limiting opportunities for genetic exchange (Johnson et al., 1974: 55). This is why long-term directional selection may produce locally adapted island populations that differ from mainland populations (Adler and Levins, 1994: 482).

What caused the Sea Island deer to shrink? Is the decreased body size due to evolutionary change, to habitat deficiencies, to behavioral change, or a combination of all these factors?

Given the relatively poor soils that characterize many barrier islands (particularly those consisting solely of Holocene-age dune deposits), one can readily frame a scenario of deficient food resources directly leading to small body mass (see Osborne et al., 1992, for relevant results from Blackbeard Island; see also Thomas, 2008: 960–961).

Selective factors likewise play a critical role in determining body mass among barrier island deer populations. Faced with significant habitat fragmentation, mammalian species commonly become either extinct or experience selective changes that enable adaptation to modified living conditions. Island biogeography theory (MacArthur and Wilson, 1967) holds that when subjected to increasingly fragmented

landscapes—whether actual islands or disparate terrestrial “islands”—medium-sized mammalian species seem to gain certain reproductive advantages over both smaller and larger taxa (Cox and Moore, 1973; Lomolino, 1985; Brown, Marquet, and Taper, 1993). This so-called “island syndrome” (Adler and Levins, 1994)—what Van Valen (1973) has termed the “island rule”—holds that in a significantly fragmented habitat, smaller mammals tend to become larger, medium-sized mammals stay the same size, and larger mammals generally decrease in size (Schmidt and Jensen, 2003). Foster (1964), for instance, has noted the tendency for gigantism in insular rodent (and perhaps marsupial) populations, but dwarfism is characteristic of insular carnivores, lagomorphs, and artiodactyls. This is because the reproductive capacity in mammalian species is heavily conditioned by body mass (Brown, Marquet, and Taper, 1993), with medium-sized species gaining certain reproductive advantages over both smaller and larger taxa (MacArthur and Wilson, 1967; Cox and Moore, 1973; Lomolino, 1985; Brown, Marquet, and Taper, 1993). In other words, a larger population of medium-sized animals is more readily supported by a limited and/or fragmented resource base, thereby increasing survivability in times of stress (as during hurricanes, droughts, hunting pressure, and other environmental perturbations).

LONG-TERM BIOGEOGRAPHY OF WHITE-TAILED DEER ON THE GEORGIA COAST: The white-tailed deer (*Odocoileus virginianus*) is extraordinarily well represented in the archaeological deposits of St. Catherines Island. In fact, white-tailed deer bones represent the most abundant vertebrate taxon in these zooarchaeological assemblages, accounting for almost a third of all nonhuman bones recovered during our excavations (Thomas, 2008: table 31.1). For all time periods, the total biomass represented by white-tailed deer (among both terrestrial and marine vertebrates) ranges from roughly 60% (during the Irene period) to nearly 90% during the Altamaha (mission) period. The superabundance of white-tailed deer remains on St. Catherines Island is an anomaly, termed by Reitz (2008: 656) a “most unexpected result ... and one that is difficult to explain based on present knowledge.”

To place the St. Catherines findings in a regional context, we have previously explored the archaeological record of white-tailed deer

exploitation on the barrier islands and the mainland along the Georgia Bight—from Santa Elena (South Carolina), through the barrier island and mainland sites along the Georgia coast, southward to St. Augustine (long-term capital of La Florida; see Thomas, 2008: chap. 31). Three important findings emerged:

(1) On the barrier islands, white-tailed deer are most heavily exploited during the Late Archaic period, with deer exploitation dropping off sharply thereafter; St. Catherines and Ossabaw islands are exceptions because deer are exploited throughout the sequence.

(2) For all time periods, and regardless of recovery methods or indices employed, white-tailed deer exploitation was much more intensive on the Georgia Sea Islands than in nearby mainland sites.

(3) For all time periods, exploitation of white-tailed deer is most intensive on St. Catherines and Ossabaw islands, but less important on barrier islands to the north and especially to the south. A parallel also exists in archaeological sites on the adjacent mainland, although white-tailed deer exploitation was always more important on the barrier islands.

In other words, the archaeological records indicate that white-tailed deer remained abundant throughout the late Holocene on both St. Catherines and Ossabaw islands, but became selectively extinct on most other barrier islands sometimes after the Late Archaic.

**THE OVERKILL HYPOTHESIS:** Both findings are intriguing and suggest a paradox: The diet-breadth model predicts that white-tailed deer, one of the highest ranking resources available to aboriginal foragers in Georgia's Sea Islands, should have always been taken upon encounter. The archaeological record of the northern Georgia Sea Islands (especially from St. Catherines Island northward) appears to be fully consistent with this projection: White-tailed deer are present and they are intensively exploited throughout time. But the available zooarchaeological evidence (mostly from St. Catherines Island) fails to demonstrate a significant depression in white-tailed deer exploitation (as also projected by the diet-breadth model).

Specifically with respect to terrestrial hunting, we hypothesize that white-tailed deer populations on each barrier island have distinctive and (perhaps) unique trajectories, reflecting the quality and distribution of local habitats and the

intensity of human hunting pressure through time (Thomas, 2008: table 31.4; Thomas, 2010). The Late Archaic human presence likely posed considerable threat to local island deer populations, which were already under stress due to extreme habitat fragmentation. In addition, the shift from density-dependent to density-independent population regulators likely took place shortly after the Sea Islands became isolated from the mainland landscape—at precisely the time that human foragers first populated the barrier islands.

We further suggested that the Late Archaic presence might have been relatively low along the northern Georgia coastline, that is, in the vicinity of St. Catherines, Ossabaw, and Skidaway islands, precisely those areas where white-tailed deer exploitation appears to be important during the subsequent aboriginal occupation (Thomas, 2008: table 31.4; Thomas, 2010). We suggested that deer populations could have survived a relatively sparse and perhaps discontinuous St. Simons period occupation of these composite barrier islands along the northern Georgia coastline. If white-tailed deer populations were subjected to less intensive hunting pressure (as along the southern Georgia and southeastern Florida coastline), then perhaps these deer populations adapted and survived for millennia by downsizing, both in terms of nutrition and genetics.

We argued that a different scenario may have played out along the southern Georgia/northern Florida coastline. When it comes to island deer populations, local extinction can be forever. Although some immigration from neighboring islands and the mainland can never be totally ruled out—white-tailed deer have been occasionally spotted swimming the estuarine waters—the odds of deer reestablishing a breeding population on an isolated barrier island seems remote (barring, of course, human intervention, which has happened numerous times in the Sea Islands over the last century).

We emphasized the importance of human predation during the St. Simons period—shortly after the island white-tailed deer populations became isolated from the mainland, but before selective pressures could produce the smaller, more adaptive phenotypes necessary to survive in the narrow and restrictive barrier island habitats. We argued, in effect, that the hunting pressure exerted on early island deer populations is directly proportional to the duration and intensity of Late Archaic occupations on each island

(Thomas, 2008: chap. 31).

#### ALTERNATIVE HYPOTHESES AND POTENTIAL NEW DIRECTIONS IN GEOARCHAEOLOGY

Although we previously argued in favor of the Overkill Hypothesis to explain the differential survival of white-tailed deer along the Georgia Bight, we also cautioned that “it seems likely that local, island-level variability in herd dynamics, boom and bust cycles, episodes of human overpopulation, times of island abandonment, natural disasters (including droughts and hurricanes), local extinctions, and, on occasion, recolonization of white-tailed deer populations from neighboring islands or the mainland are involved” (Thomas, 2008: 968).

Two such geoarchaeological hypotheses now come to mind.

**THE STORM SURGE HYPOTHESIS (REVISITED):** Following the “tempestology” model developed in the previous section, we think it highly likely that over the past few thousand years, barrier island deer populations have been impacted by multiple and catastrophic hurricane landfalls.

Based on the available archaeological record, it would seem that the major localized extinctions of white-tailed deer populations took place during the “hyperactive period” of catastrophic hurricane activity on the Gulf Coast, sometime after 1700 B.C. but prior to cal A.D. 1000. If similar long-term shifts in the position of the Bermuda High and the North American Oscillation influenced storm patterns on the Georgia Bight, then perhaps the increase in frequency and ferocity of storm damage is implicated in the long-term biogeography of barrier island white-tailed deer populations.

Testing this hypothesis, of course, requires the same kind of fine-grained coastal or marine sediment record necessary to evaluate the impact on human populations.

(1) The relevant geoarchaeological question becomes: Did the Georgia Bight experience a “hyperactive period” of heightened hurricane activity between about 1700 cal B.C. and cal A.D. 1000?

(2) The strictly archaeological question is: Can we document, with additional archaeological excavations, specific sequences of local extinction for white-tailed deer populations across the mainland and barrier islands of the Georgia Bight?

The correspondence, or lack of it, between these two independent chronologies should determine the degree to which the Overkill and

Storm Surge hypotheses explain the differential survival and extinction rates of white-tailed deer populations in the Sea Islands.

**THE REPOPULATION HYPOTHESIS:** A correlative hypothesis addresses the process of introducing (and reintroducing) white-tailed deer populations to barrier islands in the first place. We think it unlikely that a viable breeding population of white-tailed deer, once driven to extinction, could reestablish through migration.

Individual deer, or even several individuals, could certainly have (re)colonized an isolated barrier island, but breeding populations result, we think, from habitat fragmentation rather than colonization across water barriers.

But the timing and mechanisms of island isolation from the mainland are ill defined at present. As discussed throughout this chapter, we know that significant changes in sea level have taken place during the late Holocene period along the Georgia coast. The degree to which St. Catherines and the other barrier islands were reconnected to the mainland during this regressive interval is unclear; but if this late Holocene “reconnection” actually occurred, it would have had marked implications for terrestrial fauna living on the nascent Sea Islands—especially white-tailed deer. Regardless of the sea level changes involved, the newly isolated deer populations of the barrier islands likely faced the dual pressures of habitat fragmentation and intensified human predation before a genetic response had moved away from long-standing mainland patterns of reproductivity toward island dwarfism.

When it comes to island deer dynamics, we have previously assumed that local extinction is likely forever. If we could document, in a finer-grained fashion, the changes in relative sea level and its direct impact on wildlife corridors to the mainland, we would be in a vastly better position to assess the possibility of repopulation of terrestrial taxa on the barrier islands.

#### SIXTH QUESTION: DID EARLY AND MIDDLE HOLOCENE FORAGERS LIVE ON THE ST. CATHERINES LANDSCAPE?

##### CURRENT THINKING

We believe that the extraordinary potential of St. Catherines Island landscape developed when sea levels stabilized at the end of the middle Holocene, and a vast marshland developed,

fronting directly along shoreline exposures of mature maritime forest. Prior to this time, the oceanfront was miles to the east, with the sand hills of St. Catherines attached to the vast coast. We know that Middle Archaic people lived at Gray's Reef, which is 20 mi offshore (see fig. 3.3): Did anything differentiate the landscape that would become St. Catherines Island from the vast tracts of land exploited by early and middle Holocene foragers? To date, we have no archaeological deposits on St. Catherines Island that predate the Late Archaic deposits of the late Holocene (but see chap. 4, this volume).

#### SOME POTENTIAL NEW DIRECTIONS IN GEOARCHAEOLOGY

If we can learn more about the exact nature of late Pleistocene, early and middle Holocene sediments, hydrologies, plant associations, and landforms, it might be possible to chart the distribution of maritime forest and lacustrine environments that would have attracted early foraging populations to this evolving landscape.

#### SUMMARY

This has been a personal rambling through geoarchaeological terrain, as experienced on St. Catherines Island. I see American geoarchaeology as transitioning through three generational shifts. The first batch of geoarchaeologists—beginning with Thomas Jefferson—were looking for a way to make sense of archaeological sites, and they found enlightenment in the paired concepts of *superposition* and *index fossil*. This approach to geoarchaeology prospered until the last two or three decades, when archaeologists began working under different paradigms. We still needed geoarchaeology—big-time—but our questions were different and we required finer-grained solutions to increasingly specialized circumstances. Although the roots of St. Catherines Island archaeology extend back to the mid-19th century, the vast majority of archaeological investigation proceeded under this second approximation of geoarchaeological method and theory. Today, with third generation geoarchaeology coming online, I think it's worthwhile to evaluate where we've been, and tease out better ways to understand the articulation between natural and cultural. I have tossed out a six-pack of scenarios—questions we archaeologists would like

to answer and a few tentative suggestions about how the next generation of geoarchaeology might provide some answers.

I keep coming back to the words of archaeologist Joseph Caldwell (1971), after whom we have named the Caldwell conferences. Shortly after completing his own stint of fieldwork on St. Catherines Island, Caldwell observed that “no single cultural sequence will hold for the entire Georgia coast, and I suspect that we already need a separate sequence for the regions adjacent to each major estuary.”

I couldn't agree more. In fact, as we conduct increasingly finer-grained research, it becomes more evident that each of these Sea Islands has its own unique geomorphic, hydrological, catastrophic, biogeographic, and cultural history. This is certainly true, as Caldwell predicted, with respect to ceramic chronology. But the list is growing: Island/estuary-specific sequences may soon be necessary for  $^{14}\text{C}$  reservoir corrections, for the survival and/or extinction histories of white-tailed deer, for stable isotope understanding of past diets as inferred from mortuary remains (Thomas, 2008: chaps. 24, 33), for the differential introduction/rejection of maize cultivation, and for the very nature of earliest European contact, both with respect to mission and nonmission interactions.

Key to resolving this expanding list of increasingly focused, island-specific questions, I believe, is the discipline of geoarchaeology. Not only does each barrier island reflect its own unique, yet shifting, relationship with major deltaic sources of freshwater, but the differing and localized histories of catastrophic storm surges, the rates of accretion and erosion, the role of groundwater and freshwater drainage, the shifting estuarine and seaside marshland dynamics, and the local evolution/disappearance of critical landmasses (such the hypothesized Guale Island). Both long-term processes and short-term impacts have played unappreciated, yet pivotal roles—on an island-by-island basis—in conditioning the day-to-day decision-making of the foragers and farmers of St. Catherines Island for the past five millennia.

#### NOTES

1. This section benefitted significantly from comments and suggestions by Gale Bishop and Harold Rollins.
2. Jefferson's contribution to Americanist archaeology

was presented in the only book he ever published, appearing in a limited French edition in 1784 and in a widely distributed American edition in 1787.

*Notes on the State of Virginia* dealt, in part, with the aborigines of Virginia. Jefferson listed the various Virginian tribes, relating their histories since the settlement of Jamestown in 1607 and incorporating a census of Virginia's current Native American population. To Jefferson, solving the problem of Native American origin required a dual strategy: to learn as much as feasible about contemporary Indian culture and also to examine their prehistoric remains. He argued emphatically that contemporary Native Americans were in no way mentally or physically inferior to the white races and rejected all current racist doctrines explaining their origins. He correctly reasoned that Native Americans were wholly capable of constructing the prehistoric monuments of the United States.

Then Jefferson took a critical step: He proceeded to excavate a burial mound located on his property. Today, such a step seems obvious, but few of Jefferson's contemporaries would have thought of resorting to bones, stones, and dirt to answer intellectual issues. Contemporary 18th-century scholars preferred to rummage through libraries and archives rather than dirty their hands with the hard facts from the past.

Written in the flowery style of the time, Jefferson's account provides quite an acceptable report of his investigation. First he describes the data—location, size, method of excavation, stratigraphy, condition of the bones, artifacts—and then he presents his conclusions: Why did prehistoric peoples bury their dead in mounds? He first notes the absence of traumatic wounds, such as those made by bullets or arrows, and also observes the internment of children, thereby rejecting the common notion that the bones were those of soldiers who had fallen in battle. Similarly, the scattered and disjointed nature of the bones militates against the notion of a "common sepulchre of a town," in which Jefferson would have expected to find skeletons arranged in more orderly fashion.

Jefferson surmised, quite correctly, that the burials had accumulated through repeated use and saw no reason to doubt that the mound had been constructed by the ancestors of the Native Americans encountered by the colonists. Today, nearly 200 years after Jefferson's excavations, archaeologists would modify few of his well-reasoned conclusions.

Thomas Jefferson's primary legacy to archaeology is the fact that he dug at all. By his simple excavation, Jefferson elevated the study of America's past from a speculative, armchair pastime to an inquiry built on empirical fieldwork. As a well-educated colonial gentleman, Jefferson understood the importance of exposing speculation to a barrage of facts. The "facts" in this case lay buried beneath the ground, and that is precisely where he conducted his inquiry.

Unlike his contemporaries, Jefferson did not dig to obtain exotic curios for his mantel but initiated his excavations to answer specific, well-formulated questions. He collected his data in as systematic a manner as possible and then drew carefully reasoned inferences from his fieldwork. Jefferson thereby pioneered the basics of archaeological reporting: recording his finds in meticulous detail, to be ultimately published for scrutiny by interested scholars.

3. All the  $^{14}\text{C}$  determinations cited in this chapter have been calibrated at the  $2\sigma$  level.

4. The more complete geoarchaeological story is this. In 1912, while on a tour of European archaeological

sites, Nelson worked at Castillo Cave (in Spain). He was staggered by the tightly stratified deposits, reaching 45 ft thick in places, with 13 archaeological strata ranging from Paleolithic times through the Bronze Age. He admired the fine-scale stratigraphic divisions possible at Castillo and began looking for similar sites on his return to the American Southwest the next year.

But during his initial stratigraphic excavations in the Galisteo Basin (south of Santa Fe, New Mexico), Nelson was bitterly disappointed. The trash heaps of the Southwest tend to be badly jumbled, not at all like the crisp strata found in European caves. Nelson finally came across the stratigraphy he was seeking at Pueblo San Cristobal and he decided to try out a new stratigraphic method. Selecting an area with minimal disturbance, Nelson isolated a block of debris measuring 3 ft by 6 ft wide and nearly 10 ft deep. Clearly the midden had accumulated over a long interval, and several discrete kinds of pottery were buried here. But there was still a problem because the greasy black midden lacked the sharp stratigraphic divisions Nelson had seen in the Paleolithic caves of Europe. How do you dig stratigraphically without perceptible strata?

Never easily deterred, Nelson created his own stratigraphy. Dividing his test block into 1 ft vertical sections, Nelson dug each level in the way he had learned to dig the strata in Europe, cataloging the sherds recovered by level. To Nelson, the only difference was that the Castillo Cave strata were readily discernible, whereas the "stratigraphy" at San Cristobal was arbitrarily imposed as 12 in levels. Imposing arbitrary levels on nonvisual stratigraphy seems almost pedestrian today, but in 1914, Nelson's stratigraphic method was a dazzling and revolutionary innovation, immediately seized by New World archaeologists as a fundamental of excavation.

Given these arbitrarily imposed divisions, Nelson knew that, all else being equal, the oldest trash should lie at the bottom, capped by more recent accumulations. Even though the dense midden lacked tangible stratigraphy, Nelson began to search for time markers in the form of diagnostic pottery types. This is how Nelson applied the index fossil concept to the prehistoric ceramics of San Cristobal.

The most ancient levels at San Cristobal contained a predominance of black-on-white painted pottery (Nelson's Type I). Type I sherds were most numerous at and below the 8-ft mark and only rarely recovered above 7 ft. Type II pottery—red, yellow, and gray sherds ornamented with a dark glaze—occurred most commonly at and above the 7 ft mark. This evidence meant that Type I sherds are "diagnostic" of the strata 8 ft and below and the Type II sherds characterized the upper deposits. The Type III pottery (three-color glazed ware), though rather rare at San Cristobal, appeared only in the uppermost levels of Nelson's column. This made sense, as three-colored wares were still being made when the Spaniards arrived in New Mexico in the 16th century.

Creating simulated stratigraphy was a brilliant stroke, and remains today the preferred method of excavation whenever visible stratigraphic units are absent. Nelson's arbitrary levels made possible the definition of three important time markers (archaeology's equivalent to index fossils). Not only did he document the specific ceramic changes at San Cristobal, but the presence of these pottery types elsewhere provided clues to the age of undated archaeological deposits.

5. The modern Krusenstern beach contains house pits of very recent Eskimo who camped there within the past century. Five beaches or so inland are multiple-roomed, deeply entrenched house ruins of an ancestral pre-Eskimo culture called Western Thule. The artifacts and distinctive pottery found inside these houses pinpoint the Western Thule sites to an age of about A.D. 1000. Farther inland, about beach 35, are the large square pit houses and clusters of shallow summer lodges constructed by the Ipiutak people, a society known for its expertise in carving ivory. Some 15 beaches behind the Ipiutak sites, nearly a kilometer from the modern sea, are the hearths and tent sites of the Choris people, characterized by large spear points remarkably like those used to hunt extinct forms of bison on the western American plains.

Not only is the archaeology enlightening, but it also provides valuable clues to interpreting the geological processes evident there. Studies of the ocean sediments indicate that the modern beach is built of gravels that are slowly shifting southward along the coast, moved along by persistent long-shore currents. But the beachfront of Krusenstern has switched direction at least six times, changing some 20° to 32° each time. Some geologists attribute this change to the prevailing wind's shifting directions, coupled with a slight rise in sea levels. Giddings, however, argues that because the early Denbigh Flint sites have never been washed over by water, sea levels could not have risen more than a meter or so over the past 5000 years.

6. According to the philosophy of Alfred North Whitehead (1925, 1997) one commits a "fallacy of misplaced concreteness" by confusing an analytical or abstract relationship with a concrete, material entity.

7. In fairness, we must point out that Marquardt does "not suggest that the Tanner record is the only source on which we should depend. In fact, we should all endeavor to keep pace with the fast-emerging paleoclimate literature, which now includes multiple records based on everything from ice cores to dendrochronology." He also notes that "Archaeologists can

benefit from consideration of such high-resolution sea level records, but it is important to keep in mind that global climate fluctuations can have variable local effects, depending on topography, hydrology, and established human adaptations to local regions." That said, he expressed his belief that "Tanner's Jerup record has numerous advantages, in that it provides relatively fine-grained data on sea level fluctuations (therefore, implicit climate fluctuations) through much of the Holocene" (Marquardt, 2010: 253–271).

8. To make Tanner's curve "more intuitive and readable for archaeological purposes" Marquardt smoothed Tanner's raw data using a five-sample moving average, then averaged individual pairs of the resulting data in order to reduce the width of the graph. The result (Marquardt, 2010: fig. 14.2) portrays relative sea level at a periodicity of 100 years, from 7550 to 50 cal B.P. (5600 cal B.C.–cal A.D. 1950).

9. "Jumping inlets, spits, and islands" is borrowed, with acknowledgment, from Chowns (2002).

10. We note that the closing of the paper mill at St. Marys (Georgia) has allowed the cone of depression beneath that community to rapidly fill and force artesian flow at the surface. It is not outside the realm of possibility that a similar closing of the noneconomic Riceboro paper mill may revitalize the artesian hydrology of St. Catherines Island (Gale Bishop, personal commun.).

11. We also noted the steep falloff in documented mortuary activities during the Irene period, but this was an obvious sampling problem. We know that burial mounds persisted throughout the late prehistoric (Irene), but we simply had not processed the appropriate <sup>14</sup>C dates on these deposits. We have since remedied this problem (Thomas, 2008: 1035–1037).

12. Liu (2004: 13) defines an "intense" hurricane as one reaching Categories 3, 4, or 5 on the Saffir-Simpson intensity scale (Pielke and Pielke, 1997). Although such intense storms account for only 21% of those hurricanes making landfall in the United States, such "monster storms" account for more than 80% of the damage.



## CHAPTER 2

# EVOLUTION OF LATE PLEISTOCENE-HOLOCENE CLIMATES AND ENVIRONMENTS OF ST. CATHERINES ISLAND AND THE GEORGIA BIGHT

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The most ancient floras of the Pleistocene of the American Southeast date back more than 50,000 years. This limit is probably not due to the proscribed distribution of the deposits, but clearly is controlled by our ability to date them using radiocarbon techniques. Beyond about 40,000 yr B.P., things are simply radiocarbon “dead,” so one has difficulty defining actual ages before that time.

This situation notwithstanding, and regardless of the actual ages of the most ancient accumulations of plant debris, it remains true that the flora the first Native Americans encountered shaped their relationship with the land. Understanding the potential for resource exploitation that lay before them provides us with some insight into the types of economies that developed. This is true of both plant and animal resources, of course, but in this chapter we will examine the history of the flora of the general area of central and coastal Georgia and northern Florida—those areas that most likely held significant influence over the lives of the ancient occupants of St. Catherines Island.

Numerous investigators, most of whom have been palynologists, have worked on a variety of deposits from the Southeast (hereby designated as Georgia, Florida, Alabama, South Carolina, and North Carolina). While much of that work is briefly described here, it is advisable for the reader to refer to Russell et al. (2009) who provide an integrated interpretation of the late Pleistocene fauna, flora, and landscapes of a much more extensive region, but one that still lies within the geographical concept of “Southeast.” Russell et al. provide the most compre-

hensive paleoecological interpretations to date, though the work does penetrate the details of direct evidence from archaeological sites. A brief recounting of the data cited by Russell et al. (2009) appears here, with several key additions based on archaeological site investigations.

We have ordered this chapter in chronological fashion, beginning with discussions of the oldest-dated deposits, and proceeding to the time of first European contact. The chronology of events consists of contributions from a number of authors, as mentioned above, and we have endeavored to order information from oldest to youngest, using radiocarbon chronologies as a guide.

## THE MOST ANCIENT DEPOSITS

Grimm et al. (2001) note that “With the exception of Florida, sites with good Holocene records are few in the southeastern United States ...” While this is also true of late Pleistocene sites, we do have access to some very informative locales that provide a variety of data that are pertinent to the current study. As mentioned above, the most ancient deposits fall outside the range of radiocarbon dating, but they provide us with background as to what the southeastern flora looked like over some part of the last 100,000 years. Watts (1969) conducted the classic study of strata from Mud Lake, Marion County, Florida; these analyses were destined to set the tempo for most subsequent efforts. Mud Lake sediments consist almost entirely of gyttja, a pasty, amorphous, highly organic-rich sediment of many possible origins. Watts’ sample profile represented more than 13 m of lake sediment, and the samples proved to be

very productive. Two situations operated against Watts being able to fill out a complete Quaternary history from Mud Lake: sediments were radiocarbon dead at only about 5 m depth, the date at that horizon being >35,000 yr B.P. and a hiatus of great duration occurred just above the >35,000 yr horizon. Atop the >35,000 year old gyttja was a layer of silt approximately 2.5 m thick, and the sediment immediately above the silt dated to 8160 yr B.P. (9080 cal B.P.). The significance of the hiatus is, of course, that it indicates a substantial draw-down of lake level during that period of time, which corresponds to the Last Glacial Maximum (LGM). These conditions notwithstanding, Watts divided the sample sequence into six major zones: (1) a *Pinus-Carya* (pine-hickory/pecan) zone at the bottom; (2) a *Carya-Liquidambar* (hickory-pecan/sweetgum) zone; (3) a *Pinus* zone; and (4) a *Quercus-Myrica* (oak-wax myrtle) zone (all below the >35,000 year B.P. horizon); (5) a *Quercus* zone; and, finally, at the top, (6) a *Pinus-Taxodium* (pine-cypress) zone. These taxa are all important contributors to the current flora of the southeastern U.S., and even the less common taxa that Watts encountered are familiar. Unusual components of the pollen flora include some *Picea* (spruce) in the lowest horizon. Aside from the spruce pollen, most of the taxa would be familiar to someone working in the region today, and Watts notes in his conclusions that ancient Mud Lake was characterized by a diverse aquatic flora that differed from one horizon to the next primarily as a result of varying water levels. Thus, hydrologic control was more important as a cause of variation than wholesale changes in the composition of floral communities.

Another of the longest and most well-known chronologies from the Southeast comes from Lake Tulane, Florida. Grimm et al. (1993) conducted palynological investigations on samples that span nearly all of the last 50,000 years. One of the more significant findings was that floras characterized either by *Pinus* or *Quercus/Ambrosia* (oak-ragweed) species oscillated; the *Pinus*-dominated landscape was replaced by the *Quercus/Ambrosia* landscape (grassland), then the situation reversed. This switch from pine forest to oak savanna/grassland suggests two things: (1) the plant communities were in place, providing a diverse background of plant species that could occupy later landscapes, and (2) the climate waxed and waned from moist (pine) to dry (oak) as time went by. We know that climate

fluctuations occurred, but this oscillation of plant communities provides us with evidence of the terrestrial biotic response to the situation. What Grimm and colleagues learned at Lake Tulane reflects the situation that Watts encountered at Mud Lake—species remained more or less constant in the regional flora, but local changes in edaphic conditions (i.e., soil) and hydrology caused them to appear and disappear locally.

Rich, Elzea, and Newsom (2000) discovered a much more limited window on the late Pleistocene when they began work on an ancient beaver dam complex near Deepstep, Georgia. Excavation of overburden at the Boatright Mine, a kaolin operation, revealed abundant fine-grained sediments and a dense accumulation of short lengths of wood. A radiocarbon date of >47,479  $^{14}\text{C}$  yr B.P. indicates the age of the deposit, much of which was conifer wood, including *Taxodium*. Palynological analyses revealed a curious assortment of plants, including *Liquidambar*, *Pinus*, *Quercus*, *Taxodium*, *Gordonia* (loblolly bay or other Theaceae), and *Picea*. Such a mixed flora (mixed in the sense of “warm” and “cool” climate taxa) prompted the view of a mixed flora that was the result of plant migrations during the Pleistocene; northern taxa such as spruce moved south and southern taxa such as loblolly and bay remained in place.

Pirkle et al. (2007) and Rich (2007) provide descriptions and illustrations of a sequence of tree stump-bearing units at Reids Bluff, on the Florida side of the St. Marys River near St. Marys, Georgia. A series of stump-bearing (*Taxodium*) horizons and paleosols, as well as a prominent oyster- and clamshell-bearing unit have a range of dates. The lowest *Taxodium* horizon was dated at >38,130 yr B.P. *Mercenaria* shells were dated at  $36,030 \pm 610$  yr B.P. and  $36,270 \pm 1,670$  yr B.P. A bed of sand 3.1 m above river level bore wood that produced a date of  $25,830 \pm 373$  yr B.P. Reids Bluff thus spans a considerable range of time, and records at least two shoreline regressions (the tree- and wood-bearing horizons) and a transgression (the shell layer). Pollen from a variety of contexts, including paleosols and infillings of shells, reveals a diverse, but familiar coastal flora for the time represented. *Pinus*, *Quercus*, and *Taxodium* are common, as is the family Chenopodiaceae (aka, cheno-ams or Chenopodiaceae/Amaranthaceae). In a summary statement, Rich (2007) writes that most of the plants “indicate communities of freshwater wetland trees, shrubs,

and herbs, or maritime forest, which could be found anywhere along the current east coast of the United States south of Chesapeake Bay.” One exception was the presence of hemlock, *Tsuga*. Hemlock does not currently grow on the coastal plain, though its pollen was found in both Reids Bluff paleosols, and in sediment from a ghost shrimp burrow and a blue-gray clay from nearby Bells Bluff. Rich concluded that this situation, which is also known from a sample suite described by Cronin et al. (1981) further up the East Coast, leaves one with the impression that, while these late Pleistocene floras reflect a temperate climate, it must have been cooler than what we see today to support the hemlock.

Work by LaMoreaux, Brook, and Knox (2009) provides important new information on the changing Pleistocene and Holocene paleoenvironment and associated paleoclimate along the Georgia coastal plain. Their studies were based on a core of sediment recovered from the valley bottom zone of Sandy Run Creek (upper coastal plain of Georgia, south of Macon). The sediments in the bottom zone suggest a braided stream pattern, with low water table and a cool, dry climate for the period 30,000 to 25,000 yr B.P. The vegetation consisted principally of open grassland species, with stands of pine and spruce. The results of this study are supported by pollen and ostracod studies completed on lacustrine sediments underlying modern Tampa Bay (Willard et al., 2007). The latter authors note that, during the LGM the climate in central Florida was much drier and cooler than at present; this is consistent with other studies, as cited herein. The lacustrine sediments were rich in pollen of the *Chenopodiaceae* and *Carya*, though there was rare *Pinus*.

With regard to climate, the Wisconsin glacial phase of the Pleistocene Epoch peaked at approximately 18,000 B.P. (21,240 cal B.P.), when permanent ice covered most of North America north of the Ohio River and extended across the pole to cover much of Europe and Asia. The ice advance left extensive proxy evidence of its existence across the continents including the final formation phase of the Great Lakes, Martha’s Vineyard, Long Island, upstate New York’s Finger Lakes, fiords in Maine, and the Yosemite Valley of California. Present-day circulation features generally include light mean winds from the southwest on through central to eastern North America. Glacial maximum winds were primarily from the northwest and approximately

50%–80% above present levels of average wind speed (Crowley and North, 1991). Therefore, most of North America was within the cold, dry, circumpolar vortex leading to a boreal climatic regime for eastern North America.

During this glacial maximum, sea levels fell as much as 170 m (550 ft) below current levels as vast stores of water were locked in the continental ice sheets. The eastern coast of North America extended much farther than today as a result. Further, many barrier islands currently located off the Eastern Seaboard were connected to the continent during this period. As the Holocene Epoch ensued, rapid ablation of the ice sheet occurred causing rapid sea level rise, a decrease in stream gradients, and the subsequent drowning of numerous rivers, like the Chesapeake, Delaware, and St. Lawrence.

During the last glacial maximum (18,000 B.P. [21,240 cal B.P.]), the average jet stream position migrated to approximately the Gulf Coast region, about 30°N. By comparison, the average jet position today is approximately centered over the conterminous United States. During this period, much of eastern North America was overlain by cold and dry polar air. The jet stream marked the stormy transition zone between cold, dry conditions and the warmer, wetter conditions of lower latitudes. For much of southeastern North America, jet stream amplification characteristics would have been relatively unimportant as the region lay primarily within persistent cool, dry conditions. Proxy evidence indicates, for example, that central Florida was approximately 3°–4°C cooler than present, and as such, the region was significantly drier than present (Willard et al., 2007).

## FLORAS OF THE FULL GLACIAL

Russell et al. (2009) present a table of chronologies that reflects significant events of the Pleistocene, dating back to 2.7 mybp. The event that is of greatest significance to the current discussion is the LGM, reported to extend from 23,000 yr B.P. to 19,000 yr B.P. (22,490 cal B.P.). During that time the Wisconsin ice sheet had advanced southward toward the current positions of the Ohio and Missouri rivers. This had to have been a time of maximal climatic cooling, and maximal drawdown of sea level. In the chronology we borrow from Fairbanks (1989), sea level was at about –121 m in the Barbados. A map of the East Coast, with a shoreline drawn at the –120 m iso-

bath illustrates a very wide coastal plain during the LGM (Russell et al., 2009). St. Catherines Island, and all the other barrier islands on the East Coast were far inland and must have been incorporated as parts of the coastal plain. Few fossil plant samples have been analyzed that represent this period of time, though the upper levels of Reids Bluff and the flora they preserve come close. Three samples recovered from 5–10 cm below the seafloor at Gray's Reef National Marine Sanctuary, 28 km east of St. Catherines Island, provide a glimpse of the flora that existed there when the area of the reef (now under about 18 m of seawater) was exposed to the atmosphere. Familiar southeastern taxa include *Pinus*, *Quercus*, *Carya* (probably pecan), and *Liquidambar* and there is quite a diversity of herbaceous plants, including grasses, sedges, ferns, and *Sphagnum*; a complete list appears in Russell et al. (2009). Three taxa that were present at Gray's Reef that one would not expect to see now are *Alnus* (alder), *Tsuga*, and *Picea*. Although the percentages were small, there was as much as 2.3% *Alnus* (minimum 300 total grain count) and 2.1% *Picea*. This is clear evidence of floral mixing, though it is equally clear that the dominant flora was the current flora of the southeastern coastal plain.

Jackson et al. (1997) undertook a comprehensive analysis of mapped plant macrofossils and pollen from eastern North America, and gathered data from 269 sites extending from eastern Canada to the Gulf Coast. Fewer than 10 sites come from the area of interest in this chapter, but some of the data are quite significant. For the LGM, Jackson et al. note that their plant macrofossil data confirm the southward migration of boreal and cool-temperate taxa, especially species of spruce and northern species of pine (*P. resinosa* and *P. banksiana*); spruce, they note, was particularly widespread along the Gulf Coast.

Cofer and Manker (1983), in an investigation of the strata associated with a kaolinite deposit in Andersonville (Georgia), noted that a peat deposit was exposed in the south wall of the Wilburn Mine. A 1.8 m sandy/clayey peat was overlain by 0.8 m of sand, which was in turn covered by 1.5 m of sandy peat. The upper peat was covered by the thin (<1 m) soil horizon of the floodplain of Sweetwater Creek. A sample recovered from 10 cm above the bottom of the lower peat layer contained spruce seed cones, which were subsequently dated at  $21,300 \pm 400$  yr B.P. (26,000–24,610 cal B.P.) Wood fragments (unidentified) from the

upper portion of the same stratum provided a date of  $15,840 \pm 300$  yr B.P. (19,570–18,610 cal B.P.). A sample (unidentified) from the basal portion of the upper organic horizon yielded a date of  $10,570 \pm 250$  yr B.P. (12,980–11,610 cal B.P.). Thus, the Andersonville site provides us with some information that represents events in southwestern Georgia between, about 10,570 yr B.P. (12,580 cal B.P.) and 21,300 yr B.P. (25,780 cal B.P.). The critical piece of information is, of course, that the cone was identified as spruce, *Picea*. This corroborates reports cited above that document the presence of spruce on the Georgia coastal plains, both Atlantic and Gulf, during the LGM.

If we assume that the flora of the Southeast remained fairly stable during the LGM, and for the first few thousand years following glacial retreat, it would appear that the greatest environmental variable to affect the Georgia coastal plain was the presence or absence of the ocean itself. Alley et al. (2005) revisit the paleoglaciology of the Northern Hemisphere, and describe the meltwater pulses of the late Pleistocene that had such a significant effect on oceanic thermohaline circulation. The older of the two pulses has been dated at 19,000 yr B.P. (22,490 cal B.P.), with the younger one occurring at about 14,500 yr B.P. (17,420 cal B.P.) According to Alley et al. (2005), each meltwater pulse "... added the equivalent of 1.5 to 3 Greenland Ice Sheets to the oceans over a period of one to five centuries." Such additions to the world oceans might well have had an influence on conditions along the Georgia coast. Following the second meltwater pulse, a period of ice mass stabilization, the Younger Dryas cold interval ensued and lasted until about 11,500 yr B.P. (13,340 cal B.P.; Alley, 2000).

The interval between the LGM and the Younger Dryas (YD) is rather a *terra incognita*. Some data do exist, however, that help to flesh out that distant time. LaMoreaux, Brook, and Knox (2009) report a warmer and wetter climate for Georgia and Florida between 17,000 and 16,000 yr B.P. (20,130–19,180 cal B.P.) They note a change from an earlier braided channel system to that of a meandering system, with incision of the earlier valley fill deposits. Willard et al. (2007) inferred a warming of climate in central Florida at this time, with increases in *Pinus* reaching near modern levels of abundance. This occurred during the warmer and more moist climate of the Bolling/Allerod interval of 14,700 to 12,900 yr B.P. (17,770–15,250 cal B.P.) Additionally, Wil-

lard et al. (2007) were able to identify centennial-scale cold and dry events with the Bolling/Allerod sequence that corresponds to the Older Dryas (13,900 to 13,800 yr B.P.) and IntraAllerod intervals (12,900 to 12,700 yr B.P.), specifically.

The Bolling Allerod Interstadial (BAI) marks a period of rapid warming and coincident Laurentide ice sheet ablation. The period began approximately 17,500 B.P. (20,700 cal B.P.) and lasted until approximately 14,700 B.P. (17,770 cal B.P.), the onset of the cooler Younger Dryas. The BAI marks a period in which average air temperatures increased to roughly modern levels as indicated by peak abundance of *Pinus* pollen in central Florida (Willard et al., 2007). Such warming indicates significant contraction of the circumpolar vortex and poleward jet stream displacement. This likely resulted in greater amplification of the jet, or meridional, conditions. Meridional conditions occur during periods of a stronger latitudinal thermal gradient. This in turn triggers higher changes in vorticity through the jet trajectory. The result is deeper amplification of the jet flow and stronger and longer lasting midlatitude cyclones. Therefore, such periods are coincident with increased precipitation. Proxy evidence agrees with such an assessment as vegetation changes indicate warmer and moister conditions through eastern North America during this period. The Younger Dryas represents a period of time for which we have very little palynological or paleobotanical evidence from the Southeast, though some records go back to that time, and are briefly reviewed here. In any analysis of palynological and/or paleobotanical data from that time, it is well to bear in mind the observation made by Jackson et al. (1997) that the "... transition period between 15 and 9 ka was characterized by pollen assemblages without modern analogs over much of eastern North America."

Grimm and Jacobson (1992) observed that, based on their analyses of 18 sites spread across the eastern half of the continent, in the subcontinental region of eastern North America there were a number of synchronous changes in ancient floras. Times of significant change occurred during the late glacial (~14,000 to 9000 yr B.P. (~16,670–10,200 cal B.P.)), with peaks at about 13,700, 12,300, and 10,000 radiocarbon yr B.P. (16,350, 14,160, and 11,500 cal B.P.) and during the last 1000 years. We have tried to correlate those times with changes known from regional floras in the following synthesis.

At approximately 13,000 B.P. (16,200 cal B.P.), LaMoreaux, Brook, and Knox (2009) identified a horizon of organic sediment deposition along Sandy Creek Run. Low swales associated with more rapid vertical accumulation of sediments apparently developed in the valley floor of ancient Sandy Run Creek. The organic-rich deposits correlate with the age of the 4A paleosol from Yellow Banks Bluff, St. Catherines Island, and were dated at 13,600 yr B.P. (16,220 cal B.P.; Vento and Stahlman, chap. 4). During the subsequent Younger Dryas, the environment turned cool and moist, with open oak woodlands, trees of mesic forest type, and reduced amounts of pine (LaMoreaux, Brook, Knox, 2009). Similarly, the Younger Dryas stratigraphic record at Tampa Bay shows two distinct cool and dry phases, namely at 12,900–12,300 yr B.P. (15,250–14,160 cal B.P.) and 12,300–11,500 yr B.P. (14,160–13,340 cal B.P.) These dates correlate with the well-sorted eolian sands (2C), which cap the 13,600 yr B.P. Allerod subage paleosol and underlie the 10,790 yr B.P. (12,830 cal B.P.) paleosol exposed and dated along Yellow Banks Bluff. These eolian sands likely document less effective precipitation and drier climatic conditions that favored eolian deflation and subsequent burial of the Allerod subage paleosol.

Among other sites that provide us with some notion of the composition of the southeastern U.S. flora during the Younger Dryas is the remarkable archaeological site known at Windover. The Windover site, near Titusville, Brevard County, Florida, has been a wetland area, intermittently occupied by a pond, for nearly 11,000 years (nearly 13,000 cal B.P.). Doran (2002) presents exhaustive analyses of all the components of this site. An Early Archaic age is suggested for the horizon that contained abundant human remains (burials).

The oldest strata that were analyzed paleobotanically were sandy layers that predated the time of burial of the first humans. Holloway (in Doran, 2002) described a microflora dominated by pine, oak, and grasses and dated at 10,750  $\pm$  190 yr B.P. (13,070–12,140 cal B.P.). The pine-oak savanna that Holloway describes is consistent with what is known of other sites in the region, including Lake Tulane.

Proxy evidence indicates that warming occurred between the peak of the Wisconsin glacial phase, 18,000 B.P. (21,250 cal B.P.), but abruptly ended at 13,000 B.P. (15,360 cal B.P.) when a cold

phase ensued during the beginning of the Younger Dryas and lasted until 11,500 B.P. (13,340 cal B.P.) In Europe, this cold period is known as the Loch Lomond Stadial. The Younger Dryas (YD) is named after the dryas, a herbaceous tundra plant whose pollen grains in sediment and ice layers identified its chronological occurrence. The term "Younger" separates this more significant climatic episode from the Older Dryas, a less impressive stadial geological phase that occurred previously within the BAI (Yu and Eicher, 2001). The transition from the BAI to the YD was likely very abrupt, occurring over only a decade or so (Alley et al., 1993). Evidence suggests that temperatures were approximately 5°C cooler than current temperatures during this period.

During the YD, the circumpolar vortex expanded equatorward while strengthening significantly. This extended boreal conditions southward. This offset atmospheric and oceanic circulation regimes established during the previous BAI ablation period. While the cause of the YD is still debated, it is likely centered on atmospheric and oceanic circulation changes induced by cold meltwaters from the retreating Laurentide ice sheet. Before about 11,000 B.P. (12,920 cal B.P.), virtually all meltwaters were carried to the Gulf of Mexico via the Mississippi River (Marchitto and Wei, 1995). By 11,000 B.P. the ice sheet retreated to a position whereby the St. Lawrence River opened. This allowed the larger freshwater Lake Agassiz to drain significant quantities of cold meltwater into the northern Atlantic Ocean (Broecker, 2006). The resulting cold/low salinity lens in the North Atlantic significantly altered the ocean circulation. This hypothesis is supported by Bond (2005) who showed that significant Holocene climate shifts were accompanied by a 1°–2°C drop in North Atlantic sea surface temperature (SST). The lower SSTs triggered a positive feedback loop that altered the overlying atmospheric circulation leading to circumpolar vortex expansion and cooling for much of North America and Europe. This expansion brought cold, dry air over eastern North America and triggered significant ecotone changes from the previous warmer and wetter circulation regime. Proxy evidence through the southeastern United States indicates strong drying in a two- to three-step phase through the YD (Sissons, 1979; Willard et al., 2007). The YD ended as a new atmospheric/oceanic equilibrium was attained. Further ice sheet ablation eventually allowed contraction

of the circumpolar vortex and expansion of the North Atlantic subtropical anticyclone. The poleward shift of these general circulation features caused net poleward migration of the polar jet stream and allowed for the advection of warmer, moisture air masses to higher latitudes over eastern North America. Evidence indicates that the YD ended as abruptly as it began (Dansgaard, White, and Johnsen, 1989). With the termination of the Younger Dryas, and following the renewal of climatic amelioration, it appears that local water levels, including that at Windover Pond, rose. This is manifest at Windover by the deposition of waterlily peats. Stout and Spackman (in Doran, 2002) identified *Nymphaea* peat that had accumulated between approximately 11,000 yr B.P. and 9500 yr B.P. (12,920 and 10,740 cal B.P.).<sup>2</sup> Not surprisingly, Holloway discovered abundant oak at the Windover site at 8990 ± 90 yr B.P. (10,300–9770 cal B.P.), with maximum development of freshwater taxa, including the Nymphaeaceae and *Sagittaria* (arrowhead, a common freshwater marsh plant). Within the time range of 9500–8000 yr B.P. (10,740–8890 cal B.P.), Stout and Spackman recorded a rising water table at Windover, with the deposition of very fine-grained/amorphous gyttja (similar to the Mud Lake sediment studies by Watts). It was within this interval that Holloway found an abundance of Chenopodiaceae pollen in the Windover strata; abundance gave way to dominance at 8430 ± 100 yr B.P. (9550–9140 cal B.P.). At this point it is important to say that, while the Chenopodiaceae and Amaranthaceae (now combined as a single family) are useful indicators of herbaceous communities, it is nearly impossible to distinguish the pollen of the freshwater/terrestrial species from those that dominate coastal salt marshes. One must rely on associated remains to derive detailed environmental interpretations. It is clear, however, that changing hydrology at Windover during this period of time lead to the establishment of marshlands in an area that had supported oak savanna and waterlily marshes. Stout and Spackman (in Doran, 2002) determined that the Windover site must have dried out considerably at about 7950 ± 100 yr B.P. (9080–8450 cal B.P.). Mixed hardwood swamp began to take over the site, and this was the type of ground cover that greeted the first inhabitants. Interments began as people buried the deceased within the swamp.

The period 9000–8000 B.P. (10,200–8540 cal B.P.) marked a continuation of cool-season zonal

flow. However, higher warm-season potential evapotranspiration rates led to prominent drying through the southeastern United States. Climatic conditions abruptly changed during the Atlantic (8000–4500 B.P.; 8890–5180 cal B.P.) climatic episode, as wetter conditions prevailed. Many relate this transition to increased meridional jet flow. However, the extremely long-term stability of the climate suggests that zonal conditions dominated but that the average position of the polar jet increased poleward. This placed the study region within warmer and moister air masses. Precipitation was predominantly light through the seasons and increases in vegetation helped offset infrequent large precipitation events relative to runoff.

### THE EARLY TO LATE ARCHAIC

The Archaic spans roughly 4000–10,000 yr B.P. (4480–11,500 cal B.P.). Burials at Windover have a mean age of 7400 yr B.P. (8240 cal B.P. Doran, in Doran, 2002), so they fall nicely within that range, and are considered Early Archaic. Numerous additional archaeological sites of the southeastern United States fall within this range. While there are many more sites than we report on here, we have selected a few in the general area of Georgia and Florida (northern Florida, especially) that contain paleobotanical and palynological remains that reflect on the ancient environmental and habitat conditions that probably existed on or near St. Catherines Island. Among very recent reports is a compilation of data from the Mitchell River site, a complex of Middle and Late Archaic occupational horizons found at the easternmost end of Choctawhatchee Bay in the Florida panhandle (Saunders et al., 2009). The Mitchell and Choctawhatchee rivers have created a delta that was intermittently occupied between about 8000 and 3000 yr B.P. (8890–3210 cal B.P.). A multidisciplinary team identified artifacts, molluscs, pollen and spores, and siliceous microfossils in order to recover the greatest detail from the Mitchell River locality. Our interpretations of their data are necessarily brief, but we have tried to relate them to the developing matrix of site characteristics from other areas, such as Windover. The initial occupation of Mitchell River has been dated to cal 7200 yr B.P. The first occupants lived in an area dominated by sedge marsh. Returning to the Windover site, between 7000 and 6000 yr B.P. (7850–6840 cal B.P.); Stout

and Spackman (in Doran, 2002) determined that subaerial exposure at Windover lead to the continuation of the mixed hardwood swamp. This might have been the result of a change in hydrology that resulted in the persistence of the arborescent species where open water or herbaceous plants had existed much earlier.

It was within this window of time ( $6870 \pm 50$  yr B.P. [7800–7610 cal B.P.] to  $5050 \pm 50$  yr B.P. [5910–5660 cal B.P.]) that a pine savanna had developed in Coffee County, in central southern Georgia, at what has become known as the McClelland Sandpit Site (Zayac, Rich, and Newsom, 2001). McClelland is not an archaeological site, but it did preserve a beautiful forest of buried trees. Dozens of pine tree stumps and their enclosing sediments were exposed at McClelland as a result of removal of overlying sandbeds. Analysis of pollen and siliceous sediments from McClelland lead Zayac and her colleagues to the interpretation that the trees had grown in the floodplain of what must have been an anastomosed stream (many channels that tend to intertwine). Anastomosis occurs among streams, such as the Platte and Saskatchewan rivers, where sharply seasonal rainfall in a largely arid but vegetated region creates the anastomosed condition. Pollen data from McClelland led to the conclusion that the land cover in Coffee County consisted of prairie, similar to what one would find in the high plains of the western United States and Canada.

It's worth noting at this point that prairie is a truly unusual occurrence anywhere in the Southeast. As Gremillion (2004) points out, the deciduous forest of the southeastern United States changes, at its western edge, to grasslands. Within the area that she mapped as the "Southeast," grasslands exist only in isolated patches where demanding environmental conditions (dryness, windiness, and heat) prevent the growth of woody vegetation. There might be relicts of once more extensive grasslands, but they are invariably small.

It is significant that the McClelland site, and the period of maximum dryness at Windover, fall within what is known as the Holocene Climatic Optimum, or Hypsithermal. It has been shown that between about 4000 and 8000 yr B.P. (4480–8890 cal B.P.) the earth experienced a period of greater than average warmth. This is in remarkable contrast to the recently passed ice age, and the effects were widespread. Where one would have expected to find permanent streams

bounded by cypress-tupelo forest (the current condition at McClelland), the environment was clearly substantially drier than it now is. Wetland species did not leave the general area of southern Georgia and Florida, they merely relocated to more propitious sites.

Another Archaic site, known as Harney Flats, in Hillsborough County, Florida, was investigated by Austin et al. (2004). One radiocarbon date from Harney Flats, obtained from a piece of wood, showed that native people lived there  $6820 \pm 40$  yr B.P. (7720–7580 cal B.P.). This, then, is another site that was occupied during the Hypsithermal. Though palynological data were collected, the Harney Flats site proved to be rather monotonous. Rich (in Austin et al., 2004) found the strata to be dominated by the Chenopodiaceae. This now familiar association could show little more than that the site was probably coastal marshland or tidal flats. This is in contrast to the vegetation existing at the site now which, though heavily disturbed by 20th-century human activity, has a fairly high level of species diversity, including an array of woody plants. Extensive salt marsh in the area of Tampa would have been consistent with a generally warmer, perhaps dryer, condition.

Within the time of the middle Hypsithermal it has been shown that the basin of the Okefenokee Swamp, in southeasternmost Georgia, was still dry (Rich, 1979). The oldest dated peats from the swamp appeared  $6640 \pm 95$  yr B.P. (7680–7330 cal B.P.; Spackman et al., 1976). Multiple basal samples from the Okefenokee have been dated over the years, but none of them dates back to the Younger Dryas. Additionally, Rich (1979), in a survey of the palynological composition of the deepest Okefenokee peats, determined that they seem to represent only irregularly distributed wetlands of limited size. Interestingly, they included *Typha* (cattail), a plant that is no longer native to the swamp. In his reconstruction of the basal peat-forming environments, Rich (1979, and in Russell et al., 2009) described a hilly landscape composed of grass-covered sand ridges with small streams that supported intermittent wetlands.

It was at the same time as the development of the most ancient Okefenokee peats that Saunders et al. (2009) determined that sea level rose at the Mitchell River site (6640–5950 yr B.P.; 7640–6790 cal B.P.). Oddly enough, this event seems to have prompted the first of three episodes of

site abandonment. The hunter-gatherers are believed to have left the site as rising base level lead to the establishment of a *Taxodium-Nyssa* forest. This is believed to have displaced the important marine food sources that the Mitchell River people had come to rely upon. That situation notwithstanding, an apparent still-stand at Mitchell River between 5900 and 5300 yr B.P. (6710–6090 cal B.P.) led to reoccupation of the site, even though it remained cypress-tupelo forest. Coincident with these developments in Georgia and the Florida panhandle, Holloway (in Doran, 2002) determined that at the Windover site there was a dominance of grasses and composites (flowers such as the daisy, sunflowers, etc.). This, again, suggests an open pine or oak savanna type of environment.

It is interesting to note that much of the spodic soil (Bhs) package that underlies the surface A/Ap horizon and which caps the high Pleistocene core of St. Catherines Island likely dates to this period of Middle Archaic dryness. This statement is supported by a radiocarbon date on a now buried cumulic A horizon ( $6440 \pm 40$  yr B.P.; 7280–7430 cal B.P.), which is disconformably mantled by a 1.5 m (5 ft) thick uppermost soil generation (Ap-Bhs) that was emplaced during this period of late Middle Archaic dryness. The 6440 yr B.P. (7280–7430 cal B.P.) buried A horizon documents a return to more mesic conditions with subsequent drying and rapid sediment emplacement for the Ap-Bhs soil sequa. It appears that the stratigraphic occurrence of an eolian sand horizon (2C) that now buries a 10,790 yr B.P. (12,850–12,800 B.P.) paleosol and the thick spodic soil package (Ap-Bhs), which caps the 6440 yr B.P. (7280–7430 cal B.P.) paleosol, represent increased eolian deflation in response to soil water deficits and a drier climate during the Hypsithermal or the Climatic Optimum. This warm period, culminating between 8000 and 5000 B.P. (8890–5730 cal B.P.), saw average global temperatures  $2^{\circ}$ – $5^{\circ}$ C ( $4^{\circ}$ F) higher than present. Hemispheric circulation changes triggered changes in the North Atlantic anticyclone and the Intertropical Convergence Zone (ITCZ) during this period. The former involved a poleward shift of approximately  $10^{\circ}$ – $15^{\circ}$  latitude, placing much of Europe under the drying conditions of high atmospheric pressure (Davis et al., 2003). This shift also allowed for the net poleward migration of the ITCZ, bringing warmer and wetter conditions to higher latitudes (Suzuki, 1975).

The subboreal, at 4500–3000 B.P. (5180–3210 cal B.P.), marks another abrupt transition to a drier climate regime. The dryness was likely induced by expansion of the Bermuda-Azores anticyclone, particularly during the warm season. Such occurrences, which induce widespread atmospheric stability, are common today during summer. By the Sub-Atlantic period (3000–2000 yr B.P.; 3210–1960 cal B.P.) the climate system made a transition to a more meridional situation similar to present. This engendered more frequent and greater magnitude midlatitude cyclone migrations through the study region, resulting in an overall increase in moisture.

### THE ST. CATHERINES ISLAND SCENARIO

It is within this period of stable, but lower than modern sea level, and general terrestrial dryness that we see the next phase of development of terrestrial floras on St. Catherines Island. The island clearly must have been a part of the mainland during the LGM. The advance of the marine shoreline toward the island during the years between 18,000 yr B.P. (21,250 cal B.P.), and the separation of the island from the mainland is a span of time for which we have little information from the island itself. It is evident that the vegetation of the Southeast had sufficient diversity to allow conifer and hardwood forests, marshes, and savannas to inhabit what was to become St. Catherines Island. What can be said is that, according to sources cited by Thomas (2008: chap. 4; see also Thomas, chap. 1, this volume) sea level rose 2 m at the site of the island between 5300 and 4300 cal B.P. This local manifestation of higher sea level lead to the docking, or attachment of the now-eroded island of Guale to the northeast quarter of the main island at about 5000 cal B.P. This was about the same time that sawgrass marsh (*Cladium jamaicensis*) came to dominate the Windover site. Salt marsh habitat appeared around St. Catherines Island between 5000 and 4000 cal B.P. (Thomas, 2008; chap. 1, this volume) and, according to Saunders et al. (2009) there were a number of episodes of sea level rise and fall at the Mitchell River site (4900 to 4700 yr B.P.). This led to the second abandonment of Mitchell River, though the cypress-tupelo forest seems to have remained intact. Between cal 4840 and 3500 yr B.P. [5670–3790 cal B.P.], sea level rose at Mitchell River, leading to increasingly brackish conditions; this was accompanied by

reoccupation of the site during the most brackish phase of site development.

As the brackish marshes and their resources were being exploited at Mitchell River, the oldest shorelines developed on the Georgia barrier islands (4500 to 3700 cal B.P., according to sources cited in Thomas, 2008: chap. 4). This was also the time when the first ceramics of the St. Simons style began to appear. This evidence suggests a seemingly anomalous 2 m drop in sea level at St. Catherines between 4300 and 3600 cal B.P., an event that does not appear to be duplicated at the other sites. This period of time does correlate with observations in the mid-Atlantic region for a period of warm and dry conditions associated with the subboreal climate phase. Vento et al. (2008) documented that many of the drainage lines in the mid-Atlantic region responded to these drier conditions by increased lateral channel migration and episodes of rapid vertical accretion, often associated with channel aggradation.

In a final series of events, the last few thousand years of coastal history comes together. By 4200 yr B.P. and coinciding with the end of the warm and dry subboreal climate interval, inter-island marshes were established on the Georgia coast. This was the approximate time of first appearance of marine shells in the vicinity of Cracker Tom Hammock (4060 yr B.P.; 4540 cal B.P., as documented by Booth and Rich (1999). Thomas (2009) inferred that rising sea level at the island followed that time (cal 1600 B.C.). Interestingly, Spackman et al. (1976) identified 3500 yr B.P. (3790 cal B.P.) to be the likely minimal age for bay sediments in Florida Bay. Prior to this time sawgrass-waterlily peats were part of the basal sedimentary sequence, illustrating clear freshwater origins for the most ancient strata. By this time, peat accumulation was well underway in the Okefenokee Basin. Saunders et al. have written that, at the Mitchell River site, the time between 3400 and 1000 yr cal B.P. was characterized by the accumulation of tempestites. Associated with that time, brackish marsh vegetation gradually disappeared at Mitchell River, humans made only light use of the site, and it was finally abandoned for good about 800 yr cal B.P.

### HOLOCENE PALEOFAUNA

Unlike the Holocene botanical record, there is a dearth of information regarding evidence for faunal change in the southeastern United States

during the Holocene. This is due in part to early excavation methods which failed to collect microfaunal elements and to the occurrence of strongly acidic soils on the coastal plain and the effects of leaching upon postdepositional preservation.

Baker Bluff Cave in eastern Tennessee (Guilday et al., 1978) preserves 19 species of mammals in Archaic through late Woodland deposits, with only the Thirteen-lined Ground Squirrel absent from the area today—strongly indicating no major changes during the Holocene. Russell Cave and the Stanfield-Worley Bluff rockshelters in northern Alabama similarly show a continuity of the mammalian faunas throughout the Holocene. Aside from the extinct passenger pigeon, long-nosed peccary, and porcupine, all the mammalian faunal remains from Early Archaic through late Woodland horizons at Russell Cave can be found in the area today (Semken, 1983). At Stanfield Worley Rockshelter, the sparse faunal remains recovered from the entire stratigraphic sequence clearly document similar frequencies of white-tailed deer and gray squirrel for the Holocene deposits and provide little information regarding changes in Holocene climate. Semken (1983) notes that the faunal lists from these sites do not contain any mammalian species smaller than a chipmunk. This occurrence may limit the recognition of subtle climatic changes that have been identified by pollen studies conducted by Delcourt (1980) for the southeastern deciduous forests. At Salts Cave, Kentucky (Duffield, 1974), detailed excavations revealed a clear relationship between the occurrence of microfaunal remains, increase in grassland species, and associated warm and drier climatic conditions between 2940 and 2560 yr B.P. (3080 and 2670 cal B.P.). Climate was stabilized after 2500 yr B.P. (2610 cal B.P.) with the initiation of the warm and moist sub-Atlantic climate phase and forest conditions that persisted after that date (Semken, 1983).

The Devils Den fauna of Florida has been dated to 8000 to 7000 yr B.P. (8890–7850 cal B.P.; Martin and Webb, 1974). The faunal list contains eight extinct taxa regarded as early Holocene in age. The extinct taxa reflect a xeric parkland-savanna similar to that present in the region today. Martin and Webb (1974) note that the forest in the vicinity of the site was more mesic than now because wood rats, flying squirrels, and gray squirrels occur in the early Holocene deposits (Semken, 1983). Three other species found among the Devils Den taxa, the

muskrat, the meadow vole, and the gray myotis all now occur well to the north of this locality, suggesting cooler summers during the period of deposition (Semken, 1983). The Devils Den fauna suggests that the early Holocene climatic conditions in Florida were cooler and moister than today. Avery Island, Louisiana, has yielded a complex and diverse assemblage of both Recent and extinct mammals with dates as recent as 8390 yr B.P. (9450 cal B.P.) for extinct taxa (Gagliano, 1967; Semken, 1983). The stratigraphic sequence records a change from early through middle Holocene prairie grassland with parklike stands of hardwoods around water holes to a seashore environment beginning at around 5000 yr B.P. (5730 cal B.P.). By 3650 yr B.P. (3960 cal B.P.) sea levels had reached near modern levels with the establishment of coastal swamps. One of the most interesting sites is Little Salt Spring, in southwestern Florida, a freshwater collapse doline. During dry intervals of the Holocene, sediments there preserved a record for climate change since 12,030 yr B.P. (13,890 cal B.P.). The most interesting remains recovered, from a Paleo-Indian horizon, were those of a giant tortoise, which had a pointed wooden stake driven into its carapace. As noted by Semken (1983), faunal modifications resulting from climate change will likely be most apparent on the xeric Florida peninsula where the water table dropped 8 m between 8500 and 5500 yr B.P. (9510–6300 cal B.P.) and where local environments (swamps, sinkholes) are more likely to preserve the faunal remains that are often (aside from shell middens) missing as a result of the strongly acidic soils and intensive chemical weathering on the coastal plain. In sum, while there are radiocarbon dates associated with extinct taxa, none of the extinct mammals has been recovered from any defined archaic sites in Florida or Georgia.

#### LITTLE ICE AGE (LIA)

Between A.D. 1450 and A.D. 1850, a cold and dry period occurred through the Northern Hemisphere. This period is known as the Little Ice Age (LIA). Because the LIA coincides with the onset of formal climatic instrumentation, records are available from at least some locations. Three major global climatic cooling periods, each separated by slight warming phases, have been identified using these records.

It is generally recognized that reductions in

solar radiation and increases in volcanic activity contributed to the onset of the LIA. Further, ocean current changes and oscillations may have also contributed to a shift in the generalized atmospheric flow conditions over the Northern Hemisphere and possibly globally. Generally, cooling on the order of 1°–2°C was likely (Vento et al., 2008) but in some cases, there was more substantial cooling, perhaps as much as 3°–8°C.

The LIA coincides with the Maunder Minimum, a period of very low solar activity, especially sunspots. The Spörer Minimum, a period of slightly higher solar activity than the Maunder Minimum, coincides well with cooling during this time. Further exacerbating the overall reduction in insolation was the 1815 eruption of Tambora. The following year came to be known as the year without a summer due to temperature reductions related to the stratospheric ash cloud which resulted from the massive Tambora eruption. Other major volcanic eruptions contributed to cooling during this period.

Some evidence suggests that an alteration to the deep thermohaline oceanic circulation occurred during this period. The slowing of circula-

tion is likely related to the LCO, which decreased the amount of cold, salty water sinking to bottom waters. The result caused an alteration of the deep ocean conveyor that transports huge volumes of energy through the world's ocean and ultimately influences climatic conditions.

## THE PRESENT

Between the late 1800s and 1945, warming ensued. There was a short period of cooling between 1945 and 1980, and abrupt and dramatic warming has occurred since; the 10 warmest years present in the instrumental record occurred since 1990. Global sea levels have increased by 15 cm (6 in) over the past century, coincident with this overall warm period. It is believed that greater climatic extremes have developed over the last 100 years than at any other time over the past 500 million years.

## NOTES

1. Order of authorship determined alphabetically.





## CHAPTER 3

### GEOARCHAEOLOGICAL RESEARCH AT ST. CATHERINES ISLAND: DEFINING THE GEOLOGICAL FOUNDATION

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St. Catherines Island is located at the head of the Georgia Bight, midway in the string of 12 barrier islands forming the Golden Isles of the Georgia coast (fig. 3.1; Foyle, Henry, and Alexander, 2004). With no proximal source of fluvial sediment, St. Catherines Island is dependent upon net longshore transport of sand from north to south along the Georgia coast (Hails and Hoyt, 1969; McClain, 1980; Clayton et al., 1992). Net southward longshore transport is indicated by the chenierlike Savannah River Delta with southward accretion (Alexander and Henry, 2007), the chenierlike Altamaha Delta with its southward accretion, and southward migration of islands along the Georgia coast, and the building of the cape at Cape Canaveral, Florida (Davis, 1994). This net southward transport of sediment is interrupted by local effects of flood and ebb currents at Georgia's sounds, each forming a horizontal sand circulation pattern (Oertel, 1972a, 1977; Oertel and Foyle, 1993) exchanging sand with the shelf and islands themselves (Swift, 1968; Pilkey, et al., 1981). Interruption of this flow of sand by damming rivers to the north and dredging the Savannah Ship Channel across the Savannah River Delta (U.S. Army Corps of Engineers, 1991, 1996), has conspired with rising sea level to make St. Catherines one of Georgia's most erosional barrier islands (Griffin and Henry, 1984). Recent sea level trends are documented on the National Oceanic and Atmospheric Administration Sea Levels Online site for Fort Pulaski and Savannah (NOAA, 2003), indicating that currently sea level is rising at a rate of 3 mm/yr ( $\pm$  of 0.2 mm/yr; 1935–1999). At Fernandina Beach, Florida, the rate is 2 mm/yr (1897–1999).

Understanding Georgia's sea level changes demands accommodation of known data that constrain models and resultant sedimentological effects on shoreline position and elevation (Leatherman, Zhang, and Douglas, 2000; Douglas, Kearney, and Leatherman, 2001; Coe, 2003). The height of maximum sea level rise in Georgia is equivalent to the elevation of the highest coastal deposits of the Wicomico Shoreline, or terrace. Although the array of preserved Pleistocene shoreline deposits or terraces provides evidence of progressive lowering of sequential sea level highstands (Stapor and Mathews, 1983; Gayes et al., 1992), it says little about the sea level lowstands during glacial stages. Vertebrate fossils and archaeological artifacts from subtidal coastal environments (DePratter and Howard, 1977, 1981) and from the continental shelf allow partial reconstruction of lowstands (Garrison, 2006). Systematic survey and submarine excavation at Gray's Reef National Marine Sanctuary, 32 km (20 mi) offshore Georgia, and nearby J-Reef, in the Atlantic Ocean, have identified two localities containing vertebrate fossil remains and two artifacts, an organic artifact (a bone antler tool) and a lithic (a projectile point typologically assigned to the early Middle Archaic period (Garrison, 2006). Postglacial sea level must have recovered the 17–20 m (56–66 ft) depths at these locations during the Archaic period, ~8000 yr B.P., and as much as 40,000 yr B.P. prior to that, the areas surrounding Gray's Reef and J-Reef were part of an exposed coastal plain. Relative sea level rose in the Holocene (post-12,000 yr B.P.) continuing to rise from full post-Wisconsin lowstand of over 100 m (328 ft) below present sea level (Garri-

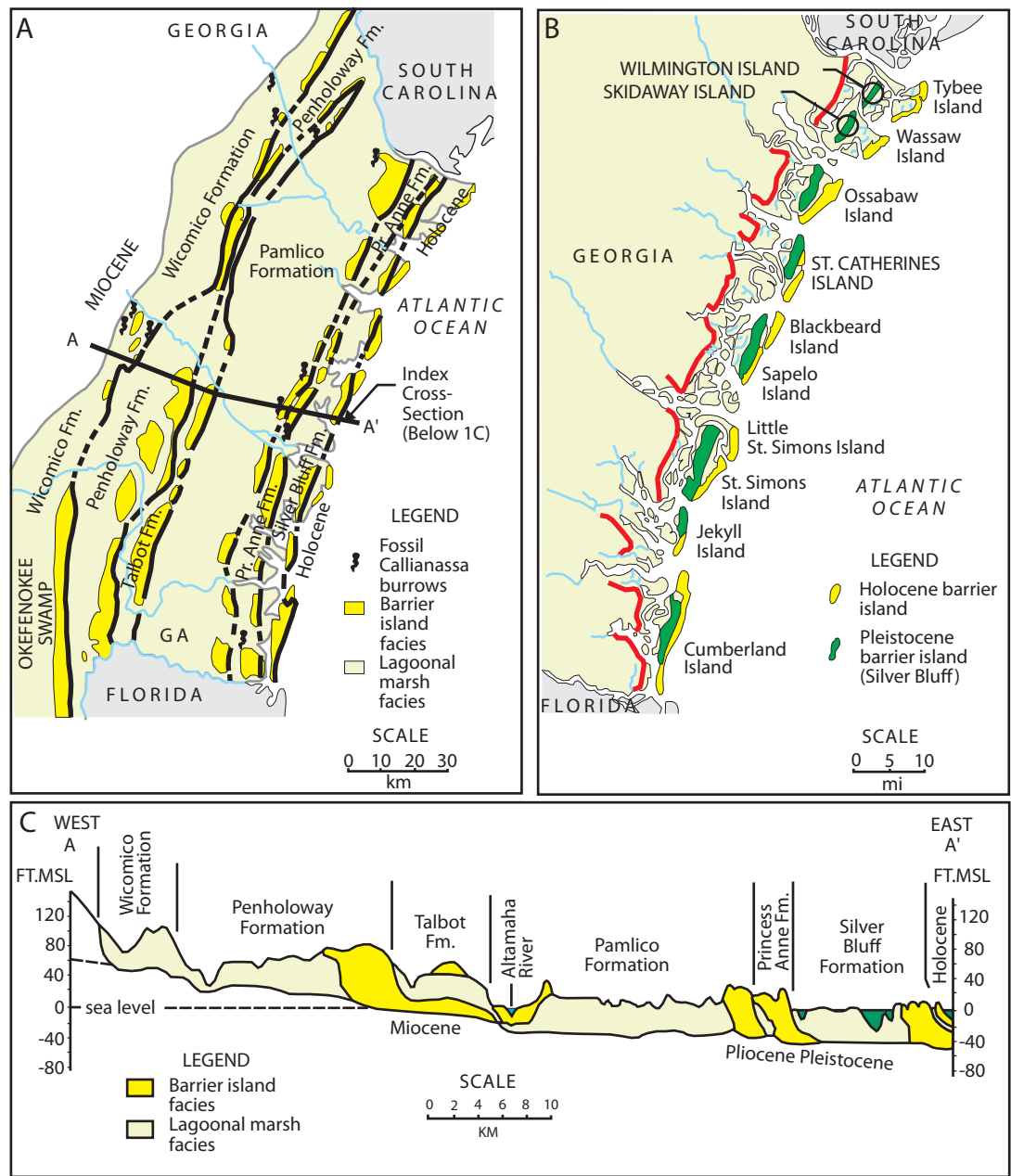


Fig. 3.1. Development of successive shorelines on the Georgia coast: **A**, successive shorelines, headlands, and intervening marshes (formations); **B**, recent Silver Bluff Pleistocene and Holocene shorelines of Georgia forming modern Golden Isles; **C**, cross section of Pleistocene to Holocene sediment veneer of the Georgia coastal plain (after Hails and Hoyt [1969] and Hoyt and Hails [1967]).

son, 2006). Sea level had dropped prior to the Late Glacial Maximum ~21,000 yr B.P. (Marine Oxygen Isotope Stage-2 [MIS-2]). Differential elevations of ancient barrier island or shoreline complexes and structural evidence suggest that tectonic as well as eustatic controls have been in effect. Superimposed upon these eustatic and tectonic effects are sedimentological pulses produced by Pleistocene climate changes and evolving physical conditions influenced by possible coastal plain stream capture of inlets and sounds along the Georgia coast (Chowns et al., 2008; Chowns, chap. 9, this volume).

The profound effects of sea level change were emphasized in a figure of Pleistocene coastal Georgia by a geographer (LaForge, 1925) in a map graphically depicting the configuration of southeast Georgia during the Wisconsin highstand. MacNeil (1950) described the shorelines/terraces from Georgia and Florida citing four marine terraces and shorelines between sea level and ~29–30 m (~100 ft) above sea level. He proposed that the higher Okefenokee and Wicomico shorelines could be correlated with the Yarmouth and Sangamon interglacial stages, respectively, the Pamlico Shoreline correlated with a mid-Wisconsin ice recession, and the lowest, the Silver Bluff Shoreline with post-Wisconsin. Hoyt, Henry, and Weimer (1968); Hails and Hoyt (1969), and Hoyt and Hails (1967) described the formation of a veneer of Pleistocene sediments across the Georgia coastal plain (fig. 3.1, lower) as sea level fluctuated throughout the Pleistocene and apparently dropped with each subsequent interglacial sea level rise; these sediments built a sequence of barrier island complexes (fig. 3.1A, B) that got progressively younger, and lower in elevation, toward the present coastline.

The problem of sea level rise and fall illustrates the complexity of geology as a unique critical thinking paradigm applying logical reasoning first to the stratigraphic problem, then to the interpretation of the stratigraphy (Frodeman, 1995). Hoyt, Weimer, and Henry (1964) described the stratigraphy of the mid to late Sangamon and Pamlico, Princess Anne, and Silver Bluff paleo-shorelines on the Georgia coast. The Silver Bluff deposits form the core of many modern barriers including Ossabaw, St. Catherines, Sapelo, St. Simons, Jekyll, and Cumberland islands with associated Silver Bluff marsh lithosomes currently submerged by the Holocene transgression. Along the Georgia coast these sea level fluctuations re-

sulted in deposition and erosion of a seaward-dipping veneer of Pleistocene sediment arranged in a series of barrier island sequences that are younger to the east. The deposition of coastal terraces or barrier island ridges (Wicomico, ~29–30 m [~98 ft]; Penholloway, ~23 m [~75 ft]; Talbot, ~12–14 m [~39–46 ft]; Pamlico, ~8 m [~26 ft]; Princess Anne, ~4.5 m [~14 ft]; Silver Bluff, ~1.5 m [~5 ft]; and Holocene) in Georgia form a continuous veneer of Pleistocene sediment of varying thickness and lithology (Huddleston, 1988). Shoreline elevations were based on the elevations of fossil burrows of *Callichirus major* (Say, 1817–1818; Rodrigues, 1983).

Hoyt and Hails (1967), Hails and Hoyt (1969), Pickering and Murray (1976), Linsley (1993), Bishop et al. (2007), Linsley, Bishop, and Rollins (2008), Reitz (2008), Thomas (2008), and others, have suggested that the most recent set of Georgia barrier islands consist of older sediment deposited about 35,000 to 40,000 years ago with younger sediment to the east accumulating against the island about 4000 to 5000 years ago (fig. 3.1, upper right). The Pleistocene parts of the islands formed when the sea level was ~2.0 m (6.5 ft) above the present level, before the formation of the last great continental ice sheet of the Pleistocene epoch, the Wisconsin Glacial Stage, that lowered sea level 80 m (~260 ft), placing the shoreline 128 km (~80 mi) offshore near the present edge of the continental shelf.

Gray's Reef (Henry and Hoyt, 1968; Hunt, 1974) is an exposed dolomitized micritic limestone hardground interpreted by Woolsey (1977) to be stratigraphically and lithologically equivalent to the Raysor shelly sand. It had been originally referred to as the Sapelo facies of the Duplin formation. Subsequent geological studies include Continental Shelf Associates, Inc., 1979; Henry and Giles, 1980; Henry, 1983; Van Dolah, Calder, and Knott, 1984; Van Dolah, Wendt, and Nicholson, 1987; Henry, Dean, and Olsen, 1987. Huddleston (1988) later revised the lithostratigraphy of the Georgia coastal sediments.

According to this literature, the present global rise in sea level began approximately 20,000 years ago, moving across the exposed continental shelves about 1 m/100 yr until ~6000 years ago, at which time the rate of rise slowed to approximately 0.3 m/century until today. Garrison (2006) documents the existence of Gray's Reef above sea level some 15,000 years ago when Georgia's shoreline was more than 60 mi east

of its present position. Off the coast, divers have discovered fossils of now-extinct land-dwelling animals, such as ground sloths, mastodons, and early camels, horses, and bison. Gray's Reef inundation began ~7000 yr B.P. (Henry, 2005). Thus, after several cycles of submergence and emergence, with the latest period of exposure lasting 40,000 years, the substrate was once again covered by the ocean and once again became a live bottom.

Swift et al. (1972) recognized that inlet, ebb-tidal delta, and estuarine deposits from low-stands of late Pleistocene and Holocene sea level are principal sources of sediments for building current beaches. Chester DePratter and James Howard (1977, 1981) studied the "History of shoreline changes determined by archaeological dating: Georgia coast," documenting the existence of intertidal archaeological sites (see also Caldwell, 1971).

Winker and Howard (1977) described difficulties in correlation of Pleistocene paleoshorelines of the lower coastal plain between Florida and Virginia and presented a new terminology (Chatham, Effingham, and Trail Ridge sequences) for paleoshorelines. Well-developed trellis-style drainage networks were described landward of the Talbot paleoshoreline and dendritic drainage patterns prevail at lower coastal plain elevations associated with the modern through Pamlico-Talbot paleoshorelines. They suggested that up to 50 m of downwarping and upwarping along the Orangeburg Trail Ridge scarp between north Florida and southern North Carolina was possible. Pilkey et al. (1981) described common lagoonal deposits on the shelf and proposed that southeastern barrier islands are not just mid- to late-Holocene features but migrated across most of the shelf during the current transgression. Mason (1993) determined the usefulness of beach ridge archaeology for identifying rates and timings of coastal change, climate change, and sea level variation for progradational coasts based on the fact that human settlement favors open coastlines that correlate with changes in the shoreline. Gayes et al. (1992) identified a mid-Holocene (4.2 ka) highstand of relative sea level at Murrells Inlet, South Carolina followed by a fall in sea level of 2 m until 3.6 ka and then a constant sea level rise of 10 cm/century to the present. McBride and Byrnes (1993) compared Louisiana, Mississippi, and Georgia barrier coastlines. Shoreline change rates on the Georgia coast have averaged about

1 m/yr over the past century, leading to stable central shorelines with most fluctuations occurring adjacent to tidal inlets. In Georgia, barrier islands commonly exhibit lateral accretion, progradation, and dynamic equilibrium, which are the primary responses of barrier coastlines.

Riggs and Cleary (1993) recognized that many East Coast barrier islands are "perched" barriers whose forms are strongly determined by antecedent topography and the types of antecedent sediments available to wave/current erosion on the shoreface and foreshore. The structural and stratigraphic characteristics of a barrier island complex influence barrier island morphology, inlet development, and beach dynamics (Hoyt, 1967). Scott, Gayes, and Collins (1995) and Scott and Collins (1995) recognized a rapid increase in sea level rise to a point about 1.5 m above current sea level in South Carolina. Wanless (2002) described Holocene coastal change on the mud-dominated microtidal mangrove coast of west Florida that is migrating landward at rates of as much as 4 m/yr with a 3 mm/yr relative sea level rise rate (causing coastal submergence).

Langley et al. (2003) described the quantification of shoreline change on the Georgia coast on Wassaw and St. Catherines islands using shoreline data from 1856 and 1924 and reviewed the history of shoreline mapping on the Georgia coast. The authors state that Wassaw and St. Catherines islands exhibit shoreline-change patterns proposed by Hayes (1994) to be typical of Georgia Bight barriers in that erosion occurs on the updrift ends and accretion occurs on the downdrift ends. While this is a good generalization, it is an oversimplification, being true at limited temporal and spatial scales (Foyle, Henry, and Alexander, 2004). Langley et al. (2003) show that St. Catherines Island does not exhibit this typical behavior. The data appear to reveal the downdrift migration of an accretionary bulge that is probably fed by onshore-migrating sand bars from the updrift ebb-tidal delta. However, the time frame within which this process typically operates on the Georgia Bight is not well known. St. Catherines Island has become shorter (1852/1871–1911/1924) and shows shoreline retreat along its entire length with some stability along its central portion (Goodfriend and Rollins, 1998). Griffin and Henry (1984) attributed this to the island's distal location downdrift of significant sediment input from the Savannah River. Shoreline retreat rates on St. Catherines Island

vary from  $-1.6$  to  $-9.2$  m/yr (see Bishop and Meyer, chap. 14: fig. 14.11; and Potter, chap. 7).

Fred Pirkle led the study of the geological history of the Georgia coast to better define and locate deposits of heavy minerals (Smith, Pickering, and Landrum, 1968; Pirkle et al., 1991; Pirkle, Pirkle, and Pirkle, 2007) and define their mode of accumulation as placers left behind on the backbeach as swash winnows out the less dense quartz fraction. Bishop studied the distribution of heavy minerals on St. Catherines Island (1990), finding them concentrated along the backbeach in a series of nodes, in the backbeach dune fields, and onto the midbeach. Vance and Pirkle (2007) summarized the distribution and provenance of heavy minerals on the Georgia coast.

A burst of geological research in the late 1990s resulted from the Georgia State University master's thesis work of Robert Booth, under the supervision of Fred Rich. Booth et al. (1998), Booth, Rich, and Bishop (1999), and Booth et al. (1999) described aspects of the stratigraphy of St. Catherines Island. Booth and Rich (1999) described a dense peat from the Cracker Tom bridge core at a depth of 5.02–5.12 m (total depth) that consisted of 85% monolet pteridophyte spores and was dated (AMS) at  $47,620 \pm 2500$  yr B.P.

Bartholomew et al. (2007) have studied joint orientations on the Georgia coast and Rich and Bishop (personal commun.) examined possible joints at Yellow Banks Bluff in September 2006.

During the 1980s and 1990s, the University of Pittsburgh group also conducted extensive geological research (largely paleoecological and sedimentological) on St. Catherines Island, including the work done by K. Beratan, R.M. Busch, J.D. Donahue, N.J. DeLillo, J.F. Fierstien, S.K. Kennedy, D.M. Linsley, P. Mannion-Rowe, R. Pinkowski, J.E. Pottinger, J.C. Rollins, H.B. Rollins, B.L. Sherrod, C. Venn, F. Vento, and R.R. West.

#### RECENT SEA LEVEL RISE AT ST. CATHERINES ISLAND

Sea level rise is occurring at the same time that we have dammed streams, dredged the Savannah Ship Channel, and interrupted the southward flow of sand along the coast of Georgia. Consequently, there is a deficiency in sand supply, placing many islands under increasingly erosional conditions, especially St. Catherines Island, which has no significant local influx of

fluvial sand from the short mainland creeks entering St. Catherines and Sapelo sounds. These conditions have made St. Catherines Island one of Georgia's most dynamic and erosional barrier islands (see fig. 3.3). In this context, St. Catherines is a sentinel island for the other barrier islands of the Georgia coast—predicting increasingly erosional conditions for all the Golden Isles as these conditions continue and strengthen.

Erosion of the east and north shores was documented in the 1970s by McClain (1980). Morris and Rollins (1977) mapped biological associations within relict marsh mud exposed as erosion exposed ancient marshes along the beaches of St. Catherines Island. Monitoring erosion and accretion of the shoreline at St. Catherines was expanded during the past 20 years by students in The University of the South's Island Ecology Program to include more than 25 stations with more or less continuous measurement of shoreline change. Bishop initiated documentation of beach habitat deterioration through an annual Rapid Habitat Assessment (Bishop and Marsh, 1999b) survey to characterize those deteriorating conditions through a semiquantitative of sea turtle habitat during the mid 1990s (see Bishop and Meyer, chap. 14: table 14.2), a technique adapted for application to all Georgia barrier islands in a continuing longitudinal study by the Coastal Resources Division of Georgia Department of Natural Resources (Dodd and MacKinnon, 2006). In 2006, investigators working on St. Catherines Island were invited to report surf conditions, rip currents, and erosional beach conditions during storms (Davis and Dolan, 1993) to NOAA Coastal Services Center, in Charleston, S.C.

#### SEA LEVEL HISTORY OF ST. CATHERINES ISLAND

St. Catherines Island is comprised of older Silver Bluff Pleistocene sediment forming the western high-standing core of the island (the island core) surrounded by younger, low-standing Holocene accretionary terrains (see fig. 3.2). These major sedimentary packages are separated by a series of scarps, bluffs, or other dichotomous boundaries (fig. 3.2). These ancient and modern erosional boundaries and sedimentary packages provide evidence of episodic erosion and deposition (see chap. 14: fig. 14.11) as the island changed through time in response to fluctuating sea level, changes in sedimentation rates, and

crustal movements (Johnson et al., 1974). Such changes are normal geological phenomena, but when set in motion with anthropogenic causes or effects are unique and sometimes dramatic.

Bishop et al. (2007) presented a comprehensive analysis of the geology of St. Catherines Island within the context of a Southeastern section meeting of the Geological Society of American

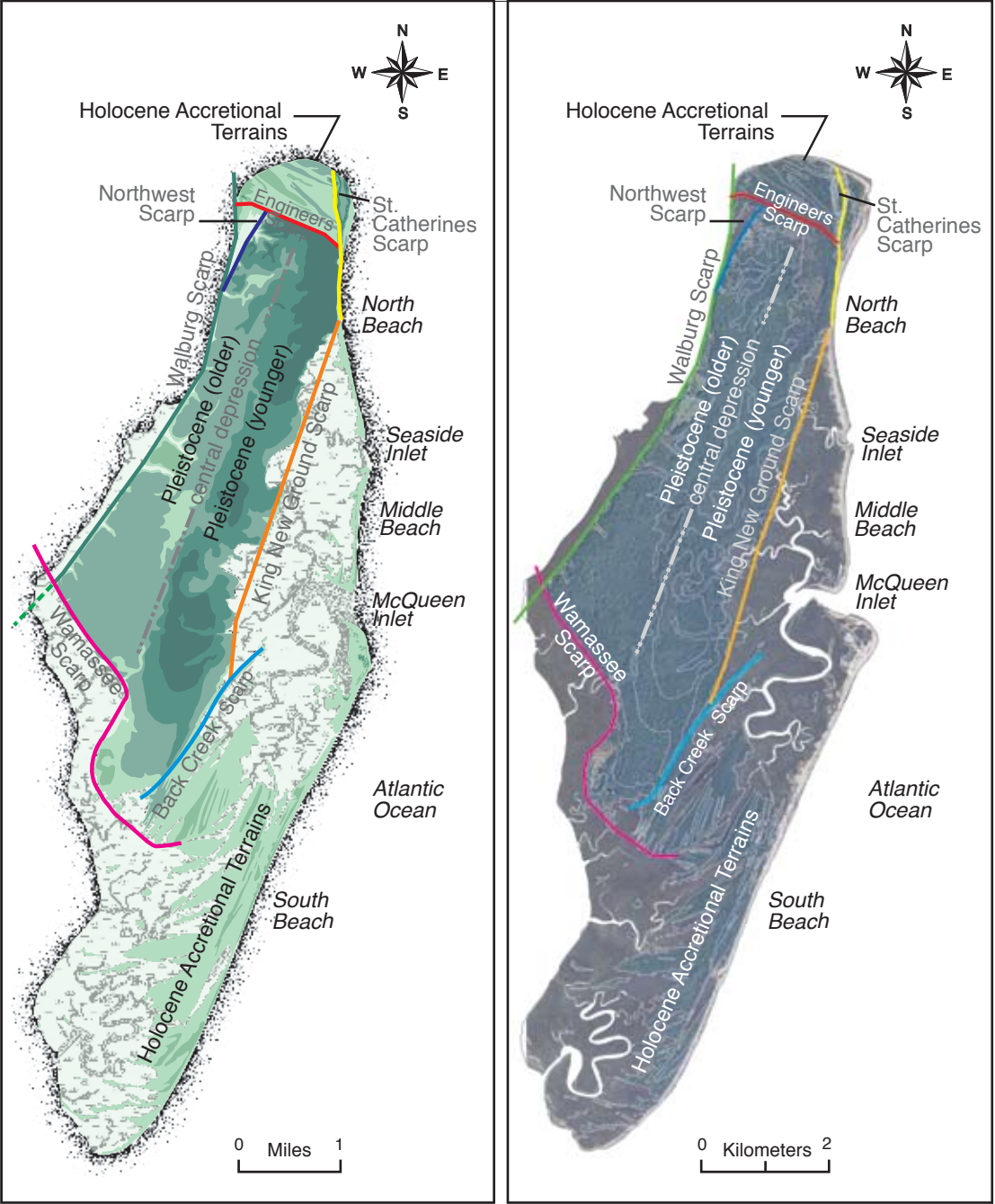


Fig. 3.2. Geomorphology sketch map (left) and 2006 color imagery (right) of St. Catherines Island (after Bishop et al., 2007, and Linsley, Bishop, and Rollins, 2008) showing major scarps and depressions.

(SEGSa) Technical Session and Fieldtrip. The basic geomorphology of St. Catherines was presented within hypotheses of the formation of the island's foundation and geological history. This work brought together aspects of geology, ecology, archaeology, and history.

Reitz et al. (2008), Linsley, Bishop, and Rolins (2008), and Thomas (2008) examined aspects of the natural history and evolution of St. Catherines Island, which, along with Bishop's fieldnotes, forms much of the observational data reported herein. The publication of *Native American Landscapes of St. Catherines Island* (Thomas, 2008) provided the impetus for development of the Caldwell IV Conference stressing the geoarchaeology of St. Catherines Island, which we hope will expand our knowledge by inclusion of new ideas from the usual suspects and new input and testing by new research colleagues.

St. Catherines Island (see fig. 3.1), consists of two distinctive entities defined by variations in topographic relief, or "texture" (fig. 3.2), a high-standing, relatively featureless central area to the west and northwest and a low-standing, highly textured fringing area to the east and southeast (Bishop, 1990; Bishop et al. 2007: fig. 3.40; Reitz et al., 2008). The high-standing area, the island core, is characterized by an elevation of approximately 5 m, a mature mixed, deciduous-pine forest, former agricultural fields in various degrees of succession, and a robust archaeological record. The high-standing portion of the island is mapped as Pleistocene Silver Bluff facies on the geologic map of Georgia and the low-standing area is mapped as Holocene (Pickering and Murray, 1976). The low-standing accretionary terrain is characterized by an elevation of ~1 m, alternating beach-dune ridge systems and swales, and intervening freshwater ponds or tidal creek-marsh meadows. The ridges are often forested by various trees, which are rather distinctly distributed along specific ridge systems (Coile and Jones, 1988) and are dominated by cabbage palm, hickory, pine, or live oak.

The central, high-standing island core is flanked by low-standing Holocene sediments at the north and south ends of the island and along the oceanic eastern margin. The eastern margin is characterized by broad marsh meadows developed behind long sand spits at Seaside Inlet, Middle Beach, and McQueen Inlet. The southeast end of St. Catherines Island consists of a sequence of approximately 22 beach ridge systems, which

generally become progressively younger seaward and southeasterly and can be seen on aerial photographs and orthophotomaps to possess discrete, often dichotomous boundaries (figs. 3.2 and 3.5 and Bishop and Meyer, chap. 14: fig. 14.6). These packages of sediment represent rapid periods of accretionary activity during the Holocene punctuated by periods of erosional activity giving rise to "sedimentary accretionary terrains," which may be chronologically sequenced based on their position by using crosscutting relationships at their boundaries, and possibly by archaeological dating (Thomas, 2008). The pattern of these accretionary terrains records the depositional history of the Holocene part of the barrier island in their presence, sequence, and distribution. Thus the Holocene sedimentary accretionary terrains provide a powerful tool to decipher the Holocene history of the entire island, as well as the record of sea level fluctuation, rate of sediment supply, and shoreline fluctuation in the recent past. This, in turn, allows sedimentological prediction of the near future as sea level rises due to global warming.

#### BOUNDARIES

In general, the boundary between the island core facies and the Holocene sedimentary accretionary terrains is demonstrably erosional (see fig. 3.2). At both ends of the island the low-standing linear Holocene beach ridge systems stand in marked contrast to the higher, less-textured Pleistocene core (figs. 3.3 and 3.4). These erosional boundaries represent surfaces formed by episodes of erosion due either to eustatic sea level changes, pulses of erosion and sedimentation, or lateral migration of subtidal erosional environments such as channels of sounds and meandering tidal rivers. Each erosional event is identifiable in map view by dichotomous beach ridge orientations and often by small differences in elevation of adjacent sequences of sediment, and differences in vegetation or archaeological age (fig. 3.3). Each erosional event *may* also be identifiable in stratigraphic sections as a minor unconformable sequence or diastem that dips either seaward or into adjacent areas that had lowered base levels (fig. 3.4). When such erosional surfaces are destroyed by subsequent erosional events, their former existence and location become conjectural. Each identifiable boundary has been given a local name to expedite communication in this chapter (Bishop et al., 2007).

The boundary between the island core facies

and the Holocene sedimentary accretionary terrains on the east side of the island consists of three major arcuate erosional scarp systems (fig. 3.2). The oldest scarp, the King New Ground Scarp, runs from the south end of Yellow Banks Bluff, the Silver Bluff (Hails and Hoyt, 1968) erosional bluff on North Beach, to Cracker Tom Creek behind South Beach. Back Creek Scarp can be traced from Cracker Tom Causeway to the south end of the island core. St. Catherines Scarp is herein restricted to the northernmost part of the island, essentially fronting Yellow Banks Bluff. King New Ground Scarp is arcuate and brings the Silver Bluff core facies into contact with marsh meadows, which lie topographically 3–5 m (10–15 ft) lower than the Silver Bluff core. This emarginate boundary, developed on the King New Ground Scarp as former meanders of the tidal creeks lying within the seaside marsh meadows, cuts into the adjacent island core (fig. 3.4). From Cracker Tom Causeway to the south is a second eastward-dipping erosional scarp, Back Creek Scarp, whose presence and age relative to the King New Ground Scarp are indicated by the presence of a straight scarp forming the east edge of the ancient island flanked to the east by depositional ridges and swales.

The sedimentary accretionary terrains at both ends of the island that are oriented perpendicular to the northeast-southwest trending beaches represent former channel margin sediments of St. Catherines Sound and Sapelo Sound. Because these areas were formed by lateral migration of sound systems relatively independent of eustatic change, the lateral erosional and depositional events at opposite ends of the island are thought to have been relatively independent of one another. Eustatic events, however, should be correlative in a large sense as they are drivers of gradients and channel morphology.

At the north end of the island we now recognize two additional scarps, Northwest Scarp and Engineers Scarp (fig. 3.2). Northwest Scarp is a short scarp that strikes northeast from Walburg Scarp forming the boundary between the island core and Northwest Marsh. Engineers Scarp is the erosional boundary between the island core and the northern Holocene accretionary terrains. Engineers Scarp is truncated to the east by St. Catherines Scarp, a former sound margin of St. Catherines Sound, and truncated to the west by Walburg Scarp.

The number, extent, and variable orientation of Holocene accretionary terrains indicates that

several times during the Holocene, the sound channels have migrated dramatically and sometimes rapidly, significantly eroding older portions of the Holocene part of the island that subsequently accreted as the sound channel migrated back in the opposite direction. This hypothesis would suggest that the sounds and Pleistocene cores of barrier islands on the Georgia coast are relatively stable features, but that the unconstrained mouths of sounds act somewhat like loose fire hoses, whipping rapidly back and forth along the coastline, giving rise to the erosional boundaries and sedimentary packages of the accretionary terrains. If this is the case, the relative ages of surface exposures and stratigraphic facies tracts ought to confirm the hypothesis. Chowns et al. (2008) have postulated the rapid relocation of fluvial-dominated sounds as a mechanism for forming the northeastern islands in island doublets (see chap. 9).

Core samples obtained by vibracoring during the fall of 1989 and the spring of 1990 demonstrated the stark contrast between the island core facies and the Holocene sedimentary accretionary terrains. The island core facies exposed at Picnic Bluff and in a core recovered at Mission Santa Catalina de Guale both consist of relatively homogeneous sands that has been deeply leached and presumably homogenized by intensive bioturbation by root growth and other organic processes. The core recovered from the Mission Santa Catalina de Guale site penetrated clean, light tan, quartz sand at approximately 60 cm and terminated at 3.23 m in an organic-rich, chocolate brown, humic sand. The only evidence of sedimentary structures was a few sparse root casts and mottling at 2.10 m. Four cores were taken from the Holocene sedimentary accretionary terrains on Cracker Tom Causeway, an intermediate-age, east-west oriented terrain (see chap. 10: fig. 10.4), and from the northern end of Beach Pond, immediately behind the present beach ridge system. All four cores show remarkable vertical sequences of sediment derived from deposition in coastal environments similar to those nearby. Three of the four terminate in deeply colored sediments at approximately 5.0 m below current high marsh level. One of these, the Cracker Tom Bridge core (GAB 9005051), terminates in the upper 14 cm of an unknown thickness of deep blackish-brown, dense peat that has been dated by  $^{14}\text{C}$  methods (figs. 10.2D and 10.7). The surface, represented by deeply colored terrestrial

sediments at approximately 5.0 m in cores taken along Cracker Tom Causeway (see chap. 10: figs. 10.6 and 10.8), is considered to be the contact between the Holocene and the top of the Pleistocene as well as the disconformity representing Back Creek Scarp in the subsurface.

Relict marsh exposed near the southern tip of St. Catherines Island constrains the age of southward accretion of the Holocene terrains by representing the youngest preserved, datable lithologic sequence of marsh deposited before the current erosional cycle began. This marsh mud contains a detrital peat layer near its surface, overlain by rooted marsh muds with in situ articulated and disarticulated shells of the marsh-dwelling bivalves *Mercenaria*, *Geukensia*, and *Crassostrea* as well as the marsh-dwelling gastropod *Littoraria*. The bedded peat, a piece of wood included in the mud beneath the peat, and shells of *Crassostrea*, *Geukensia*, and *Mercenaria* from above the peat were sampled and are being dated by  $^{14}\text{C}$  methods.

The presence of extensive seaside marsh meadows along the Atlantic margin of St. Catherines Island, the presence of a significant erosional bluff on North Beach, the presence of thick, relict marsh muds exposed along stretches of North Beach, Middle Beach, and South Beach, and the abundance of significant heavy mineral placers all firmly substantiate that not only has there been significant erosion along the Atlantic margin of the island, but that there was a formerly significant barrier island to the east of St. Catherines Island. Seaside and McQueen marsh meadows developed as interisland marshes before they entered their current erosional phase. The geomorphology of the proposed St. Catherines Island couplet would be analogous to other Georgia Sea Island couplets, such as St. Simons–Sea Island or Sapelo–Blackbeard Island (fig. 3.6). This comparison leads to the conclusion that a seaward barrier island, named Guale Island (Bishop, 1990; Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008; and Reitz et al., 2008), once existed off the northeast edge of modern St. Catherines Island. Guale Island suffered total destruction from erosion by southerly longshore currents entering the Georgia Bight from the northeast and is perhaps linked to stream piracy of the Canoochee River by the Ogeechee River (Chowns et al., 2008) and a subsequent decrease in sediment delivery to St. Catherines Sound and to St. Catherines Island.

Although still largely speculative, the recent history of St. Catherines Island built on the

Guale Island hypothesis (Bishop, 1990) allows a framework for evolution of St. Catherines Island to be set and tested, although absolute timing of some events forming the island core remains unknown (fig. 3.3).

#### CONSTRAINTS ON HISTORICAL SPECULATION

The reconstruction of the geological history of St. Catherines Island remains partly speculative at this time because subsurface data are only now being systematically gathered and analyzed in the context of surface geology, geomorphology, and archaeology. The major constraints on such speculation include the lithologies, orientation, and surficial textures of different parts of the island; presence of major erosional boundaries as indicated by differing orientations of surficial textures and relative ages of sedimentary accretional terrains; relative dating derived from crosscutting relationships; archaeological dating; and absolute dates provided by  $^{14}\text{C}$  dating. These data, when integrated with analogous findings from adjacent island systems, provide a technique to decipher the major historical events that have shaped St. Catherines Island. Among these events, the presence, position, and relative age of major erosional boundaries seem most liable to provide sound sequencing of past events. Such boundaries clearly separate older sedimentary accretional terrains from younger ones. Such erosional boundaries are not only surficial, but also form disconformable relationships in stratigraphic sections.

In constructing our more recent geological history of St. Catherines Island, we summarize evidence as we knew it in 2007 and 2008. From that base, we have constructed an interpretation of the geological history of the island constrained by parameters cited above (fig. 3.3). The interpretation of the island's geological history continues to evolve as new data become available.

The evidence, as known in 2008, consisted of the following observations:

1. The oldest part of the island, the Pleistocene Silver Bluff core, consists of homogeneous sands, nearly lacking surficial textures, and deeply leached with concentrations of organic-rich humate at depth with a central depression and a lineament that may be a boundary between older and younger depositional units in the island core.

2. Major erosional boundaries are identifiable at the edges of the core, including Back Creek Scarp, St. Catherines Scarp, Walburg Scarp, Wa-

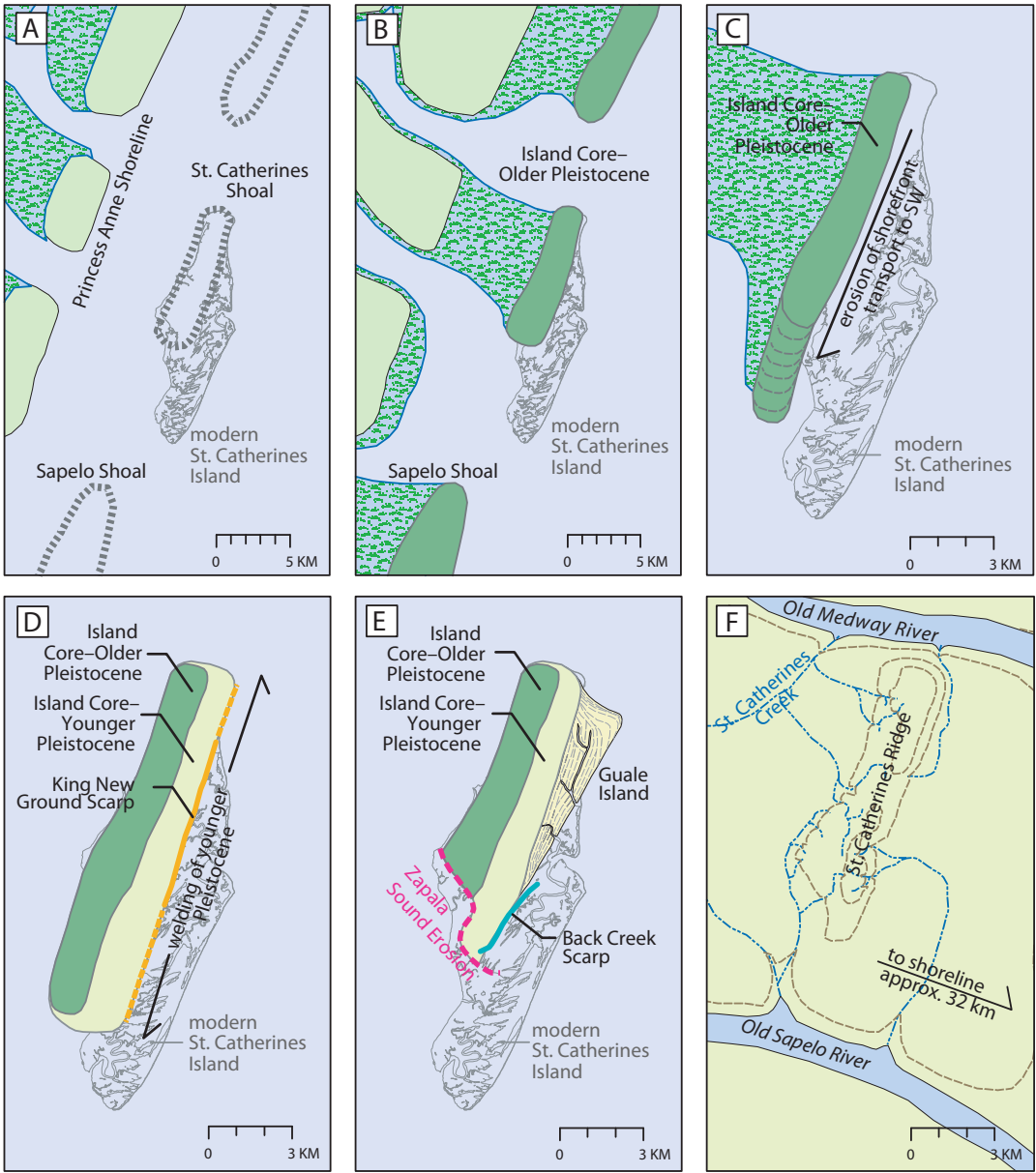


Fig. 3.3. A geomorphological depiction illustrating one possible scenario for the development and evolution of St. Catherines Island (Bishop et al., 2007): **A**, St. Catherines shoal at time of deposition of Princess Anne paleoshore; **B**, formation of initial Silver Bluff Pleistocene core of island; **C**, erosion of older Pleistocene core results in long, narrow island and adds sediment to the south; **D**, welding of younger Pleistocene core onto entire length of island; **E**, meander of Zapala Sound erodes older Pleistocene coupled with development of complex St. Catherines/Guale barrier island doublet; **F**, Wisconsin low-stand shoreline recedes 32 km east near Gray's Reef, island is part of low-relief mainland.

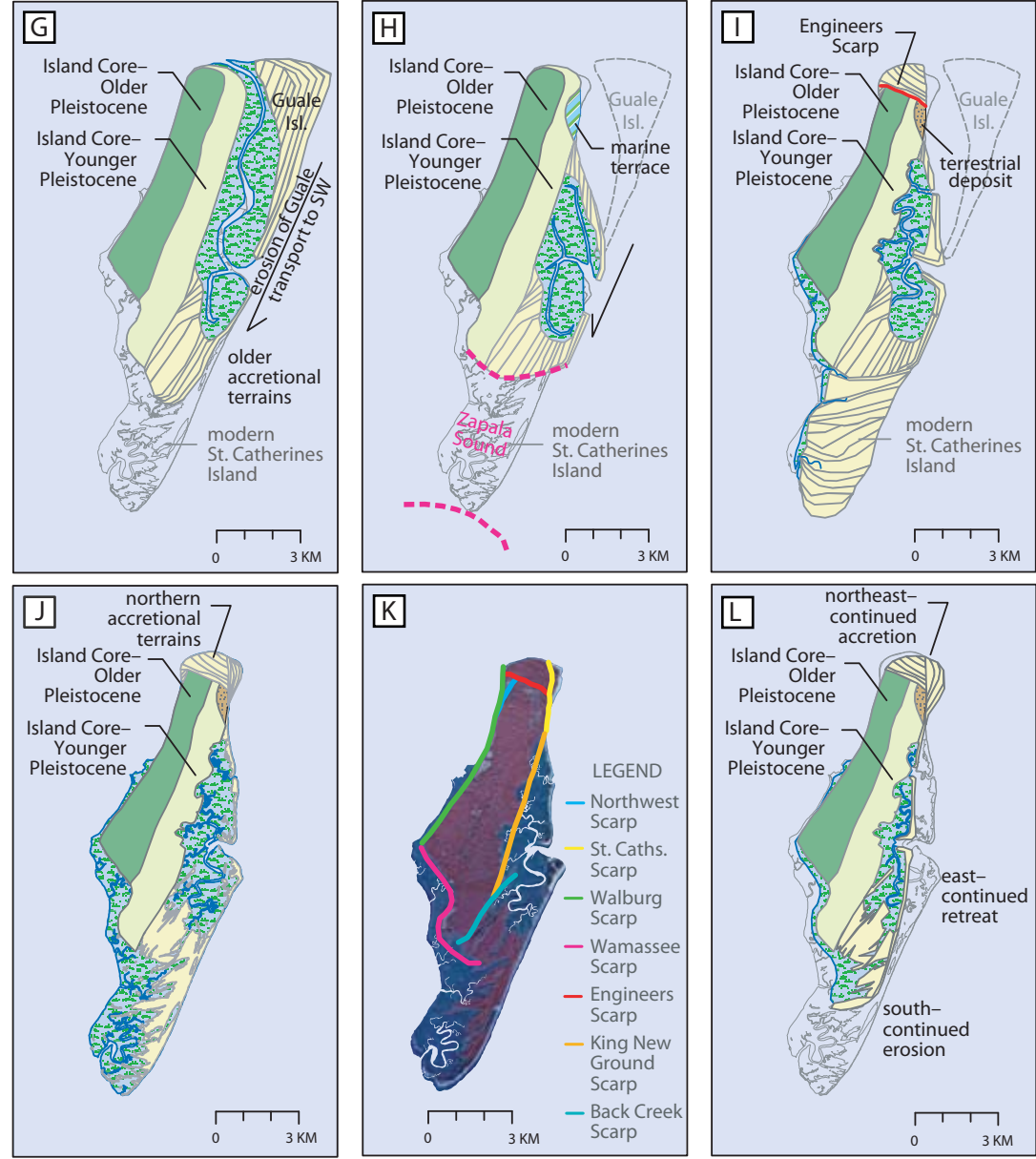


Fig. 3.3 (continued). **G**, Sea level rises, Guala Island erodes and sand is transferred southward forming the older accretional terrains; **H**, destruction of Guala with transfer of sand forms barriers protecting Seaside and McQueen marshes as North Beach is exposed to the ocean and erosion forms a marine terrace as Zapala Sound migrates north, truncating older accretional terrains and forming terrain #6 of fig. 3.5B; **I**, sand transfer south from Guala continues building southern accretional terrains, meandering tidal creeks erode emarginations into King New Ground Scarp, and blowing sand buries the terrace; **J**, present configuration of the island as Native Americans found it; **K**, present-day island with major scarps overlain, and **L**, future configuration of the island using current accretional/erosional areas.

massee Scarp, and the modern shoreline, which is undergoing erosion over most of its length.

3. The King New Ground Scarp, forming the north-south boundary between the Silver Bluff Core and the Holocene Seaside Marsh Meadow from Picnic Bluff at least to Cracker Tom Causeway has been partially obscured by ancient meander scars of tidal creeks where they impinged on the island core.

4. The newer Holocene part of the island consists of highly variable, textured sequences of sediment of varying type, often exhibiting dichotomous boundaries and orientations of beach ridge systems, which can be ordered in relative depositional sequence.

5. Relict marsh is currently exposed along all beaches, especially the south end of North Beach, nearly all of Middle Beach, and the north and south ends of South Beach (Morris and Rollins, 1977).

6. The Seaside Marsh muds exposed behind Black Hammock Spit on the south end of North Beach are at least 9.14 m (30 ft) thick in places.

7. Evidence of ancient tidal creeks is preserved as two oxbows at the north end of Picnic Bluff and as sand-filled meanders near the south end of North Beach.

8. The concentration of heavy mineral placers on the beaches is anomalously high (Jack Reynolds, personal commun.), indicating winnowing of a considerable amount of sediment from eroding shorelines.

9. Vibracores through the Holocene accretionary terrains penetrate multiple progradational sequences separated by erosional surfaces.

10. Vibracores in the sedimentary accretional terrains on Cracker Tom Causeway and on the west side of the island at St. Catherines Shell Ring penetrate deeply colored peats and marsh deposits near the Holocene-Pleistocene contact at approximately 5 m.

11.  $^{14}\text{C}$  dates, where possible, allow surfaces and lithosomes to be dated.

12. Archaeological data could indicate when a surface was available to human utilization, a minimum age of formation.

#### SEA TURTLES, SEA LEVELS, AND GEOLOGY

Observations that are anomalous or represent a misfit to our worldview form the basis of the search for new knowledge (Brannen and

Bishop, 1993; Darrell, Brannen, and Bishop, 1993; Bishop and Marsh, 1999a; Bishop et al., in press). In the normal operations of the St. Catherines Island Sea Turtle Program, opportunities have arisen to make numerous observations and deductions, and to participate in application of new technologies to investigate the formation of the island. Some observations were directly associated with the St. Catherines Island Sea Turtle Program and others were made as asides to this program. A review of the timing of these observations (Bishop: personal records, field notebooks) was made to attempt to define the flow of the observations, deductions, and applications ... and what each had to do with our evolving concept of St. Catherines Island.

During the initial phases of research on St. Catherines by Bishop (1986–1990) and during initialization of the St. Catherines Island Sea Turtle Program (1990–present), it became obvious that unknown circumstances were negatively affecting hatching success of in situ sea turtle eggs in nests along part of North Beach between Sand Pit Road entrance and Yellow Banks Bluff. It was postulated that ground water conditions were responsible for the poor hatching conditions, so four standpipes were jet-drilled into the accretional terrace from the backbeach toward the southwest into an ancient oxbow. Two oxbows were present at that time, one between Picnic Bluff and the major part of Yellow Banks Bluff and one to the north, just south of Sand Pit Road (into which the southwestern-most standpipe was inserted). During the drilling process, and as indicated in a vibracore taken by Bran Potter in his island ecology class (Bishop et al., chap 10: fig. 10.3), a peat and underlying marsh mud were encountered at a depth of about 2 m on the front side of the island. Another core, further south near the south end of Yellow Banks Bluff, replicated this anomalous condition in an area in which we expected to encounter mostly sandy sediment.

On August 26, 1996, colleague Nancy Marsh reported the presence of exposed ghost shrimp burrows eroding along the front of North Beach. Upon checking, the knobby, mud-lined burrows proved indeed to be the lower part of the burrows, a horizontal burrow maze that forms at 2–5 m below the midbeach level. This elevation of the lower part of burrows indicated that, at the time the burrows were active, sea level was higher than it is now by about 2–5 m or so. This deduction, along with continuing erosion of Yellow

Banks Bluff, led to a close examination of the bluff (often cited as the only exposed and eroding Pleistocene on the Georgia coast). On July 17, 2001, Bishop measured a detailed section at Yellow Banks Bluff and depicted small, unlined burrows throughout half of the section and a zone of truncated burrows in a horizontally laminated humate layer about 20 cm below an intensively burrowed surface 3.6 m below the top of the bluff (fig. 3.4). In this section, a possible ghost shrimp burrow was identified about 1.7 m below the modern surface and charcoal and a whelk shell were collected at 1.39 m below the top of the bluff. Bishop's field notes record attempts to resolve the anomalously high occurrence of a ghost shrimp burrow, at least two possible disconformities, and the presence of charcoal in the "Pleistocene" sediment of Yellow Banks Bluff. Later that summer, on September 29, 2001, a "short section" of the bluff was measured and joints were recognized, being marked by nearly "vertical burrow clumps cemented by humate along joints." One joint set was oriented parallel to the bearing of North Beach and inclined steeply toward the ocean, forming the surface along which the bluff scarp formed. Charcoal was seen and sampled 1.37 cm from the top of the bluff (but not dated).

During the 1990s, sea turtle skeletons were buried in the sand dunes behind North Beach to recover osteological specimens from dead and stranded vertebrates, especially sea turtles and birds. Burial in the backbeach sand allows the soft parts to decompose and the skeleton to be collected as a virtually clean specimen in about a year. Several skeletons were buried in the highest "clean" sand at the point where Sand Pit Road drops off the "Pleistocene" older part of the island. Excavation of a shallow burial trench about 1 m deep (in which a sea turtle would be buried) exposed interlaminated horizontal heavy mineral and quartz horizontal sand layers at this position. The horizontally laminated sand was recognized as a backbeach facies at an anomalously high elevation (Wharton, 1978; Howard and Frey, 1980; Howard and Scott, 1983; Frey and Howard, 1988; Bishop et al., 2007: figs. 11–12; Milliken, Anderson, and Rodriguez, 2008).

The acquisition of a vibracore rig by Rich and Bishop in 1989 (Bishop et al., 2007) initiated a program of vibracoring on St. Catherines Island, which was rapidly enlarged by Bud Rollins and his drill team on 8/17/90 (Rich Busch, Chris Ma-

ples, Ron West, Dave Linsley, and Blaine Cecil), and then by Bran Potter and Tim Keith-Lucas and the island ecology program (~1990). This led to the testing of stratigraphic hypotheses and the development of several transects to define boundaries constraining the island. On May 25, 1990, Bishop met with Bud Rollins and Dave Thomas and presented a hypothesized geological history of St. Catherines Island, the trigger for much subsequent work on its evolution.

Data from isolated vibracores provided intriguing evidence of the marine origin of the island's foundation. This evidence included the presence of lined burrows known as *Ophiomorpha nodosa*, the burrows of the Carolinian ghost shrimp, *Callichirus major* (Say, 1817–1818) (Bishop and Bishop, 1992; Bishop and Williams, 2005), interlaminated layers of heavy minerals and quartz sand indicative of the backbeach facies, and occasional shells of marine molluscs, comparisons with uplifted barrier islands (Howard and Scott, 1983; Pirkle et al., 2007) and palynological data (Booth and Rich, 1999).

In preparation for publication of *Native American Landscapes of St. Catherines Island* (Thomas, 2008), several collaborative chapters on island natural history and geology were written (chap 3: *Stratigraphy and Geologic Evolution of St. Catherines Island* [Linsley, Bishop, and Rollins, 2008] and chap 5: *A Brief Natural History of St. Catherines Island* [Reitz et al., 2008]). Linsley, Bishop, and Rollins (2008), describe several vibracore transects that were constructed along the margins of St. Catherines Island, including the Cracker Tom Transect drilled by Bishop, Rich, and Hayes and described as single sections in Booth, Rich, and Bishop (1999) and as transects in Bishop et al. (2007: fig. 36), and Linsley, Bishop, and Rollins (2008: fig. 3.3.9). In addition, two new transects across Yellow Banks Bluff (transect A–A') and the north end of Seaside Spit (transect B–B') were described in Linsley, Bishop, and Rollins (2008). Subsequently the St. Catherines Shell Ring transect near Long Field was drilled by Keith-Lucas, Potter, Bishop, and Thomas' AMNH archaeology crew (Bishop et al., 2007: fig. 3.6I; chap 10, this volume).

These collaborative publications sparked further collaborative research by the AMNH archaeology program and brought the vibracore technique into their archaeological repertoire on St. Catherines Island in 2005 as the island ecology program class drilled three vibracores in the

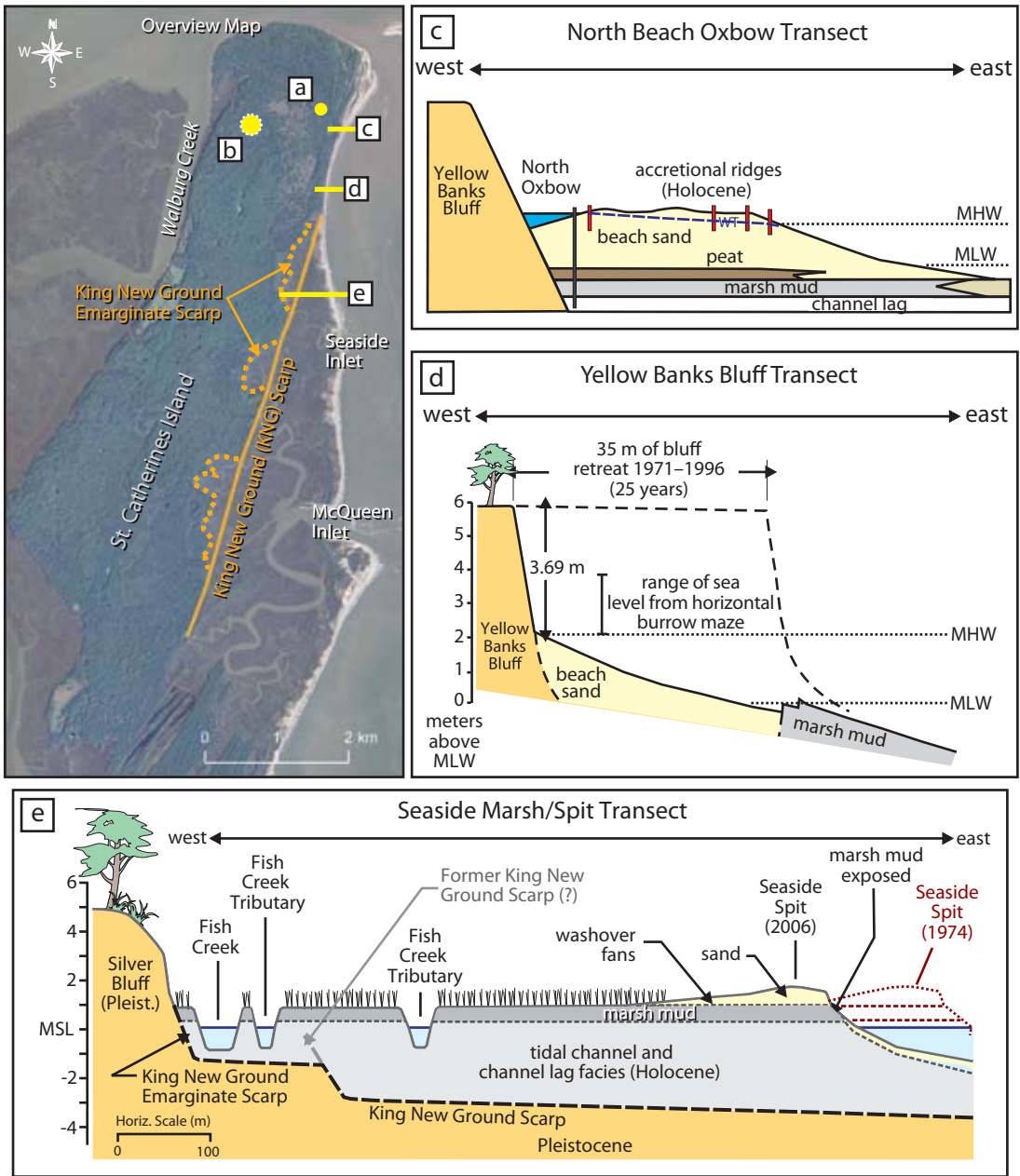


Fig. 3.4. Evidence of a mid-Holocene sea level highstand on the north end of St. Catherine's Island. Subsurface depth and sediment type adapted from Linsley, Bishop, and Rollins (2008), position of scarps from surface geology/aerial imagery, subsurface relationship of scarps suggested from surface geology, limited core data, and modern depositional environments.

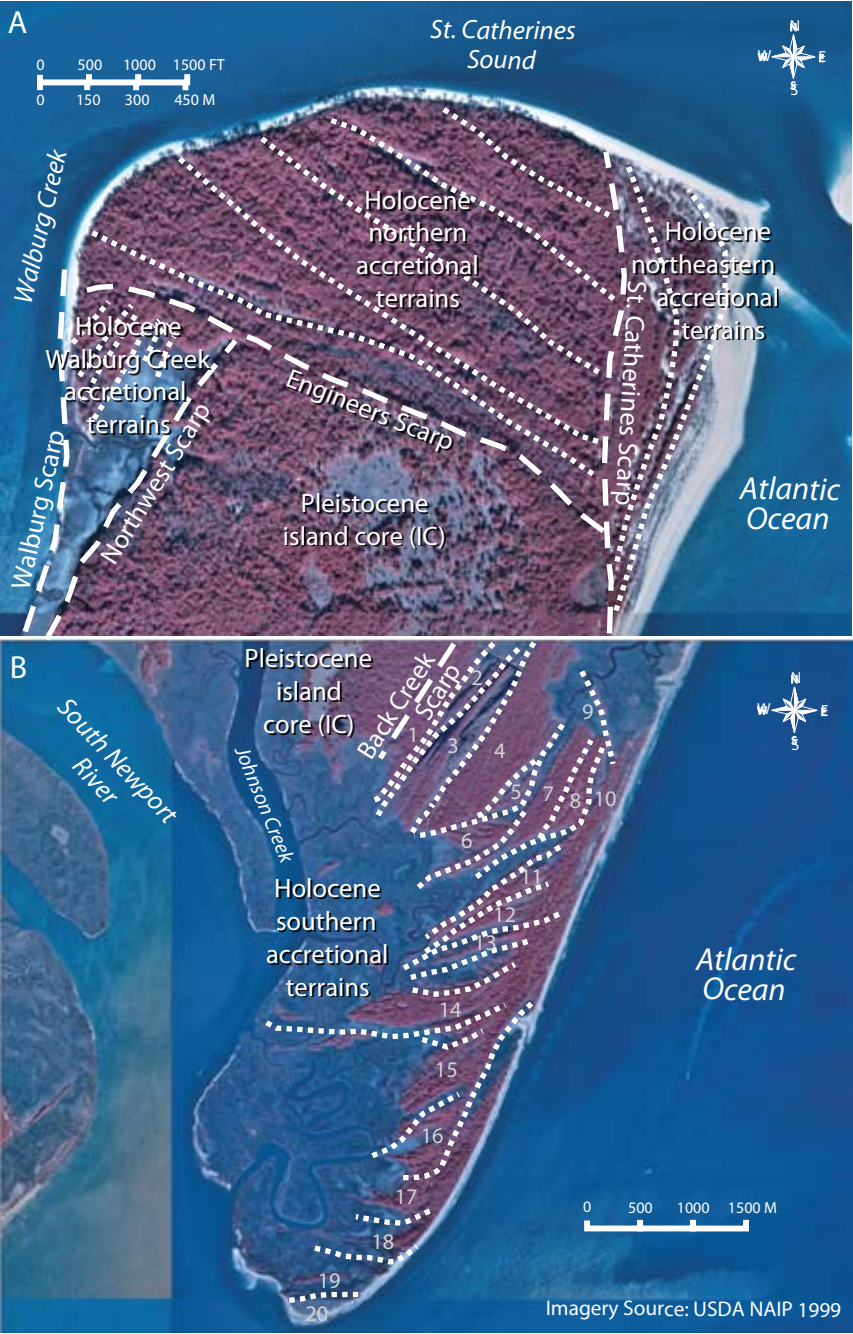


Fig. 3.5. Depositional components of St. Catherines Island include a Pleistocene Island Core (IC), erosional scarps, accretional terrains composed of progressively younger beach ridge systems, and modern dune fields: **A**, north end of St. Catherines Island showing the Pleistocene Island Core (IC), scarps, and Holocene accretional terrains deposited as St. Catherines Sound migrated back and forth; **B**, south end of St. Catherines showing progressively younger Holocene accretional terrains (1 is the oldest) toward east and southeast.

marsh north of the newly documented St. Catherines Shell Ring in Meeting House Field. Bishop and the AMNH archaeologists, led by Matt Sanger and Elliot Blair, extended this transect by drilling four new cores connecting the island ecology program with subsequent vibracoring within the shell ring to further define geophysical anomalies located by magnetic, resistivity, and ground penetrating radar (GPR) geophysics (Bishop et al., chap. 14).

In 2005, Kelly Vance began the geological profiling of St. Catherines Island using a new GSU ground penetrating radar unit. Profiles were done along existing roads and on the beach (see Vance et al., chap. 11). Several anomalies including the Gator Pond collapse site at the north end of the island, the Central Depression, and a disconformity near South End Settlement were identified by this reconnaissance work, and additional attention was focused on the "Pleistocene" bluff (which was beginning to be thought of as possibly a Pleistocene or Holocene dune fill of a Pleistocene erosional terrace). In 2006, Tony Martin and Andy Rindsberg visited St. Catherines Island to assess Neogene traces and especially the burrows present in Yellow Banks Bluff (Martin and Rindsberg, 2008; chap. 5, this volume), which they ascribed to fiddler crabs at the base and burrowing by beetles (perhaps cicadas) throughout the sediment above. The age of these dune sediments has now been dated by absolute methods (see also chap. 4).

The geological research on St. Catherines Island and its implications for sea level change in the western North Atlantic along the coast of Georgia resulted in the organization of a technical session at the Savannah meeting of the Southeastern Section of Geological Society of America (Bishop, Vance, and Meyer, 2007) and a SEGSA fieldtrip to St. Catherines Island (Bishop et al., 2007).

In 2008, Tim Chowns, who had just attended the SEGSA St. Catherines fieldtrip, published a paper hypothesizing the rapid movement of the Georgia sounds as they responded to rising and falling sea level (Chowns et al., 2008). He suggested a vibracoring program on St. Catherines Island and Blackbeard Island (chap. 9, this volume) to define what he envisioned as cutoff spits forming Blackbeard Island on the Sapelo/Blackbeard Island doublet and the hypothesized Guale Island on the St. Catherines/Guale Island doublet (Bishop et al., 2007: fig. 6).

## OBSERVATIONAL RESULTS

The sum of this collaborative research led us to question the timing and effects of the Pleistocene sea level rise at St. Catherines Island and attempt to define hypotheses to answer these questions. The geological record has left its imprint as the stratigraphy and geometry of the island (Demarest and Kraft, 1987). Specifically, past observations used in 2007 and 2008 now need to be integrated with new observational evidence on the evolution of St. Catherines Island, including: (1) a central depression apparently separating an older terrain from a younger, slightly higher, terrain, (2) horizontal backbeach laminations in State Road vibracore (chap. 10: fig. 10.5) 2.5 to 2.9 m in the center of the central core on State Road Pond, (3) horizontal backbeach laminations at an anomalously high elevation on Sand Pit Road as it leaves the central core, (4) the highly eroded backbeach scarp hosting large meander scars, (5) the two oxbows cut into St. Catherines Scarp north of, and within, Yellow Banks Bluff, (6) horizontal burrow mazes of ghost shrimp in front of and covered by Yellow Banks Bluff in the recent past, (7) the erosional terrace or washover fan (Martin and Rindsberg, chap. 5) at 1.5 m above high tide line at Yellow Banks Bluff burrowed by fiddler crabs, (8) covering of the erosional terrace by apparent terrestrial dune sediment burrowed by beetles and weathered into several paleosols (Vento et al., 2008; and chap. 4, this volume) with possible associated cultural features, (9) GPR data of Kelly Vance documenting a disconformity under South End Settlement and a collapse structure under the north end Gator Pond, (10) Pleistocene fern-peat beds flanking the eastern and western sides of the island, (11) the sequencing of the accretional terrains in the Holocene, (12) the development of two northwest trending dunes on top of the east-west terrains on the north end (Brian Meyer, personal commun., 2009), and (13) an erosional event subsequent to that of 1867 (chap. 8) on the north end forming a new accretional terrain now hosting the Sand Pit Road sea turtle rookery (chap. 14: fig. 14.9A and table 14.2).

The observations listed above, and those made by others, must be explained by scenarios of the development of St. Catherines Island, such as those by Booth et al. (1999), Bishop et al. (2007), and Rollins, Prezant, and Toll (2008). As visual

learners, and thinkers, Bishop and Meyer have attempted (several times) to construct a sequence of evolutionary stages for the development of St. Catherines Island (as in fig. 3.3).

Any island geological history must also be directly tied to the present geomorphology because the topography, bathymetry, scarps, palynology, and accretional terrains are the physical record of past island morphology and its contingency (Gould, 1989). However, the position of these features only constrains the portion of the island that is still preserved and visible; it cannot address the portions that formerly existed before the preserved features formed. This type of constrained reconstruction was done by Bishop et al., 2007, fig. 3.70, in which the island core was cut and pasted into an evolutionary diagram. Thomas, Rollins, and DePratter (2008), in their analysis of the shape of St. Catherines, presented the changing shape of the island on a background of the present island outline, a nice metaphoric device followed here (and also on previous hand-drawn analyses by us), but strongly enhanced, we think, by placing the developing island onto the geomorphological map of St. Catherines Island (fig. 3.3). The hypothesized formation of parts of the St. Catherines and Blackbeard islands by piracy of St. Catherines Sound and Sapelo Sound (Chowns and Stogner, 2008; Chowns et al., 2008) is developed elsewhere in this volume (chap. 9).

### CONSTRUCTING A SCENARIO OF ISLAND HISTORY

In setting any scenario, we must first determine what we know and integrate that with what we think we know, then formulate multiple working hypotheses to explain them (Chamberlin, 1890). We do know that sea level is not static, and, in fact, has fluctuated significantly throughout the last 1.8 million years with the waxing and waning of the ice sheets of the Pleistocene, causing sea level to fluctuate approximately 200 m (~600 ft) and currently coming to stand near its median height.

St. Catherines formed sometime prior to 44,000 yr B.P. as a barrier island of the Silver Bluff paleoshoreline from an older island or shoal (marked by horizontal backbeach laminations at -2.5 m under State Road Pond (chap. 10: fig. 10.5). Modern St. Catherines Island originated as a Silver Bluff barrier island as determined by its elevation and alignment with other barriers in the

Silver Bluff shoreline. Sea level then dropped, and this shoal developed into St. Catherines Island, which probably developed a fairly level surface by eolian transport of beach sediment. Sea level then rose slightly against this old island and eroded its front and back sides, forming a narrow strip-like older Pleistocene barrier island, then dropped slightly (?), and rose again approximately to its previous level, welding a younger Pleistocene island onto the older Pleistocene one. Rising sea level established a new offshore island on the northeast, Guale Island, forming the island doublet of St. Catherines–Guale Island similar in size and shape to the seaward islands of extant island doublets, such as Sapelo–Blackbeard (fig. 3.6). These islands effectively baffled the front of modern St. Catherines, allowing the formation and continued growth of an inter-island marsh that kept pace with rising sea level, eroding new scarps along the front of the island (King New Ground and Back Creek erosional scarps).

During the last glaciation, the Wisconsin, sea level dropped to at least 80 m (262 ft) below its current level, causing the seashore to withdraw far to the east (approximately 32 km east near Gray's Reef) and exposed the upper shelf to colonization by plants and animals and to erosion. St. Catherines Island (10,000 yr B.P.) would have been part of the mainland, a hill-like ridge probably lying between two valleys occupied by small streams, with Ancient Sapelo and Ancient Medway rivers (Riggs and Cleary, 1993) occupying the courses of modern Sapelo and St. Catherines sounds. Because of its relief, St. Catherines Ridge would have undergone erosion as the streams extended themselves headward, forming small tributary gullies cutting into the hill. Plants and animals would have been free to colonize St. Catherines Island at this time. Fern peat on either side of the island ( $47620 \pm 2500$  yr B.P., USGS WW1197 and  $>44,800$  yr B.P. Beta 217823) records the presence of conifer forests with a fern understory on St. Catherines Ridge, as the shoreline lay 50–80 km east. As the Wisconsin Ice Sheet reached its maximum extent, sea level was near its minimum, about 120 m below current sea level, then began its rapid rise about 10,500 yr B.P. By about 6020 yr B.P., the peat at Cracker Tom Marsh (Booth and Rich, 1999) was covered by saltwater with marine shells cast upon the disconformity, or in the sediment deposited immediately above them. Sea level must have continued to rise and started to erode Guale Island, passing its sediment as a

packet or bulge southward along the face of the Pleistocene core of St. Catherines Island, first allowing erosion of a marine terrace exposed at the base of Yellow Banks Bluff reaching its highest level of recent age (1.5 m above current high tide level), depositing laminated backbeach sediment at Sand Pit Road and eroding the Yellow Banks Bluff marine terrace marked by fiddler crab burrows near the base of Yellow Banks Bluff. Sea level then dropped, exposing the St. Catherines Ebb Delta to wind erosion, building a dune field along the leading edge of the island and filling the void left by the Yellow Banks Bluff marine terrace with dunes that were home to cicadas or other beetles. Human occupation occurred approximately 5000 yr B.P. (Thomas, 2008).

The north end of St. Catherines exhibits three

major erosional scarps, all apparently associated with migrations of St. Catherines Sound. The first (Northwest Scarp) eroded the northwest corner of the island followed by progradation of a narrow marsh and a few north-south trending beach ridges. The second erosional event (Engineers Scarp) was a significant southward migration of St. Catherines Sound, which eroded the northern tip of St. Catherines Island back to a significant degree and then was followed by northward progradation forming the bulk of the northern tip of modern St. Catherines Island. A third event, dated by historical data at 1867 (Picnic Bluff Scarp) eroded into the northeastern corner of the island and is currently rehealing itself by progradation to the east, forming the accretional terrain on the northeast shoulder of the island and the Sand Pit

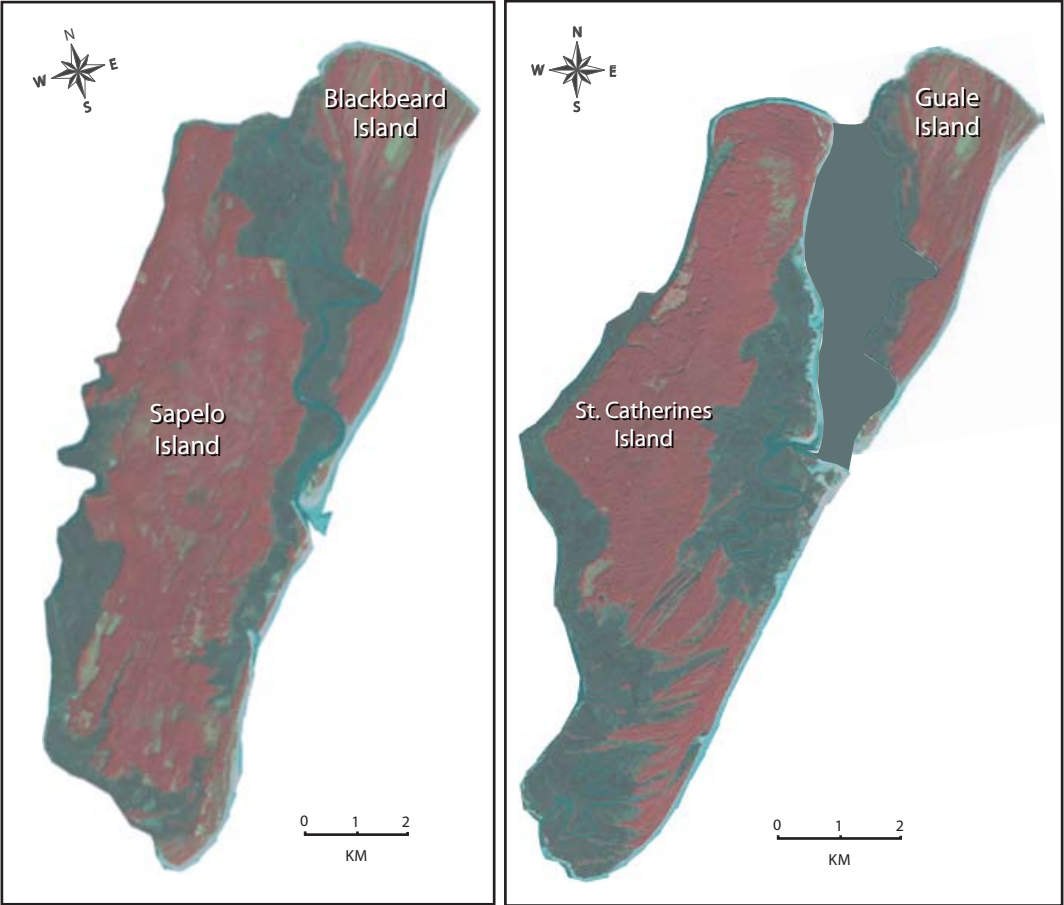


Fig. 3.6. The Sapelo/Blackbeard Island doublet as a modern analog to the hypothesized St. Catherines/ Guale Island doublet.

Road sea turtle nesting rookery (see chap. 8). The St. Catherines Scarp formed when the east face of the island was exposed once Guale Island was destroyed and the northern accretional terrains had been deposited and now form the arcuate trace of Yellow Banks Bluff.

Meandering tidal creeks in Seaside Marsh periodically cut meanders into the adjacent, high-standing island core forming King New Ground Scarp. A second, or later event, marked by the Back Creek Scarp occurred, cutting deeply into the southeastern part of the Silver Bluff core, which was immediately followed by lateral transport of sediment forming the oldest preserved sedimentary accretional terrain (terrain 1) comprised of beach ridges and a long northeasterly trending spit (Gardener's Hammock), which reaches far into the marsh north of Cracker Tom Causeway. St. Catherines Sound periodically meandered southward, eroded the east-west portion of St. Catherines Scarp, and laid down a series of east-west terrains as it migrated back toward the north. As the sediment from Guale Island continued to be transported southward, it accreted to the southeast of the island as a series of accretional terrains that were often marked by dune ridge systems forming parallel to the shorelines. An interval of progradational sedimentation with minor episodes of erosion followed, building the accretionary terrains (terrains 2–5) exposed on the inner part of Cracker Tom Causeway. As this transport was occurring, the sound south of St. Catherines migrated northward, its north margin eroding across the island, forming a sound margin called Zapala Shoreline. A major erosional event, marked by the Zapala Shoreline, then occurred as Sapelo Sound swept northward and completely truncated the south end of St. Catherines along a transverse erosional surface running completely across the island from South Settlement to the beach. The channel margin of Sapelo Sound then began migrating southward, leaving behind a series of transverse ridges and swales (preserved as terrains 6–22).

Meanders formed the two oxbows at Yellow Banks Bluff as sea level was dropping. A pervasive marsh existed on the ocean side of St. Catherines, with meandering tidal creeks (that still exist today) and ebb deltas like that at McQueen Inlet (Shadroui, 1990). Meander reentrants cutting across Back Creek Scarp into the Pleistocene core formed as sea level was dropping, and con-

tinued forming today. Drowned beach ridges north of Cracker Tom Causeway must have formed on the rising sea level and are partly drowned by inundation. Another major erosional event, marked by the Cracker Tom Scarp, occurred cutting an arcuate reentrant into the middle part of the island and forming an oblique edge on Cracker Tom Hammock as well as depositing a prominent beach ridge extending from the outer edge of a feature we call hickory hill hammock northwestward into the marsh. Subsequent to this erosional event, the reentrant was rehealed by progradation of the island to the east, eventually straightening its front edge along South Beach. The south end of the island has progressively prograded southward with only minor erosional fluctuations, including the one in which we find ourselves today (Griffin and Henry, 1984).

The presence and chronology of human occupation will indicate the age status of the accretionary ridges at the time of immigration (DePratter and Howard, 1981; Mason, 1993; Thomas, 2008). Sediment from the now eroded Guale Island and St. Catherines Ebb Delta continued to be transported southward, accreting as a series of hooklike terrains to the southeast of the island, forming a series of accretional terrains south and east of Zapala Shoreline. Discrete boundaries and "stranded" marshes attest to fluctuating sedimentological conditions as either sea level fluctuated, sediment supply fluctuated, or storms modified the beaches (Langley et al., 2003). Two longitudinal dune ridges arose northwestward from St. Catherines Bluff covering the east-west terrains of the north end of St. Catherines Island (see chap. 8). Attachment of fringing marshes to the west side of St. Catherines Island has since occurred, although its timing is yet unknown.

The position and shape of St. Catherines Island seems remarkably stable through time, although its size apparently changes. The surface of St. Catherines Island core is remarkably level and represents a packet of sediment that overlies and buries the cultural features across the island. The depth of burial of cultural features gives an approximate measure of the rate of sedimentation across the island. The relative flatness of the island surface indicates that alluviation is by processes that result in relatively even distribution of sediment or redistribution of the sediment by subsequent processes that level it. Along the beaches, we have observed windblown sand being eroded from North Beach and/or Yellow Banks Bluff

being transported on northeastern winds up the face of Yellow Banks Bluff, accumulating on top behind the lip of the bluff. Hayes (1967) studied the hurricane effects of Hurricane Carla on the Texas coast, attributing the most profound effects to wind waves and storm surges. Morton, Gelfenbaum, and Jaffe (2007) summarized the effects of Hurricane Camille on the Alabama barrier islands in 1969. In addition to dune and scarp erosion commonly attributed as hurricane effects, they documented the transfer of that eroded sand across the barrier islands as a series of washover fans, terraces, and sheetwash, often washing and leveling the sand 200–300 m behind the eroded scarps and dunes. Scott et al. (2003) present evidence for prehistoric hurricanes on the South Carolina coast. This catastrophic process over time becomes a powerful transporting and leveling process. Of course, once the sand is blown or washed on top of an island, it can be redistributed by plant roots, animals, rain sheetwash, and human activities ... bringing us into the realm of archaeology.

### CONCLUSIONS

The conclusions supported by the data cited herein include:

1. St. Catherines Island remains a dominantly erosional barrier island, if not the most erosional island of the Georgia Golden Isles, truly a sentinel island for the Georgia coast.

2. Erosion is now occurring on virtually all margins of the island. Erosion rates average ~2.0 m/yr with most rapid erosion at Middle Beach and Seaside Spit and at the south end of the island (chap. 14: fig. 14.13).

3. Coastal erosion can be adequately characterized and indexed by observational criteria, including scarping, boneyards, washover and washin fans, exposed relict marsh mud on the beach, and root zones and peat beds exposed on the beach.

4. Ancient scarps, depositional terrains, and dichotomous boundaries can be related to past episodes of coastal erosion and accretion.

5. The evolution of St. Catherines Island is decipherable, but the accepted scenario will continue to evolve as new observations are made and more data becomes available.

6. The erosional conditions documented at St. Catherines will migrate northward and southward on the Georgia coast as sea level continues to rise, sediment continues to be impounded, and anthropogenic modification of the coast continues.



## CHAPTER 4

# DEVELOPMENT OF A LATE PLEISTOCENE- HOLOCENE GENETIC STRATIGRAPHIC FRAMEWORK FOR ST. CATHERINES ISLAND: ARCHAEOLOGICAL IMPLICATIONS

FRANK J. VENTO AND PATTY A. STAHLMAN

Stratigraphers are becoming increasingly aware that relatively minor physical and biological events have played major, although often cryptic, roles in the accumulation of strata. Stratigraphic analyses have too often avoided the stratum-by-stratum (i.e., stratinomic) examination of sequences in favor of “broad brush” recognition of lithostratigraphic units (formations, members, alluvial facies, colluvial facies, etc.) (Busch and Brezinski, 1989).

### GENETIC STRATIGRAPHY: INTRODUCTION

Although most stratigraphers would support a stratinomic approach, in practice they either group stratigraphic intervals of a single rock type (e.g., sandstones) into facies units, or group multiple types of strata (i.e., polytypic facies units) into presumed, but not always documented, single events (Busch and Brezinski, 1989). For example, researchers may regard a sequence of barrier island depositional units as marine island facies (monotypic facies units), ignoring the presence of polytypic facies (dune, beach, tidal mud flats, tidal channel, paleosols, etc.). Such overgeneralization ignores much event formation (e.g., basic genetic units such as storm events or soil horizons) and is particularly apparent in alluvial sequences, and now barrier island sequences, where the preserved stratigraphic record may account for only 5% of the included time interval (Bown and Kraus, 1987).

#### ALLOGENIC AND AUTOGENIC GENETIC UNITS

Genetic units can be categorized relative to their lateral extents. Walker (1990); Busch and Rollins (1984); Goodwin et al. (1986); Busch

and West (1987); and Busch and Brezinski (1989) recognized allogenic genetic units and autogenic genetic units. Allogenic genetic units can be correlated widely, presumably reflecting the depositional signature of an event that affected a wide geographic area (allogenic event). Paleosols, specifically buried A horizons, which document episodes of barrier island stability, can be considered allogenic units. Autogenic genetic units, on the other hand, are locally developed, the result of a circumscribed event that is constrained geographically and/or environmentally (autogenic event). A sand horizon deposited as a result of a large storm event over several days is a classic autogenic unit, which is time parallel. Although these events are temporally constrained, their geographical reach or recognition within a soil profile is quite limited. Genetic units, when identified (e.g., in exposures, cores, etc.), are of unknown lateral extent prior to correlation. The scale of allogenicity and autogenicity is relative and is dependent upon the scale of observation and lateral extent. Allogenic events, for example, may be global or confined to a single depositional basin, coastal segment, or drainage system. Autogenic events may be correspondingly scaled from local tectonism down to delta switching, washover fan, storm scour, or channel avulsion. In order to determine the geographical extent of a genetic unit one must assume initially that it is extensively correlatable.

Genetic surfaces are, in addition, commonly associated with: (1) heterochronous deposition (exhumation and redeposition to form condensed, time-averaged intervals); (2) erosion or ravinement; or (3) little or no deposition (firm-

grounds, hardgrounds, palimpsest surfaces, and paleosols). Genetic surfaces may change laterally: hardground may be represented laterally by an erosional disconformity; a distal paleosol with a well-developed A horizon may change laterally to a proximal immature paleosol with only a B horizon or C horizon preserved, or to an erosional disconformity.

#### GOAL OF GENETIC STRATIGRAPHY

The primary goal of genetic stratigraphy, whether applied to marine or terrestrial strata, is the development of a high-resolution pedostratigraphic or chronostratigraphic framework, which will facilitate predictive stratigraphy. The recognition of allogenic genetic surfaces that “punctuate” small-scale allogenic genetic units permits refined chronostratigraphy at archaeological sites (Vento et al., 2008). The basic genetic units can often be combined into a hierarchical framework of allogenic genetic units, leading to an integrative type of stratigraphic analysis (Busch and Rollins, 1984; Vento et al., 1994).

#### APPLICATION OF GENETIC STRATIGRAPHY TO PEDOGENIC SEQUENCES

Genetic stratigraphy, as applied to marine sequences, has been adapted to alluvial sequences containing paleosols (Vento et al., 2008). Alluvial sequences are now viewed as representing long intervals of stasis (indicated by buried soils), punctuated by brief episodes of deposition or erosion (Bown and Kraus, 1987). Alluvial paleosols provide only a small fraction of the physical sediment package, but represent up to 95% of the involved time interval of accumulation of an alluvial sequence (Retallack, 1984; Bown and Kraus, 1987; Kraus and Bown, 1993). As such, paleosols are ideal genetic units for establishing a chronostratigraphic framework. Because they reflect extensive temporal stability, paleosols, in general, are allogenic genetic units traceable over considerable distances. The degree of temporal stability, or time interval represented by paleosols, varies widely. A horizons may form on alluvial, colluvial, or coastal deposits in humid regions in only a few hundred years (e.g., Scully and Arnold, 1981). On the other hand, paleosol formation may take tens of thousands of years in more arid regions (Bown and Kraus, 1987, and references therein).

The bulk of the physical stratigraphic record on St. Catherine's Island is, in a sense, a record of

the punctuational events—the brief and episodic deposition of an eolian sand sheet, washover fan, beach-dune ridge migration, tidal channel avulsion, etc. Thus, most of the late Pleistocene core deposits are predominantly autogenic genetic units, untraceable over extensive geographical areas. Alluvial sequences, as well as barrier island sequences, commonly vary greatly in thickness and contained facies over short lateral distances, making lithofacies correlation virtually impossible. However, such pronounced facies development is likely to be constrained within very distinct genetic surfaces connected with the identified paleosols. Paleosols can be used like the transgressive surfaces and climate-change surfaces in marine genetic stratigraphy. Walther's law will only operate within the boundaries of the allogenic genetic surfaces of the paleosols.

The lateral changes in the distinguishing characteristics of marine allogenic genetic surfaces also have an analog in alluvial sequences. In the stratigraphic record of marine basins, proximal (marginal) hardgrounds may grade distally basinward into cryptic time-averaged shell lags. Similarly, Bown and Kraus (1987) and Kraus (1987) described morphological variation in laterally developed paleosols (“pedofacies”) in early Eocene overbank deposits in the northern Big Horn Basin. Pedogenic sequences near channel margins (proximal) developed only incipient (stage 1) paleosols, whereas those in floodplain areas (distal) tended to exhibit relatively more mature (stage 2 or stage 3) paleosols. The more mature distal paleosols will usually be more easily traced over wide areas, but the more cryptic immature (proximal) paleosols will provide greater details of autogenic overprinting (episodic channel migration, avulsion, etc.). In practice, both the more mature distal and cryptic/immature proximal paleosols represent “marker” horizons or “events” that permit the floating of adjacent stratigraphic sections into a meaningful integrated chronostratigraphic framework. Judicious application of the criteria presented by Retallack and McDowell (1988) for the field recognition of paleosols should greatly enhance the genetic use of paleosols in Holocene depositional sequences, whether they are alluvial or coastal in origin.

Any carefully constructed chronostratigraphic framework using paleosols should investigate the merits of a hierarchical approach. Temporally extensive alluvial sequences are likely to record more than a single level of allogenic genetic units.

Kraus (1987) subdivided the early Eocene Willwood alluvial deposits into third-order sequences (small paleosol sequences, 3–7 m thick), second-order sequences (tens of meters thick and harboring a number of vertically stacked, third-order cycles), and first-order sequences (hundreds of meters thick, containing several second-order sequences). The larger genetic units (first-order) probably reflect such events as basinwide climatic and/or tectonic change. Smaller genetic units (third-order and second-order) most likely are controlled by such factors as channel migration, avulsion, overbanking, etc. (Kraus, 1987). Cycles of relative sea level change along the southeast coast of the United States might, for example, provide a control on the development of paleosol sequences via episodic deposition and stability.

#### METHODOLOGY AND PRACTICE OF GENETIC STRATIGRAPHY

The following discussion details how the methodological application of genetic stratigraphy can be applied to barrier island sedimentary units and, finally, as a predictive tool in archaeology. This methodology, including constraints and suggestions, is as follows:

(1) **STRATIGRAPHIC SECTIONS:** Stratinomic (stratum-by-stratum) description and measurement of individual pedostratigraphic sequences is essential. Particular attention must be paid to the identification of all types of soil horizons.

(2) **PALEOSOLS AS ALLOGENIC UNITS:** Buried soil horizons serve as the basic units in application of genetic stratigraphy to barrier island stratigraphy. Of particular value are the buried cumulic A horizons, such as those now exposed on St. Catherines Island along Yellow Banks Bluff, which reflect conditions of temporal stability in humid regions. A horizons are frequently traceable over wide areas of a single drainage basin, and even among drainage basins. As such, they can be ideal allogenic units, analogous to the use of seismically determined unconformities in the establishment of Atlantic and Gulf coastal plain chronostratigraphy (Poag and Schlee, 1984; Galloway, 1989). As is often the case with marine unconformities, alluvial soil horizons may encompass the bulk of time represented by a stratigraphic sequence (see Kraus, 1987). In this regard, genetic stratigraphy of alluvial sequences departs from the use of transgressive surfaces in high-resolution genetic stratigraphy of marine

glacial-eustatic cycles (Busch and Rollins, 1984; Rollins, West, and Busch, 1989). In the latter situation, the genetic surfaces (e.g., transgressive surfaces) are more geologically “instantaneous” and are allogenic only because of the physical “forcing” of sea level change. Thus, in genetic stratigraphy of nearshore and alluvial sequences, the paleosol proper, not the enclosed alluvial deposits or the eolian sands, should be viewed as the basic genetic unit! Even buried soil horizons, however, may reflect very different durations of accumulation (different degrees of temporal stability) ranging from hundreds of years in humid regions (Scully and Arnold, 1981) to tens of thousands of years under more arid conditions (Bown and Kraus 1987). Paleosols like those on St. Catherines Island can occur as exhumed surfaces associated with erosional unconformities; as now deeply buried horizons mantled in some places by more than 4 m (13.5 ft) of late Wisconsin and Holocene eolian sands; and finally as relict surfaces that may document formation under a different set of climatic conditions.

(3) **INITIAL ASSUMPTION OF ALLOGENICITY:** Genetic stratigraphy depends upon the initial assumption of allogenicity. Operationally, one must “expect” to detect and trace buried A horizons among all sections. In practice, of course, individual sections may not contain specific A horizons. This reflects autogenic (local) influence, which, in the case of barrier island sequences, may be a result of such situations as:

- (a) bluff erosion due to rising sea levels;
- (b) eolian deflation of relict and once buried paleosols;
- (c) scouring by washover fans or tidal channel migration.

(4) **A HORIZONS VS. B/C HORIZONS ON BARRIER ISLANDS:** Stacked A and B or cumulic A horizons underlain by eolian or nearshore marine C horizons provide archaeologists with different interpretational opportunities. For example, the frequently thick eolian sands that both underlie and overlie now identifiable buried A horizons exposed along Yellow Banks Bluff provide surfaces that were not sufficiently stable for human occupation, either as a result of slow, continuous vertical accretion of an eolian sand sheet, or by more rapid deposition of eolian sands by large cyclonic storm events. A horizons, on the other hand, represent greater landform stability and were available for human occupation for decades or centuries and, therefore, are more likely to

contain evidence of multiple occupations.

(5) **FLOATING SECTIONS AND USE OF MARKER HORIZONS:** Stratigraphic sections are compared by tracing and matching of genetic units. In nearshore marine and alluvial sequences this involves correlating stacked A horizons whenever possible. Relative stratigraphic thicknesses play little or no role in the process of "floating" stratigraphic sections. However, "marker horizons," in the broadest sense, play an essential role in the formation of the pedostratigraphic or chronostratigraphic framework. Marker horizons can be faunally or florally defined (e.g., distinct pollen assemblages like the boreal pine/oak suite), culturally defined (e.g., fiber-tempered ceramics), or zones that have been radiocarbon dated. Such marker horizons permit first-order adjustment in the floating of the genetic units. The array of genetic units (e.g., soil horizons) between marker horizons (allogenic units) permits higher resolution chronostratigraphic adjustment of the matched sections.

(6) **HIERARCHICAL PACKAGING AND THE QUESTION OF SCALE:** The genetic stratigraphy of some marine sequences has involved the recognition that individual allogenic units can be packaged into a nested hierarchy (Busch and Rollins, 1984). The different hierarchical levels have their own "emergent properties" and, as such, are more than just a sum of the individual genetic units. Different controls function at the various levels of the hierarchy, and, to some extent, each level in the hierarchy can be studied and understood independently of the other levels. This is the *modus operandi* of hierarchical modeling and its primary departure from a purely reductionist approach. In genetic stratigraphy, the maturity and extent of small-scale pedogenic units (e.g., individual A horizons or B/C horizons) can be influenced by a variety of downward causalities, including broad fluctuations in zonal and meridional atmospheric circulation (Knox, 1983; Larsen and Schuldenrein, 1990) changes in sea level related to climate change or tectonism to climatic phases (e.g., pre-boreal and boreal), to (at a finer scale) relative length of temporal stability of the soil surface. An integrated genetic stratigraphic framework should be robust enough to include all interaction, upward and downward. Such framework has been developed for late Pleistocene and Holocene alluvial stratigraphy in the mid-Atlantic region; however no such stratigraphic framework has been attempted for the southeastern United States.

## PREDICTIVE ASPECTS OF INTEGRATIVE GENETIC STRATIGRAPHY

If a genetic chronostratigraphic framework of barrier island deposits with spatially disparate sections is "floated" according to buried soil horizons, aided by integration of other types of marker horizons (e.g., radiocarbon dates, cultural horizons), that framework can then be used predictively. First, the genetic framework permits the determination of motifs and rates of alluvial deposition in "slices of time," the immediate result of correlating the different sections by intervals of temporal stability (i.e., the buried A horizons). A spatial array of stratigraphic intervals, bounded by the same (correlated) A horizons, provides a lateral facies mosaic that encodes information regarding changes in environments of deposition, as well as differences in rates of aggradation and degradation. Intervals bounded by soil horizons might be used to establish sequential paleogeographic reconstructions (if a regional scale is involved), which display details of evolving landscapes. Or, isopleth maps might be used to convey information of temporally restricted lateral changes in magnitude or abundance or selected features (e.g., isopach map, showing thickness differences in alluvial sediments from floodplain to levee; isopleth map contouring changes in spatial abundance of organic carbon content, etc.).

Secondly, the incorporation of cultural attributes into the genetic framework might lead to predictive reconstruction of patterns of human dispersal, interaction, and/or trade. Of particular note is the capability of this integrative framework to utilize "negative" cultural information. The absence of artifacts in a stratigraphic interval, for example, has special significance in the integrated framework because it permits consideration of such questions as landform age and stability, changes in subsistence, and shifting environments (e.g., tidal marsh to washover), etc.

## PRELIMINARY RESULTS FROM ST. CATHERINES ISLAND

Over the last year, geologists from Clarion University of Pennsylvania, in association with David Hurst Thomas of the American Museum of Natural History, have begun detailed soil stratigraphic mapping of the Yellow Banks Bluff area of St. Catherines Island, Georgia. This preliminary study serves to complement an existing

extensive volume of previous geological studies completed on St. Catherines Island over the last 25 years (Thomas, 1980; 1988a; Linsley, 1993; Goodfriend and Rollins, 1998; Bishop et al., 2007a; Linsley, Bishop, and Rollins, 2008).

St. Catherines Island is one of a series of barrier islands that extends along the coast of Georgia for 175 km between the mouth of the St. Marys River to the south and the mouth of the Savannah River to the north. St. Catherines Island proper is situated at the head of the Georgia Bight, located between two major through-flowing rivers, the Savannah River to the north and the Altamaha River to the south. The northern end of St. Catherines Island is bound to the north by St. Catherines Sound, which has formed an extensive ebb delta tidal flat and to the south by Sapelo Sound. The island consists of 14,460 acres (5.929 ha), and is approximately 20 km long and 4 km to 2 km wide.

Geomorphologically, four gross landforms occur on the island and include: (1) a high standing late Pleistocene core which lies 4 m to >6 m above sea level; (2) an accretionary terrain on the north end of the island formed principally by the northern migration of St. Catherines Sound; (3) a

series of arcuate beach-dune ridges of recent to late middle Holocene age on the southern margin of the island; and (4) marsh and broad tidal channels with dispersed hammocks to the west (chap. 3: figs. 3.1, 3.2, and 3.5).

Within 30 m (100 ft) of present sea level, six distinct marine terraces can be recognized. These include the Wicomico (30 m), Penholoway (23 m), Talbot (12–14 m), Pamlico (7.5 m), Princess Anne (4.5 m), and Silver Bluff (1–3m) (table 4.1; chap. 3, fig. 3.1). The Silver Bluff terrace forms the Pleistocene core of the island. This island core is bound to the north and south by late Holocene to recent accretionary terrain formed by the stabilization of a series of generally arcuate beach-dune ridges. The soils developed on these low-lying (less than 3 m) accretionary terrains can best be classified as Entisols with organic rich A horizons overlying minimally weathered eolian and washover fan sands. On the southern end of the island, these Holocene beach-dune ridge deposits document primary long shore drift to the south with the beach-dune ridges becoming progressively younger in a south-southeast direction (chap 3: fig. 3.5B). Preliminary soil studies appear to show better soil development

TABLE 4.1  
Relict Shoreline of the Georgia Coastal Plain

Shoreline or terrace name	Elev. (MSL)	Estimated age
Hazlehurst (Brandywine)	82 m	early Pleistocene?
Pearson (Coharie)	66 m	early Pleistocene?
Argyle, Waycross, Okefenokee (Sunderland)	52 m	early Pleistocene?
Wicomico	30 m	1.5 Ma (“Aftonian”)
Penholoway	23 m	1 Ma (“Yarmouthian”)
Talbot	13 m	OIS 11, 15?
Pamlico	7.5 m	100–500 ka
“Sangamon”	5–7 m	80–115 ka, OIS 5e,7,9
Princess Anne	4.5 m	40–80 ka, OIS 3,5
Silver Bluff	1–3 m	26–55 ka
Holocene accretionary terrains	< 2 m	4 ka–present

(oxidation and humate increases in the underlying C horizons) as one proceeds from the younger beach-dune ridge on the east to older, late-middle Holocene age beach-dune ridges to the west, and abutting the island core. To the north, a prominent scarp marks the boundary between the Pleistocene core and the lower lying Holocene age accretionary deposits. Deposition of these Holocene age accretionary deposits on the northern end of the island is from beach-dune ridge migration in response to sound migration and formation of extensive tidal mud flats. Figures 3.2 and 3.5A (chap. 3) show the locations of Yellow Banks Bluff, the northern accretionary terrain, and the Pleistocene core.

The Pleistocene core, which is of late Pleistocene age, is attributed to the Silver Bluff age shoreline. As noted by Bishop et al. (2007), the internal structure of the island core is still unclear and questions remain whether the core consists of one depositional unit or more than one unit; however, geomorphic features like the Central Depression argue for several episodes of island core construction.

Yellow Banks Bluff, the principal focus of

this study, extends along the northeastern shoreline for a distance of 0.8 km (0.5 mi), from Seaside Inlet on the south to the southeastern edge of the St. Catherine's Island Scarp on the north. Along its entire length the bluff attains a nominal height of 5 m (16.5 ft) above the spring high tide line. Over the last 30 years, the bluff has retreated eastward at a rate of more than 1.5 m (5 ft) per year (Bishop et al., 2007; chaps. 3 and 7, this volume). This landward retreat is evidenced by the numerous downed trees that litter the beach (fig. 4.1) and relict marsh muds.

The preliminary geomorphology studies at Yellow Banks Bluff entailed detailed mapping of more than 16 distinct segments along the eroded section of the Pleistocene core. In addition to performing on-site mapping, we collected soil/sediment samples from select profiles for granulometric, geochemical, thin section, and  $^{14}\text{C}$  analysis.

As a result of the field mapping, as many as five distinct soil generations (e.g. A-B; A-C horizons) have been identified along sections of the bluff. These distinct pedostratigraphic units have formed during episodes of subaerial weathering of late Pleistocene through Holocene age



Fig. 4.1. General view of Yellow Banks Bluff (facing southwest). Note the large numbers of trees eroded from the island core on the shoreface. The bluff is retreating at a rate of  $>1.5$  m per year. Photograph taken by Patty Stahlman, April 30, 2008.

eolian sands, which disconformably mantle the marine sands of the Silver Bluff marine terrace (fig. 4.2). In places along the base of the bluff, mid-Wisconsin age Silver Bluff marine sands are variously exposed and consist of quartz sands that contain a high percentage of heavy minerals. This is in sharp contrast to the overlying, extremely well sorted, eolian sands that contain a mineral suite depauperate in heavy minerals. The age of the marine sands at the base of the bluff, which comprise the late Pleistocene core of the island, has been debated extensively. Vibracoring of the Pleistocene core has identified marine horizons at depth that date to as early as 44,000 B.P. (Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008), and possibly to as recent as 26,000 B.P. (Linsley, 1993). The mid-Wisconsin age (isotope age 3) for this marine submergence is supported by complementary dates on other segments of the southeastern coast (Hails and Hoyt, 1969; Hoyt and Hails, 1974; Sussman and Herron, 1979; Moslow, 1980; Finkelstein and Kearney, 1988). Arguments raised against these radiocarbon dates are that they represent older, reworked, and transported marine shells, or that the ages have been

compromised by an episode of mid-Wisconsin solar radiation bursts that skewed the radiocarbon ages (Dockal, 1995). One possible mechanism for the occurrence of a mid-Wisconsinan submergence that does not include eustatic sea level fluctuations related to glacial ice ablation is submergence due to localized tectonism along the Georgia Bight. As noted by Thieme (2005), some problems with correlating subsurface deposits on the basis of surface elevation in the Atlantic coastal plain may be due to tectonic tilting or warping of the earth’s crust (Winker and Howard, 1977; Zullo and Harris, 1979; Markewich, 1985). The effects of tectonic activity have long been recognized on the Cretaceous and Tertiary rock landward of the Hazlehurst (Brandywine) shoreline in the “middle” or “upper” coastal plain (Thieme, 2005). While there are few direct indications of tensional or compressional stress or catastrophic failure in the sediments themselves, the terrace remnants are offset in some locations, or stand at slightly higher elevations in adjacent states compared to those in Georgia (Thieme, 2005). One of the best indications for late Pleistocene tectonism in Georgia is the discontinuity

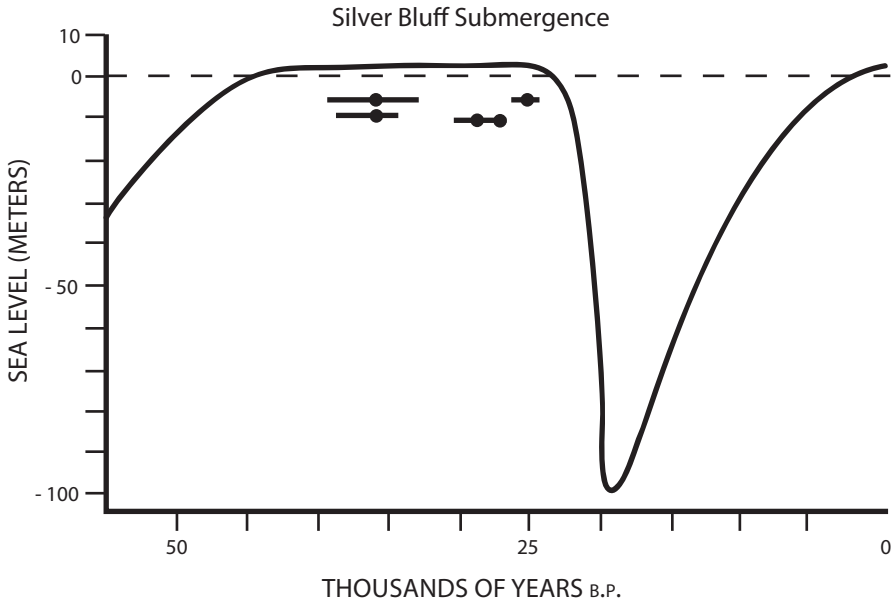


Fig. 4.2. Georgia sea level curve adapted from Hoyt (1968) showing Silver Bluff submergence; only the most recent part of the Pleistocene record is represented. Control points are from  $^{14}\text{C}$  dates of shells from Sapelo Island. Length of horizontal line represents age uncertainty.

that offsets the positions of the Talbot and Penholloway shorelines along the present course of the Altamaha River (Georgia Geological Survey, 1976; Winker and Howard, 1977; Thieme, 2005). Approximately 10 m of the relief here are probably tectonic rather than eustatic, and the magnitude of the uplift appears to increase both toward the northeast in South Carolina, and toward the south in Florida. Geological skeptics for Quaternary tectonism argue that the Atlantic coast is a passive margin with little recorded seismic activity (Thieme, 2005). However, a major earthquake did occur in 1886, having its epicenter at Charleston, S.C. (Weems and Obermeier, 1989). The consensus, nevertheless, is adamantly opposed to any sea level higher than that following the OIS 5e ("Sangamon") interglacial (Bloom, 1983; Coleman et al., 1989) whether from climate change or tectonics (Thieme, 2005).

The basal marine sands of Silver Bluff age (26–60 ka) that are generally exposed along the base of Yellow Banks Bluff are consistently overlain by either a thin, white eolian sand that, in turn, is capped by a strongly developed paleosol (designated 4A or 5A), or directly by one of the other lower paleosols (see alternative interpretation in chap. 5). The now buried A horizon contains abundant organics and redoximorphic iron oxides. A recent  $^{14}\text{C}$  assay has dated this basal paleosol to  $22,820 \pm 130$  B.P. (Beta-244622). This date corresponds with a previously dated shell lag horizon collected from a vibracore along North Beach (transect A-A',  $22,600 \pm 310$  B.P., Pitt-381; Linsley, 1993; Linsley, Bishop, and Rollins, 2008).

The lower paleosols (designated 4A and 5A) that can be traced along most of the exposed bluff were originally interpreted as marine firmground or hardground. This assignation is unlikely given the fact that this unit lacks any marine fauna, is extensively bioturbated, lacks laminations, exhibits a general absence of the heavy minerals that occur in abundance in the basal upper foreshore sands, has a high organic matter content (composed of small rounded fecal pellets and disseminated organics), and is bracketed stratigraphically above and below by eolian sands. Rich and Booth (chap. 6) recently conducted a preliminary pollen analysis of this lower paleosol along Yellow Banks Bluff and noted that, given its stratigraphic position, it is of probable late Pleistocene age. While pollen preservation was generally poor due to in situ weathering and

diagensis, *Alnus* (alder) or Tubuliflorae (composites) grains that had lost part of the external pollen wall (ektexine) were identifiable. Among the numerous identifiable grains, the most abundant arboreal taxa were *Carya* (hickory and pecan) and *Pinus* (pine); however, a very large amount of pollen from herbaceous plants and woody shrubs characterized the sample, including abundant Tubuliflorae (41% of the palynoflora), *Alnus* (17%), Poaceae (grasses, 10%), and *Ambrosia* (ragweed, 5%) (see chap. 6). This research indicates that the lower paleosol sample suggests the local presence of an alder-composite-grass community unlike anything that occurs on St. Catherines Island now. This community appears to be potentially more similar to the tag alder wetlands of the upper Midwest, which are commonly dominated by *Alnus rugosa*, species of the composite *Eupatorium*, and several species of grasses. Additionally, there is little or no indication of halophytic species in the Yellow Banks Bluff sample; there were no Chenopodiaceae/Amarathaceae (lamb's quarters, goosefoot, etc.), and *Iva* (marsh elder, a common seaside inhabitant) constituted less than 1% of the pollen/spores.

As further support of a terrestrial origin for the lower paleosol, the 22 ka date corresponds to a time when sea levels were some 120 m (394 ft) lower than current levels, and when St. Catherines Island was attached or welded to the continent (fig. 4.3). In examining earlier vibracore profiles and associated radiocarbon dates, the 22,820 B.P. age for organics has been identified in other parts of the island core (Linsley, 1993; Bishop et al., 2007). These dates document a stable surface at approximately 22,000 B.P. for the island core during the maximum glacial eustatic sea level drop when the island lay as much as 100 m (330 ft) above sea level and was essentially "welded" to the mainland.

Using profile 2-A along Yellow Banks Bluff as type section, the basal stratum designated 5A (lowermost paleosol) is underlain by heavy mineral-rich marine sands and overlain by a variably thick (20–50 cm) eolian sand horizon, designated 4C. The 4C white eolian sands are capped by a second cumulic A horizon designated 4A. The 4A horizon is slightly less developed than the lower 5A paleosol, but also exhibits high organic matter content, evidence of bioturbation, and redox of iron. Although this horizon is not dated at profile 2-A, it may correlate to a dated paleosol along the southern end of the bluff. At this location, a



Fig. 4.3. Photograph of two exposed paleosols (arrows) along Yellow Banks Bluff. The lower paleosol in photo has been dated to  $22,820 \pm 130$  B.P. (Beta-244622). Note mapped soil horizons in photo. Photograph taken by Patty Stahlman, May 1, 2008..

paleosol consisting of a dark black peat occurs in a deep swale or slough (fig. 4.4). Radiocarbon dating of organics from the swale (or slough) has yielded a date of  $13,610 \pm 40$  B.P. (Beta-244621), and may correspond with the climate amelioration during the warmer Boelling-Allerod Subage. In a similar fashion to the lower paleosol, the 4A paleosol (or allogenic genetic unit) documents a period of stability and A horizon development probably associated with warm and moist climatic conditions. During the Fourth Caldwell Conference, Rich and Booth concurred that the vegetation present in the swale dated 13.6 ka was of freshwater origin (personal commun., 2009). Martin indicated that the insect and vegetation traces were of freshwater taxa, clearly different from that which is observed in the island's salt marsh communities today (personal commun. 2009).

The 4A horizon is then overlain by a variably thick package of white, fine-grained, well-sorted eolian sands, designated 3C. These eolian sands may document a period of dry climatic conditions associated with the Younger Dryas (ca. 11,000 B.P.). During this time, sea levels would have been more than 40 m (131 ft) below their present position, and the island would have remained welded to the coast (see chap. 3: fig. 3.3). The 3C sands are then overlain by a moderately well-developed cumulic A horizon that has yielded a date of  $10,790 \pm 60$  B.P. (Beta-255650). This horizon documents at least a moderately lengthy

episode of moister or wetter conditions that favored A horizon development and the termination of the warm and dry conditions of the Younger Dryas. The 3A horizon is then overlain disconformably by a thin (20–30 cm thick) white eolian sand 2C horizon. The 2C horizon is once again overlain by a 10–12 cm thick 2A horizon. The 2A horizon has yielded a date of  $6440 \pm 40$  B.P. (Beta-255651). This date documents an interval of wetter climatic conditions during the middle Holocene Atlantic climatic phase.

The 2A horizon at profile 2A is then overlain by the upper soil sequa (or generation): A-AB-Bh/Bw-C. This upper soil sequa typically attains a nominal thickness of 150 cm (fig. 4.5). During the field studies, three probable prehistoric fire features were noted within the Bh horizon along the northern portion of the bluff. One of the features (designated feature 44) was identified at a depth of 80–120 cm below ground surface in the Bh horizon and was submitted for conventional  $^{14}\text{C}$  dating (fig. 4.6). The feature has now yielded a date of  $6270 \pm 40$  B.P. (Beta-255652). This date corresponds nicely in that it overlies the 6440 B.P. date on the 2A horizon and underlies Late Archaic period artifacts that have been recovered from the A/AB horizons along the bluff (Thomas, 2008: chap. 20, 535–601). Given the age of the 2A ho-



Fig. 4.4. Photograph of a section of Yellow Banks Bluff (facing west). The extensive organic horizon (2A1/2A2; arrow) is likely attributable to a freshwater pond or slough. The 2A horizon at this location has been dated to  $13,610 \pm 40$   $^{14}\text{C}$  yr B.P. (Beta-244621), and may correspond with the 4A horizon at profile 2-A. Photograph taken by Patty Stahlman, April 30, 2008.

rizon and the date from the probable feature, it is clear that the eolian sands that comprise the upper soil generation (A/AB-Bh/Bw-C) along Yellow Banks Bluff are entirely of Holocene age.

An interesting observation concerning the upper solum (A and underlying B horizon) present on the southern end of Yellow Banks Bluff, which lies in places more than 1.5 m (5 ft) below the higher standing northern section of the bluff, is that the B horizon is markedly less developed (or weakly cambic) and exhibits a darker chroma, less oxidation, and evidence of humate translocation. This may indicate less stability (e.g., greater eolian deflation and heightened effects of washover) due to a lower topographic position relative to sea level. An examination of the age of previously recorded prehistoric sites present on the bluff may help to answer whether the age of the upper solum varies north to south.

SUMMARY DISCUSSION  
OF PETROGRAPHIC AND SOIL  
GRAIN SIZE ANALYSES

Martin and Rindsberg (2008) have proposed that the lower two humate-rich horizons (4A–5A) may represent strongly bioturbated washover fan deposits. To examine more fully the depositional origin of these horizons, both thin section and grain size analyses were completed for profile 2-A along Yellow Banks Bluff (see fig. 4.5). We believe that the results of the grain size studies provide further support for subaerial eolian deposition of the sands along Yellow Banks Bluff. Only the lower 1 m (3.3 ft) of the exposed bluff profile is comprised of heavy mineral-rich littoral marine sands of Silver Bluff age. Grain size analysis of the 5A, 4C, and 4A horizons capping these marine sands was strongly unimodal, lept-

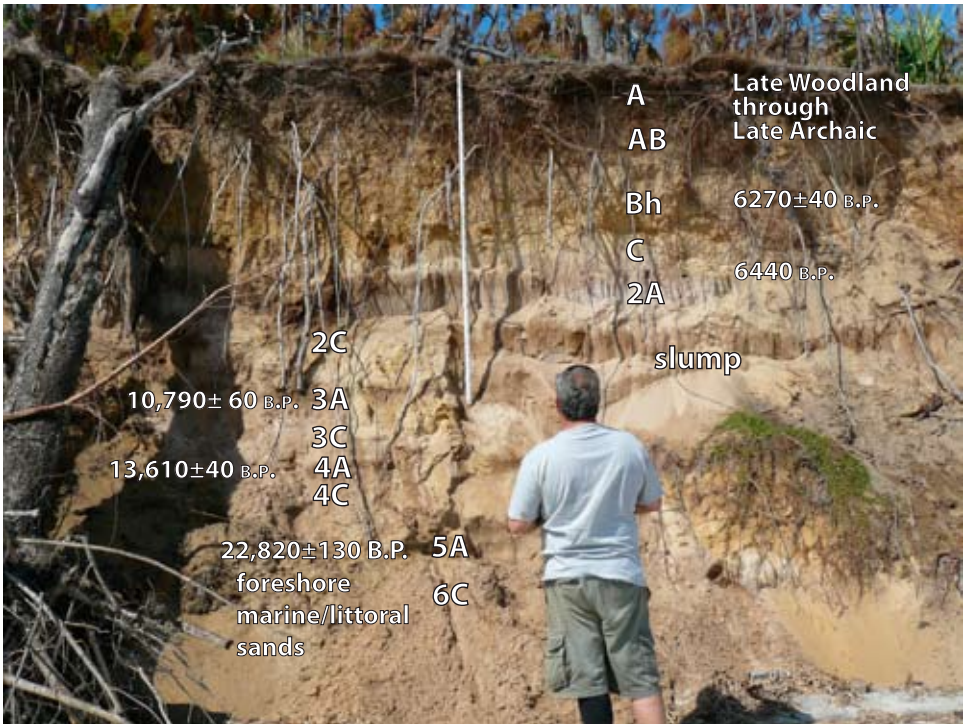


Fig. 4.5. Photograph at profile 2-A location along Yellow Banks Bluff (facing west). Note the occurrence of at least four buried A horizons (2A, 3A, 4A, and 5A) each of which is capped by minimally weathered eolian sands. The upper sola consists of an A/AB horizon overlying a spodic Bh horizon. Photograph taken by Patty Stahlman, October 10, 2008.



Fig. 4.6. Photograph (facing 310°) of a probable prehistoric cultural feature in the B horizon exposed along Yellow Banks Bluff. Recent radiocarbon dating has yielded a date of  $6440 \pm 40$   $^{14}\text{C}$  yr B.P. Beta-255651. Photograph taken by Patty Stahlman, October 10, 2008.

kurtic, and extremely well sorted (fig. 4.7). The argument against a washover origin include: (1) absence of any marine forams or other faunal elements; (2) no evidence of a fining upward trend; (3) a clear absence of marsh muds; (4) the lack of sharp basal contact for these horizons; (5) a high degree of sorting and low percentage of heavy minerals—1% to 2%; and (6) absence of shell or coarse sand basal lag deposits. An alternative hypothesis is that these are highly bioturbated eolian sands that exhibit a high organic matter content caused by elevated water table conditions that may reflect broad regional climate controls or localized water table conditions.

The thin section analysis of profile 2-A along Yellow Banks Bluff also strongly supports an eolian origin for all but the lower 1 m (3.3 ft) of exposed sands along the bluff. The 6C horizon at the base of the bluff is clearly comprised of Silver Bluff age littoral marine sands (fig. 4.8). These sands contain a higher percentage of heavy minerals and much lower organic matter content than the overlying 5A, 4C, and 4A horizons (figs. 4.9, 4.10). The petrographic study also indicates that while the eolian sands along Yellow Banks Bluff exhibit a high degree of sorting, most of the grains examined were typi-

cally subangular to subrounded (fig. 4.11). The absence of rounding documents short eolian transport and limited subsequent reworking of the sands.

## CONCLUSIONS

Although the study to date has generated more questions than answers, the following tentative observations and recommendations for further study are proposed:

(1) A mid-Wisconsin age (26–60 ka) for the Silver Bluff submergence that formed the core of St. Catherines Island is now further supported by the dating of a basal paleosol (22 ka) that lies only 1 m (3.3 ft) above nearshore marine sands of Silver Bluff age. The age of this lower paleosol is, however, problematic. If, in fact, the horizon is actually bioturbated, then the date is in error, given that sea level at 22 ka would have been some 100 m below present-day sea level. Secondly, one might consider whether the 22 ka date is from organics contributed to a palimpsest surface that is significantly older (e.g., 45–100+ ka) and that the date represents later organic contribution to this relict surface. As a planned “next step,” samples of both the lower paleosol and the underlying marine sands will be submitted for OSL dating. These dates should answer the question as to the age and timing of the Silver Bluff submergence and negate concerns regarding the mid-Wisconsin cosmic bombardment effect on  $^{14}\text{C}$  samples. In addition, we hope to collect and submit a sample from the probable Younger Dryas age eolian sands that overlie the 13.6 ka organic rich, freshwater slough and underlie the 10.7 ka paleosol. This sample will also be analyzed for its nanodiamond content to elicit either supportive or negative data for a late-Wisconsin-age meteorite event that has recently been offered as a causal mechanism for the Younger Dryas climate interval and also late-Wisconsin extinctions (Firestone et al. 2007; Kennett et al. 2009; Surovell et al. 2009).

(2) The fact that at least four buried A horizons dating to 6440 B.P., 10,790 B.P., 13,610 B.P., and 22,820 B.P. (as well as one additional undated paleosol) have been identified within 4 m (13.5 ft) of the bluff surface argues that soils on St. Catherines Island have the potential to contain prehistoric occupations that predate the Late Archaic. A recent date of  $6270 \pm 40$  B.P. (Beta-255652) from a probable prehistoric fea-

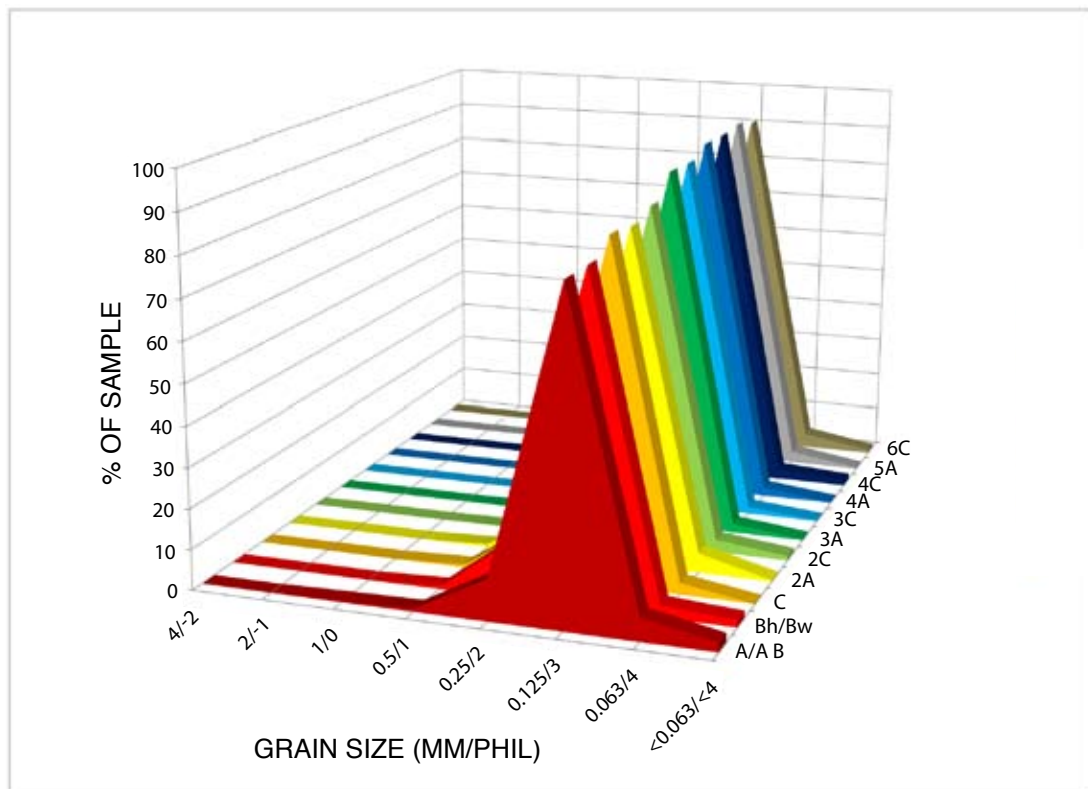


Fig. 4.7. Chart of soil grain size (profile 2-A) of Yellow Banks Bluff, St. Catherines Island, demonstrating the uniform grain size for the entire bluff sediment package. All samples were strongly unimodal, leptokurtic, and very well sorted. The grain size, sorting, and mineralogy all argue for an aeolian origin for all but the lower 1 m of strata along the exposed bluff.

ture identified at a depth of 80–120 cm below ground surface in the spodic B horizon provides additional support for this conclusion.

(3) The buried A horizons clearly document episodes of island core stability during probable warm and moist climatic intervals. The paleosols are consistently capped by eolian sand deposits that may document episodes of enhanced eolian deflation during warmer and drier climatic intervals. Given the preservation of organic material in some of these horizons, it should be possible to provide important new information on vegetation and climate change on the Georgia Bight over the past 22,000 years.

(4) None of the paleosols that occur along Yellow Banks Bluff is traceable along the entire length of the escarpment, due to localized

erosion by eolian deflation, rapid rates of eolian accretion, or erosional ravinement by interior channels and sloughs.

(5) Does the age of the upper solum or soil generation (A-Bh/Bw) along Yellow Banks Bluff decrease from north to south? The observed soils along Yellow Banks Bluff indicate that the spodic B horizon underlying the surface A horizon on the north end of the bluff is comprised of strong yellowish-brown sands that are more deeply weathered than the weak, brown cambic B horizon occurring on the southern margin of the bluff. Do these changes in soil development reflect greater stability of the slightly higher island core on the north end of the bluff and, if so, how does this occurrence correlate with the age of observed prehistoric sites? Finally, does

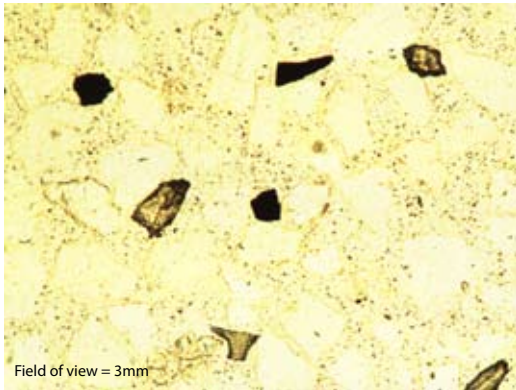


Fig. 4.8. Photomicrograph under plain polarized light showing abundant heavy minerals present in lower basal marine (littoral) sand unit. The percentage of heavy minerals drops off significantly in the overlying eolian sands. Photomicrograph taken by Frank Vento.

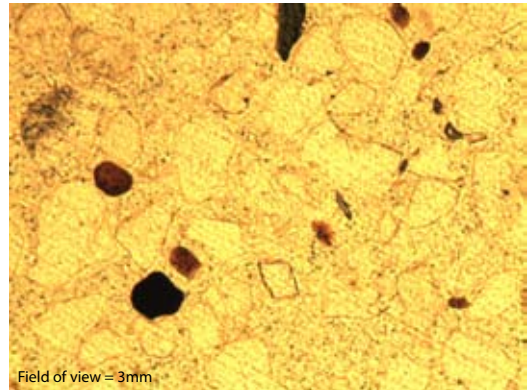


Fig. 4.9. Photomicrograph under plain polarized light at 50 $\times$  showing abundant organics in 5A horizon from profile 2-A. The rounded organics are likely either fecal pellets or seeds. Photomicrograph taken by Frank Vento.

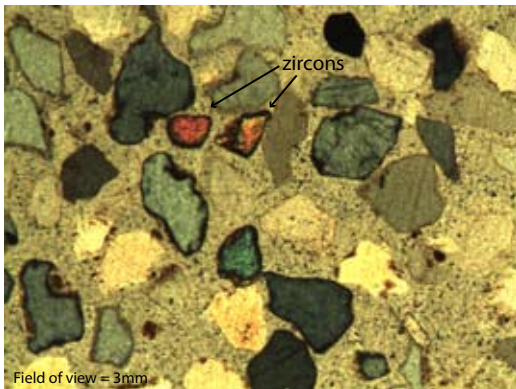


Fig. 4.10. Photomicrograph of 5A horizon under cross-polarized light at 50 $\times$ . Note zircons in photo (high birefringence grain) and strong angularity of the fine sand-sized quartz grains. Also note abundant disseminated organics. Photomicrograph taken by Frank Vento.

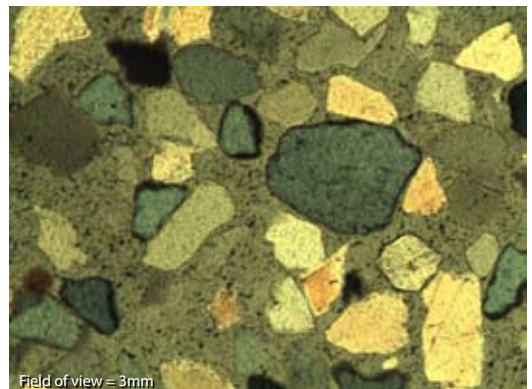


Fig. 4.11. Photomicrograph of 3C horizon from profile 2-A under cross-polarized light at 50 $\times$ . Note angular, subangular to subrounded character for the fine sand-sized quartz grains. The sparse heavy mineral assemblage in the eolian sands consists primarily of zircons, almandine garnets, and various opaques (e.g., magnetite, ilmomite). Photomicrograph taken by Frank Vento.

this change in soil character affect the potential for the occurrence of more deeply buried prehistoric cultural resources?

(6) The apparent absence of the upper buried paleosols, at least on the western margin of the Pleistocene core, may reflect greater stability farther from its oceanward edge, essentially documenting less autogenic influence from nearshore

depositional processes (hurricanes, eolian scour, and deposition etc.).

(7) Bishop and others (2007) have proposed that a “ghost” island named Guale Island existed east of Yellow Banks Bluff and was the sediment source for the late middle to late Holocene (4 ka to present) accretionary terrain on the southern end of the island. If present, how did Guale Island

affect sediment transport and subsequent paleosol development on the Pleistocene core of the island now exposed along Yellow Banks Bluff? Additionally, how did the eventual destruction of this "ghost" island influence the development of the southerly accretionary terrain and, in turn, prehistoric occupation of these now stabilized beach-dune ridges over time?

(8) Do the stratigraphic profiles exposed along Yellow Banks Bluff and to the south along the now stabilized beach-dune ridges provide supportive data for a proposed sea level regression or still stand (DePratter and Howard 1981; Gayes et al., 1992; Colquhoun, Brooks, and Stone, 1995; Goodfriend and Rollins, 1998; Chowns et al., 2008) between approximately 4300 and 3600 B.P.?

(9) Additional mapping and vibracoring of the

Yellow Banks Bluff zone should be conducted to determine whether the paleosols present along Yellow Banks Bluff extend further westward into the Pleistocene core of the island.

(10) Finally, an ultimate objective of geomorphological studies on St. Catherines Island is the construction of a genetic stratigraphic sequence for the barrier islands of the Georgia Bight. It may eventually be possible to float stratigraphic sections among islands, permitting interisland stratigraphic correlation. Careful construction of this sequence will demand attention to the effects of climate change, sea level fluctuation, and tectonism. Once completed, this genetic sequence will aid in predictive archaeological stratigraphy and in identifying those landforms with the potential to contain deeply buried prehistoric cultural resources.



## CHAPTER 5

### ICHTNOLOGICAL DIAGNOSIS OF ANCIENT STORM-WASHOVER FANS, YELLOW BANKS BLUFF, ST. CATHERINES ISLAND

ANTHONY J. MARTIN AND ANDREW K. RINDSBERG

Ichnology, the study of modern and fossil traces, has a long and venerated history as a science with diverse applications, such as in paleoecology (Cadée and Goldring, 2007; MacEachern et al., 2007a; Mángano and Buatois, 2007; Savrda, 2007), stratigraphy (MacEachern et al., 2007b), evolutionary biology (Walker, 2007; Wilson, 2007), petroleum production (Pemberton, 1992; Hubbard et al., 2002), and archaeology (Gautier, 1993; Johnson, 2002; Lim et al., 2007; West and Hasiotis, 2007; Roberts, 2009). With regard to the latter, ichnology has been used to interpret paleoenvironments of archaeological sites, as well as discern the effects of bioturbation on provenance of artifacts (Johnson, 2002; Canti, 2003). In a broader sense, though, ichnology can continue to assist in developing models for the geological history of a given place, such as the Pleistocene and Holocene of the Georgia barrier islands (e.g., Weimer and Hoyt, 1964; Hoyt and Hails, 1967; Hoyt, Henry, and Weimer, 1968; Farrell, Hoffman, and Henry, 1993; Gregory, Martin, and Campbell, 2004). In this respect, one of the advantages enjoyed by ichnologists on the Georgia coast is the ready availability of modern analogs of traces and tracemakers in a wide variety of environments, which lend easily to comparisons with fossil examples (Weimer and Hoyt, 1964; Frey and Howard, 1969; Howard and Reineck, 1972; Basan and Frey, 1977; Morris and Rollins, 1977; Howard and Scott, 1983; Pemberton and Frey, 1985; Bishop and Bishop, 1992; Farrell, Henry, and Cofer-Shabica, 1993; Gregory, Martin, and Campbell, 2004; Gregory et al., 2006; Martin and Rindsberg, 2007a, 2007b).

With such facility in mind, in this study we

will (1) look at storm-washover fans as environments that contribute to stratigraphic and ecological changes in coastal ecosystems; and (2) demonstrate how modern traces of these environments, when incorporated with other facies information, can provide models for interpreting ancient examples of storm-washover fans. With regard to the latter, we further explore a hypothesis proposed recently about the storm washover origin of enigmatic strata within Yellow Banks Bluff, the most extensive purported outcrop of the Pleistocene Silver Bluff Formation on St. Catherines Island (Martin and Rindsberg, 2008). We also hope to convey how trace fossils can be used to better discern paleoenvironmental changes that contribute to the geological history of the Georgia barrier islands, especially when such interpretations are informed by ichnological processes and tracemakers observed in the context of modern environments. Although the washover fans interpreted here predate human occupation of St. Catherines and other Georgia barrier islands (Vento and Stahlman, chap. 4), their interpretation will add to a more general understanding of the geological history of the island (Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008).

#### PREVIOUS RESEARCH ON ICHNOLOGY OF STORM-WASHOVER FANS

##### OVERVIEW OF MODERN-ANCIENT STORM-WASHOVER FANS AND ICHNOLOGY

This study is one of a few to focus on the ichnology of washover fan deposits (Frey and Mayou, 1971; Hippensteel and Martin, 1999; Martin and Rindsberg, 2008). More studies are available

on the physical stratigraphy and geomorphology of washover fans (Andrews, 1970; Deery and Howard, 1977; Sedgewick and Davis, 2003; Morton, 2007), some of which include valuable ichnological data. In addition, several works on Georgia coastal ichnology contain information pertaining specifically to washover fans (Frey and Mayou, 1971; Deery and Howard, 1977; Frey and Pemberton, 1987; Linsley, Bishop, and Rollins, 2008; Martin and Rindsberg, 2008).

Washover fans, among the most readily accessible coastal environments, are generally glossed over in works on coastal ichnology, apparently because they are not as interesting as neighboring environments such as dunes, beaches, and marshes (Dörjes and Hertweck, 1975; Basan and Frey, 1977; Frey and Howard, 1986, 1988; Frey and Pemberton, 1987; Martin, 2006; Martin and Rindsberg, 2007a). Washover fans tend to have not only a low degree of bioturbation (with some exceptions, as noted later), but also a low diversity of tracemakers. Ancient washover fans are recognized largely by their stratigraphic position and physical sedimentary structures, especially planar lamination, proximal channels, and distal delta foresets, but also antidunes and trace fossils (Schwartz, 1975, 1982; Barwis and Hayes, 1985; Zonneveld, Gingras, and Pemberton, 2001; Donnelly and Sallenger, 2007). Washovers commonly contain a low diversity of molluscan shells, as well, especially robust forms in an abraded and broken condition, explained further on. Algal mats may develop on top surfaces of washover fans, particularly where they may wash over into intertidal or ponded areas (Sedgewick and Davis, 2003). Washover fans form at, or slightly above, high tide level along the backbeach (Deery and Howard, 1977), which constrains the elevation of high tide level in the past.

Plants that inhabit washover fans are of low diversity but may have large populations. The few species that can tolerate the difficult physical conditions prevailing on washovers may thrive here particularly, and can be valuable as indicator species where abundant. In general, however, plant cover is incomplete, leading to excellent preservation of original physical sedimentary structures with relatively little biogenic reworking (with some exceptions, noted later), as long as storm washovers continue to repeatedly drape the fan with sediment. Plants living on washover fans commonly include low-growing marsh plants, rather than trees or shrubs; among

these on the Georgia barrier islands are some halophytes, including *Spartina alterniflora*, *S. patens*, and *Salicornia virginica*. In instances where washovers spill into the edges of maritime forests, plants may also include red cedar (*Juniperus virginiana*), wax myrtle (*Myrica cerifera*), and other plants more adapted to freshwater, yet tolerant of some salinity. For example, in cores from St. Catherines Island, Linsley, Bishop, and Rollins (2008) described and interpreted modern washover fans overlying Pleistocene deposits. These bioturbated muddy deposits were interpreted as evidence of poststorm colonization by high marsh organisms, which are typically represented by halophytes (*Spartina*, *Salicornia*, and *Distichlis*), as well as ribbed mussels (*Geukensia demissa*), marsh periwinkles (*Littoraria irrorata*), and fiddler crabs (*Uca* spp.). Linsley, Bishop, and Rollins (2008) also point out, however, that such ecosystems may be short-lived as continued deposition of storm washovers soon places sedimentary surfaces well above the mean tidal range, resulting in a more depauperate halophyte assemblage or one more typical of eolian dunes.

Animals may live permanently in washover fans or enter briefly to forage. Permanent inhabitants must respond to extreme daily and seasonal changes in physical conditions, which may include high ranges of temperature, immersion, and exposure to sunlight, wind, and predators. As a result, elite residents tend to be animals that are active and can burrow rapidly, such as some arthropods (e.g., ocypodid decapods, talitrid amphipods), and the largest residents may burrow deeply to escape inclement conditions at the surface. Ocypodids include sand fiddlers (*Uca pugnator*), mud fiddlers (*U. pugnax*), and ghost crabs (*Ocypode quadrata*). Where washovers breach dunes and spill over into marshes, fiddlers tend to occupy the marshward (distal) areas, whereas ghost crabs prefer the shoreward margin (Frey and Mayou, 1971). Abundant snails (*Littoraria irrorata*) feed on microbiota, including algal films, on grass stems and the sediment surface, making characteristic trails (Basan and Frey, 1977). Terrestrial vertebrates, some of which are common tracemakers in supratidal environments of the Georgia coast (Frey and Pemberton, 1986), frequently affect surfaces and upper portions of fan deposits by walking across these open areas or digging into fans in search of sustenance. On the Georgia coast, common tracemakers include sandhill

cranes (*Grus canadensis*), great blue herons (*Ardea herodias*), raccoons (*Procyon lotor*), armadillos (*Dasypus novemcinctus*), deer (*Odocoileus virginianus*), and feral hogs (*Sus scrofa*). On the shoreward sides of washovers and closer to dunes and the upper beach, sea turtles (e.g., the loggerhead *Caretta caretta*) will nest in thick, sandy deposits they deem suitable for egg laying (Brannen and Bishop, 1993; Bishop et al., chap. 13).

Although washover fans might be less attractive than other coastal environments as objects for study, to an ichnologist they have certain advantages. For example, modern washover fans are prominent in beach and barrier geomorphology, especially in the study of storm effects. Such deposits and their geometry are easily identified from aerial photographs or satellite imagery. For example, with the Georgia barrier islands, including St. Catherines, fans can be detected by using the freeware Google Earth™, enabling better planning for ichnological investigations. Additionally, traces of washovers have a fairly high potential for preservation in the geological record, particularly if filled with contrasting sediments. The traces, moreover, should be easily distinguishable because of low overall bioturbation, especially where sandstone beds are bound by algal films on top surfaces or separated by films of clay (Sedgewick and Davis, 2003), which can provide for readily split surfaces. Contrasts in sediment color and texture among microbially bound layers, muddy sediments, and sandy sediments also should help in identifying trace fossils in ancient washover fan deposits, explained in detail later.

Criteria for recognition of ancient washover fan deposits are chiefly based on physical sedimentary structures, and secondarily on body fossils and biogenic sedimentary structures (Frey and Mayou, 1971; Deery and Howard, 1977; Anderson and McBride, 1996). Washover fan deposits are characteristically transported through a channel cut in previous beach and/or dune sediments, and spread laterally on the landward side of a barrier. This avulsion results in the fanlike geometry of modern washover fans, analogous to crevasse splays in fluvial systems. Sediments composing washover fans tend to consist of sand to gravel originating in beach and dune environments (Deery and Howard, 1977; Sedgewick and Davis, 2003; Morton, 2007). Sorting in general is poor, and organic matter may be lacking, al-

though driftwood may be incorporated with the sediment load along with suspended, fine-grained organic matter (Deery and Howard, 1977).

Additionally, Anderson and McBride (1996: table 3) summarized previous work on shell beds in washover fan deposits and showed that storms may carry large amounts of shell debris in washovers, creating single-event shell beds without biological reworking. Molluscan species in such deposits are typically shallow-marine, but may also include shells from exhumed estuarine deposits. Shells are commonly abraded and consist largely of robust species; individual shells are oriented convex-upward, convex-downward, or at random, and may be nested (Albertzart and Wilkinson, 1990; Sedgewick and Davis, 2003). Coarse and fine shell beds may alternate; individual beds are ungraded and commonly are cross-stratified. Similarly, foraminifera in washover fans may have low diversity but very high populations. For example, on the Atlantic shore of the Virginia part of the Delmarva Peninsula, Culver et al. (1996) found an average of about 42 specimens ml<sup>-1</sup> (especially of the indicator species *Quinqueloculina seminula*) in washover samples.

Biological signatures of former inhabitants of washover fans, represented by trace fossils, can be distinctive. As mentioned earlier, actual biodiversity is low but can be coupled with numerous individuals for each species living on or near fan deposits. The most abundant modern animals living on, within, and near Georgia washovers include ocypodids, especially fiddler crabs (e.g., *Uca pugnax* and *U. pugilator*; Frey and Mayou, 1971; Deery and Howard, 1977). Hence trace fossils matching known forms of modern ocypodid traces should be present in any Pleistocene interglacial deposits in the same area. Similarly, root traces of plants common to or ecologically succeeding washover fans should be present; such traces are especially valuable in falsifying interpretations of shallow marine paleoenvironments (Gregory, Martin, and Campbell, 2004). Where depositional rates become low, plant bioturbation may dominate the ichnoassemblage (Warme, 1971; Edwards and Frey, 1977). In general, the animal traces of the Georgia littoral environments are much better characterized than the plant traces. More work is needed to describe modern roots in these environments. Lastly, escape (equilibrium) traces may also be present in washover deposits where infauna attempted to burrow up

in reaction to a rapid influx of sand. Although such traces have not been documented in detail, bivalve escape traces have been noted in wash-over fans of St. Catherines Island (Harold Rollins, personal commun., 2009).

### YELLOW BANKS BLUFF: DESCRIPTION AND INTERPRETATION

#### GEOLOGICAL SETTING, PREVIOUS INVESTIGATIONS OF ST. CATHERINES ISLAND

St. Catherines Island is one of several regressive barrier islands formed along the Atlantic coast of Georgia and South Carolina from Pleistocene times to the present (fig. 5.1). Bishop et al. (2007) and Linsley, Bishop, and Rollins (2008) outlined the stratigraphy of the island and provided interpretations of its geological history. Johnson et al. (1974), Hudson (1978), and Coile and Jones (1988) studied island vegetation, whereas Booth, Rich, and Bishop (1999), Booth et al. (1999), Booth and Rich (1999), and Rich and Booth (chap. 6, this volume) examined the palynology and other plant fossils of Pleistocene-Holocene deposits, including those at Yellow Banks Bluff. Morris and Rollins (1977), Fierstien and Rollins (1987), and Prezant et al. (2002) provided thorough reviews of the island's marine invertebrates. Ichnological studies have been limited mostly to neoichnology, the study of modern traces and their makers, such as intertidal and subtidal tracemakers (Morris and Rollins, 1977; Bishop and Bishop, 1992) and sea turtles in beach-dune environments (Brannen and Bishop, 1993). In contrast, Booth, Rich, and Bishop (1999), Bishop et al. (2007), Linsley, Bishop, and Rollins (2008), Vento and Stahlman (chap. 4, this volume) studied different geological aspects of the Silver Bluff Formation on St. Catherines Island, but did not focus on its ichnology. Our study is the first in-depth examination of trace fossils on St. Catherines, specifically in the Silver Bluff Formation as exposed on Yellow Banks Bluff.

#### STRATIGRAPHIC DESCRIPTION OF YELLOW BANKS BLUFF

Yellow Banks Bluff is a seacliff and the tallest exposure on the island, revealing about 5 m of vertical section, with the lowermost portion representing the Pleistocene Silver Bluff Formation (figs. 5.2, 5.3). Most of the bluff consists of poorly consolidated yellowish sand, with mi-

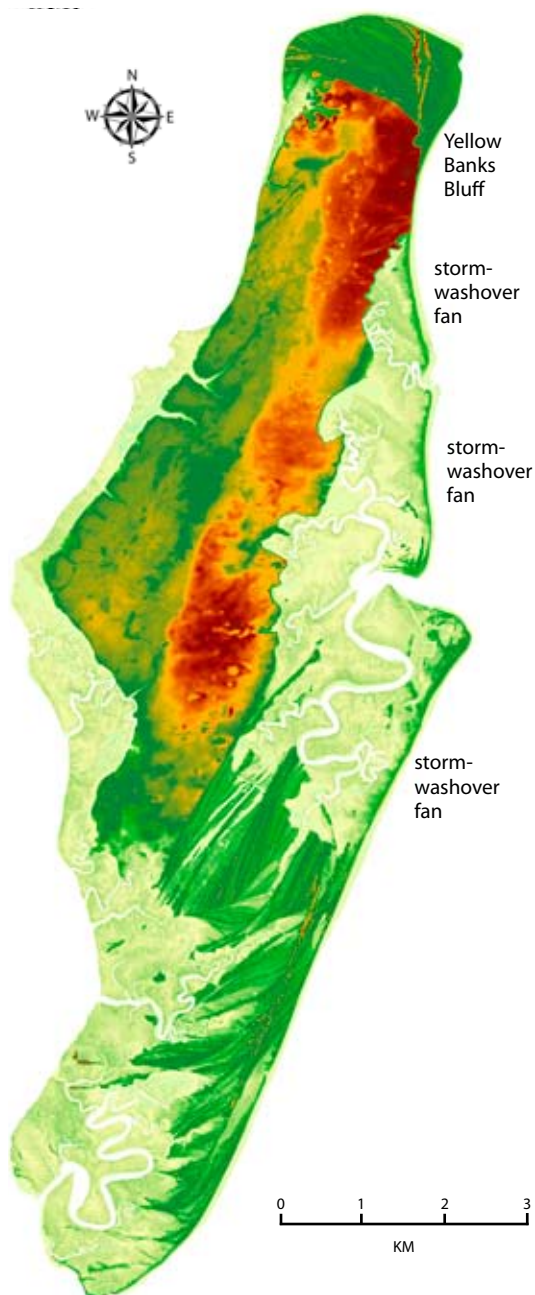


Fig. 5.1. Locality map of Yellow Banks Bluff and modern storm-washover fans, St. Catherines Island, Georgia. Map created by Brian K. Meyer.

nor clay in lenticular deposits. Dark-brown to black clay is also exposed at the northern and southern ends of the cliff, interpreted as relict Holocene marsh deposits, with the southern deposit explained in more detail later. Geographical coordinates of the Magnolia Bluff overlook toward the southern end of Yellow Banks Bluff are 31.67791°N, 81.13721°W.

The Silver Bluff shoreline complex was deposited during a sea level highstand of about 1.5 m (Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008). Yellow Banks Bluff probably originated as a cut bank along an estuarine channel between St. Catherine's Island and a hypothetical Gualie Island eroded away during the Holocene, which is now represented by the submerged substrate lying off Yellow Banks Bluff (Bishop, 1990) and by sediment transported southward as Gualie Island was eroded. Within historical time, the bluff has been rapidly eroded and refreshed when storms (hurricanes or nor'easters) coincide with high spring tides, and is now retreating at an average of about 1.8 m per year (Potter, chap. 7). The oak-pine-palm forest atop the bluff contributes fallen trees to the beach, forming a "tree bone yard," which complicates reconnaissance of the outcrop in places. Furthermore, the outcrop face is riddled with the roots of modern trees, particularly those of cabbage palms (*Sabal palmetto*) and saw palmettos (*Serenoa repens*),

which will be discussed later with regard to their impact on proper diagnosis of trace fossils in the Silver Bluff Formation.

Basal strata of the examined section (fig. 5.3) have planar to ripple laminae composed primarily of very fine quartz sand; some laminae are rich in dark heavy minerals, also present as very fine sand. These beds show some evidence of disruption by bioturbation, and although trace fossils are difficult to classify from vertical sections, they seem to include: 0.5–1.0 cm wide *Skolithos* isp. (simple vertical burrows); abundant 1–3 mm wide *Planolites* isp. (simple horizontal burrows with organic-enriched, structureless fill); and 0.5–2.5 cm wide *Psilonichnus up-silon* (vertical and oblique burrows) (fig. 5.4A, B). Sections scraped parallel to bedding planes revealed that *Psilonichnus* is indeed the most likely ichnogenus for the larger burrows, which are more common just above the zone containing *Planolites* and *Skolithos*. Accompanying this upward increase in *Psilonichnus* is a decrease in heavy minerals and ripple bedding, which is probably a direct result of increased bioturbation. This zone grades upward into sediments dominated by 0.5–1.0 cm wide *Taenidium* isp., evident as horizontal and oblique burrows with meniscate fill.

Overlying strata include two or more weakly consolidated (possibly with humate) dark brown-



Fig. 5.2. Outcrop view of Yellow Banks Bluff, indicating relative position of one thin, dark, ephemeral stratum examined in this study and interpreted as an ancient storm-washover fan; arrows point toward lateral extent of bed, which is about 29 m wide. Photograph is a digital composite of three successive, lateral shots (left to right) taken from same vantage point.

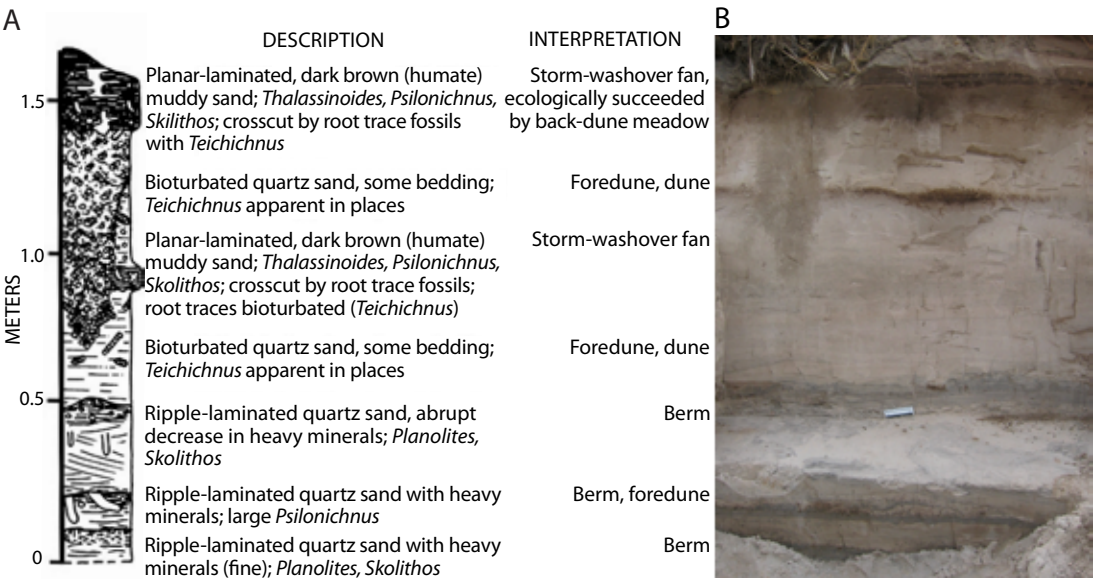


Fig. 5.3. Graphic log and photograph of studied 1.5 m thick interval in lower part of Yellow Banks Bluff, accompanied by verbal descriptions and paleoenvironmental interpretations: **A**, graphic log; **B**, photograph of excavated interval, with bedding-plane exposure at about 25 cm above modern berm level.

ish, bioturbated zones separated by a completely bioturbated quartz sand. These beds are thin (5–15 cm) and ephemeral, but can be as much as 30 m in lateral extent. The beds contain laminae discernible as dark brown and light brown alternations of sediment, and also are crosscut by *Thalassinoides* isp., small *Psilonichnus* isp., and *Skolithos* isp., which in turn are crosscut by *Taenidium* isp. (fig. 5.4C–E). These trace fossils have sharp boundaries with surrounding sediment, and most are contrasted from the host lithology by white quartz-sand fills. Bedding-plane views of burrows show circular to oval cross sections with discrete boundaries, ranging from 0.5 to 1.5 cm wide, but with most about 1.0 cm. Most burrows and strata are crosscut by large, conical-downward root traces in places, which are also crosscut by *Taenidium* isp. (fig. 5.5), obscuring outlines of former root traces that are now only detectable through original color differences (i.e., root traces are typically dark brown against a pale brown host sediment). Some root traces originate at the upper of the two brownish beds and extend vertically below for nearly a meter, whereas others do not have a

clear upper origin. Aside from sandy deposits, Yellow Banks Bluff includes a lenticle of peat, peaty clay, and very fine quartz sand exposed near the south end of the outcrop. Based on outcrop expressions and some excavation, this channellike deposit, which crosscuts older strata, is at least 1.5 m deep and 3–5 m wide, incised into sandy deposits below that are similar to the lowermost part of the stratigraphic section described previously. The peat contains terrestrial plant debris such as wood fragments, pinecones, and nuts, the latter possibly from hickory. This peat is also noteworthy for what it lacks, such as in situ remains of *Spartina alterniflora*, *Geukensia demissa*, and other species characteristic of exhumed relict salt marshes on St. Catherines and other Georgia barrier islands (Morris and Rollins, 1977; Frey and Basan, 1981; Pemberton and Frey, 1985). The contact between the peat and overlying fine-grained quartz sand is gradational because of extensive bioturbation, most of it attributable to *Taenidium* isp. We also noted that the lowermost part of the boundary between the dark clay and the underlying sand, corresponding to the base of a channel, is sharp and

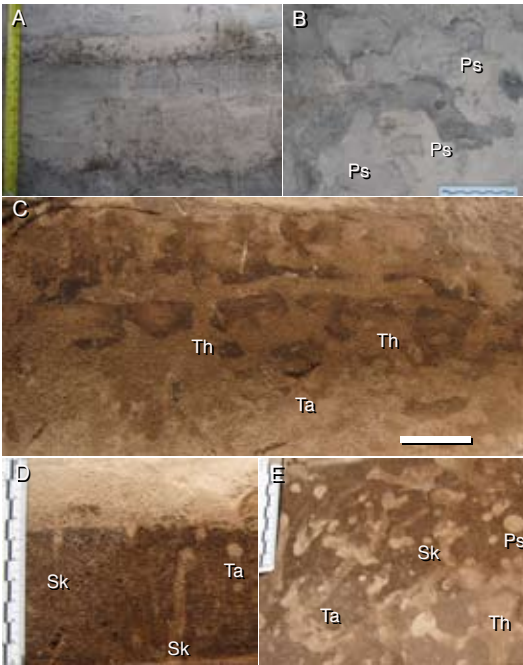


Fig. 5.4. Trace fossils within studied interval of Yellow Banks Bluff (see fig. 5.3 for stratigraphic positions): **A**, *Planolites* isp. (Pl), cross-sectional view, with organic fills contrasting with surrounding cross-bedded sand, at 10–20 cm in vertical section (see fig. 5.3A); scale in cm (left); **B**, larger *Pylonichnus* isp. (Ps), bedding plane view, showing partial collapse and fill of heavy minerals in burrows, at about 20 cm; scale = 10 cm; **C**, *Thalassinoides* isp. (Th), cross-sectional view, in upper dark-brown laminated bed, at about 135–150 cm in vertical section; scale bar = 5 cm; **D**, *Skolithos* isp. (Sk), and *Taenidium* isp. (Ta), cross-sectional view, in lower dark-brown laminated bed, at about 110 cm; scale in centimeters (left); **E**, *Taenidium* isp. and circular cross sections of smaller *Pylonichnus* isp. and *Skolithos* isp., bedding plane view, at about 150 cm; scale bar = 5 cm.

unbioturbated, but further up the original channel banks the higher portions of that same contact are blurred by bioturbation. Remarkably, a 9.1 m vibracore taken in relict marsh mud south of the bluff consisted entirely of marsh mud, whose unusual thickness is still anomalous, and used as evidence of an extensive marsh system between St. Catherines and Gualie islands (Bishop et al., 2007: 43, 50).

As mentioned earlier, modern roots from the

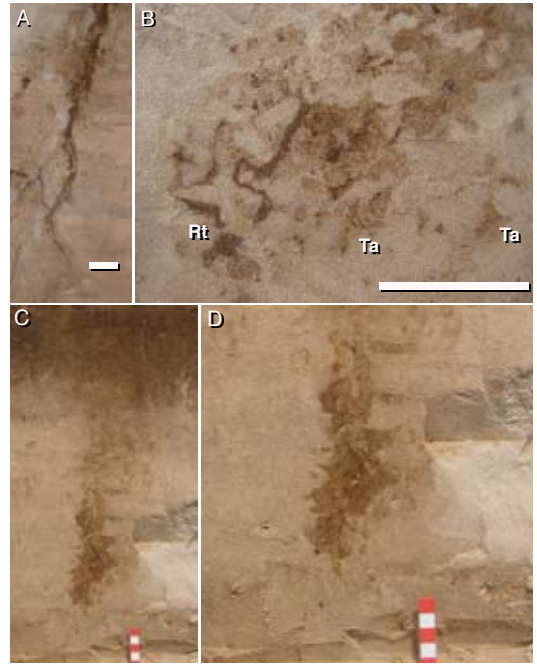


Fig. 5.5. Root trace fossil in Yellow Banks Bluff. **A**, root trace fossil in vertical view; scale bar = 10 cm. **B**, cross-sectional (bedding plane) view of same root trace fossil, showing dark halo, associated *Taenidium* isp., and other forms of bioturbation; scale bar = 5 cm. **C**, root trace originating from dark laminated zone and extending into bioturbated zone; scale in cm. **D**, close-up of distal end of root trace, showing direct association of *Taenidium* isp. in former site of root.

overlying oak-pine forest extend downward to as much as 5 m, or the total exposed thickness of the outcrop above the beach surface. These roots include those of live oak (*Quercus virginiana*), longleaf pine (*Pinus palustris*), cabbage palm (*Sabal palmetto*), and saw palmetto (*Serenoa repens*). Live oak-dominated forests are likely to have existed in prehistoric times (Coile and Jones, 1988), hence these modern root traces are potentially confused with fossil ones. In regard to abiogenic structures that might be mistaken for root traces (modern and fossil), Bishop et al. (2007: 50) also reported obscure, nearly vertical joints in the bluff sand. Some joints have been followed by roots or marked by clay deposition from soil eluviation. Mass wasting of undercut slopes follows joints in places.

## ICHTHOLOGY OF YELLOW BANKS BLUFF

**DIAGNOSIS OF YELLOW BANKS BLUFF:** Because Yellow Banks Bluff is the only extensive outcrop of its age on the island, the two dark-brown laminated beds are key for determining a part of St. Catherines prehistory. Partly on the basis of the bioturbate textures of the beds, Bishop et al. (2007: 50) proposed two hypotheses regarding their origin: (1) the beds might be marine firmgrounds formed during Pleistocene highstands preceding the Silver Bluff highstand; or (2) they might represent marine erosional terraces on the Silver Bluff shoreline. During our initial visit to the island in March 2007, we discussed these possibilities with Bishop et al.; an in-depth investigation of the ichnology of the outcrop then took place during a follow-up visit in June 2007.

Aided by the newly described ichnological data related previously, we interpret the lowermost 1.5 m of the Silver Bluff Formation exposed at Yellow Banks Bluff as foredune facies succeeded vertically by backdune, storm-washover fans, and backdune meadow facies. These new interpretations overturn previous hypotheses of the Silver Bluff Formation as marine still-stand facies and the dark-brown strata as marine firmgrounds or terraces formed during a Silver Bluff sea level high (Bishop et al., 2007). Instead, we propose that facies were deposited well above the high-tide mark and adjacent to terrestrial environments, albeit affected occasionally by marine processes such as storm surges. Accordingly, facies must have been deposited while sea level was only slightly higher than the current level; moreover, the vertical succession of facies suggests a shallowing-upward sequence similar to that interpreted from the Raccoon Bluff Formation (Pleistocene) of Sapelo Island (Gregory, Martin, and Campbell, 2004).

Foredune facies are inferred from low-angle cross-bedding of very fine sand, heavy mineral concentrations in the basal part of the section, small-diameter burrows (*Skolithos*, *Planolites*) that are likely from insects or juvenile ghost crabs (*Ocypode quadrata*), and large-diameter sand-filled burrows consistent with those of *Psilonichnus* and attributable to ghost crabs. Backdune facies are diagnosed from a gradual decrease in heavy mineral abundance corresponding with an increase in pervasive, small-diameter backfilled burrows (*Taenidium*). This facies is punctuated by two thin dark-brown laminated beds (each separated vertically by about 30 cm), which are

from storm-washovers that breached coastal dunes. Their distinctive color was imparted by suspended organics mixed with very fine sand and mud deposited in low-amplitude, mostly continuous sheet deposits (fans), some of which later had their surfaces bound by algal mats.

Rapid poststorm colonization of fan surfaces was mainly facilitated by fiddler crabs (*U. pugnax* or *U. pugilator*), as evinced by crosscutting vertical, J-shaped, and horizontal burrows (*Skolithos*, *Psilonichnus*, and *Thalassinoides*); the abundance and numerous intersections of these burrows suggest multiple generations of burrowing, although some may also represent branching networks. These burrows were later passively filled with eolian sand, burrowed in places by insects and crosscut by root traces that were then burrowed by insects. Some root traces, which imparted darker hues to affected sediment, originate at this stratum and extend downward for 40–50 cm, further supporting poststorm colonization and the start of ecological succession. Eolian sand buried and filled open fiddler crab burrows, which provided for excellent visual contrast and definition of the trace fossils (fig. 5.6). Infaunal insects bioturbated these eolian sands, forming more pervasive zones of *Taenidium*, some of which are more easily discerned around root traces because of sediment contrast; some *Taenidium* crosscut the burrows of the washover fan, further demonstrating ecological succession. Different species and/or growth stages of infaunal insects are probable, based on significant size differences between some backfilled burrows. At least some of the root traces, however, are related to recent roots of extant trees on the top of Yellow Banks Bluff (fig. 5.6A); some of these even contain root tissues. This circumstance hints at the potential complexity of root-trace histories within the outcrop.

**INVERTEBRATE TRACE FOSSILS:** *Taenidium* (figs. 5.4C–E, 5.5D) is interpreted as an actively backfilled burrow made by either an insect larva or nymph; among the most commonly invoked tracemakers for *Taenidium* in terrestrial deposits are cicada nymphs (O'Geen and Busacca, 2001; Gregory, Martin, and Campbell, 2004; Smith and Hasiotis, 2008), but beetle larvae are also implicated as possible tracemakers (Ekdale, Bromley, and Loope, 2007). *Taenidium* has been previously identified in Pleistocene deposits of the Georgia barrier islands, specifically in the Raccoon Bluff

Formation of neighboring Sapelo Island (Gregory, Martin, and Campbell, 2004).

Larger-diameter *Psilonichnus* (fig. 5.4B) are interpreted as the burrows of *Ocypode quadrata*, a common infaunal component of foredune areas, particularly along the Georgia coast. These burrows consist of gently curved J-shaped burrows with subcircular cross section and distinct walls; the tracemaker generally added a branch in the same plane to form a Y-shaped burrow system (Fürsich, 1981; Frey, Curran, and Pemberton, 1984; Frey and Pemberton, 1987; Nesbitt and Campbell, 2006). Although not as clearly defined in vertical section, horizontal sections scraped from the lower portion of the section revealed large-diameter burrows marked by sediment contrasts provided by heavy minerals. One caveat is that the loose consolidation of the Silver Bluff Formation here allows for the possibility of modern ghost crabs burrowing into the formation, then having these burrows filled by water- or wind-borne sand to give a false appearance of being part of the original ichnocoenose. We reduced this possibility of mistaken interpretation by digging nearly 1 m horizontally into the out-

crop; moreover, the rapid rate of erosion of Yellow Banks Bluff makes it less likely that recently made burrows would have been filled and buried before our excavations.

Smaller *Psilonichnus* and *Thalassinoides* (figs. 5.4D, E) are interpreted as the burrows of fiddler crabs belonging to various species of *Uca*, although we think they are most likely attributable to the sand fiddler crab *Uca pugilator*. This is the only local fiddler crab whose mouthparts are modified to feed on sandy substrates (Miller, 1961), although *Uca pugnax* and *U. minax* also live in high marsh sandy substrates. Basan and Frey (1977: 59) described similar burrows from sandy high marshes on nearby Sapelo Island. The modern burrows of *Uca pugilator* are simple, L- to J-shaped, with the upper shaft steeply inclined or vertical and the lower gallery angled to a gentler slope, in many cases terminating with a flat-floored, horizontal chamber at a depth of 10–20 cm within the substrate. The burrows' cross sections are circular to subcircular or somewhat irregular, ranging from 1 to 2 cm in diameter. The animals also construct shallow excavations that may represent tempo-

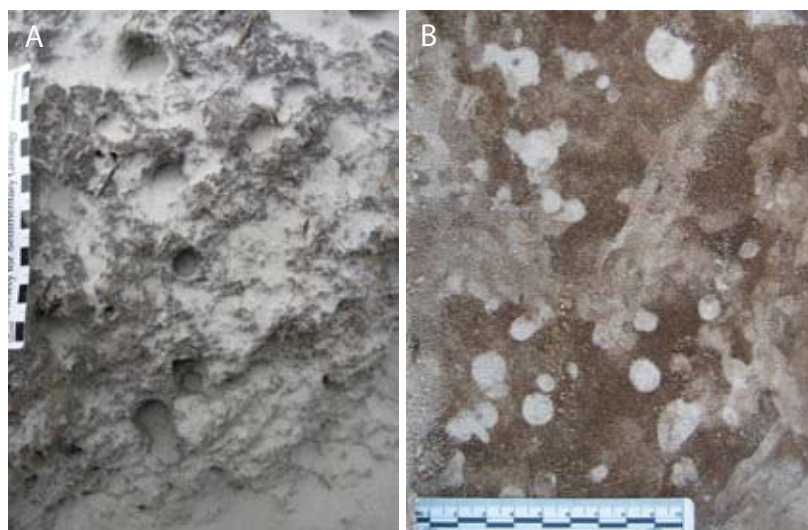


Fig. 5.6. Taphonomic comparison of bedding-plane views for burrows attributed to *Uca* spp. in relict marsh from Cabretta Beach (Sapelo) and Yellow Banks Bluff. **A**, probable *Uca* spp. burrows in relict marsh, showing eolian sand filling burrows with circular cross sections and causing sediment contrast between host sediment and fill. **B**, probable *Uca* spp. burrows, cross sections of *Thalassinoides* isp., *Skolithos* isp., and *Psilonichnus* isp., in interpreted washover fan, with similar sediment contrast between host lithology and fill.

rary hiding or resting burrows (Basan, 1975). Prezant et al. (2002) reported that *Uca pugilator* is also common in St. Catherine's marsh flats and tidal creeks. The burrows of *Uca pugilator* are generally unconnected with one another.

A slight alternative to this hypothesis is that these burrows were made by the mud fiddler crab *Uca pugnax*, the only local fiddler known to excavate multibranched burrows, which occur where populations are especially dense. Basan and Frey (1977: 59) described burrows of *U. pugnax* on Sapelo Island as "unbranched, nearly straight or highly sinuous shafts, to simple or complex systems consisting of shafts and U-shaped components; all burrows unlined, mostly 1–2 cm in diameter, commonly intersecting burrows of other species." Many variations of these burrow forms exist, and they would thus account for the geometric complexity of the burrows. Interactions with plants are also important. *Uca pugnax* tends to dig more shallowly in densely rooted substrates than in root-free areas; moreover, roots commonly penetrate open burrows (Basan, 1975). Nonetheless, *Uca pugnax* and *U. pugilator* are restricted ecologically by grain size and probably represent amensalism (habitat displacement); various species of *Uca* represent divergence from a common ancestor influenced by behavioral and ecological selection pressures (Strumbauer, Levinton, and Christy, 1996; Rosenberg, 2001). At Yellow Banks Bluff, with numerous interconnected horizontal, oblique, and vertical burrow components, we interpret the complexity of the ichnofabric in the inferred washover fans as a result of intersecting individual burrows, rendering a false branching and "networks" that may be only apparent.

**ROOT TRACE FOSSILS:** The ichnological aspects of the root traces (fig. 5.5) at Yellow Banks Bluff are complex owing to the taphonomic mixing of modern and fossil root traces along with closely associated invertebrate traces and trace fossils, discussed in the following section. Nonetheless, root trace fossils are discernible within Yellow Banks Bluff, particularly where such traces originate at washover horizons; accordingly, these are interpreted as having formed shortly after deposition of washover sediments and representing poststorm ecological succession.

Criteria used for distinguishing root trace fossils from abiogenic structures (e.g., joint fills) or invertebrate trace fossils were those outlined by Gregory, Martin, and Campbell (2004): (1) inconsistent diameters within any given length,

which are especially notable if they taper; (2) secondary and tertiary branching that also shows distal tapering with each successive branch; (3) dichotomous, Y-shaped branching with junctions that are not noticeably enlarged; (4) downward, near-vertical to oblique orientations (with some exceptions based on responses of a plant to the originally affected substrate); (5) lack of evidence for active fill (or, conversely, evidence favoring passive fill from overlying layers); and (6) carbonized or otherwise preserved plant material in the structures (noting, however, that some invertebrate traces contain plant material placed in burrows). The most diagnostic traits of root traces include both distal tapering and dichotomous branching, unaccompanied by enlarged branch junctions.

The only one of these criteria not fulfilled by the suspected Yellow Banks Bluff root-trace fossils is the presence of carbonized material within traces, signifying former tissue. Of course, as is typical for trace fossils, body-fossil evidence of the tracemaker is not necessary for confirming identity, but the *in situ* nature of roots as trace-making parts of vascular plants makes such a combination more likely.

**MODERN TRACES:** As mentioned previously, Yellow Banks Bluff is eroding actively at a rapid rate (nearly 2 m per year), resulting in the fendering of mature trees from the maritime forest adjacent to the bluff (Potter, chap. 7). This erosion has also exposed the roots of trees still in place (however temporarily), which allows for viewing their root architecture and effects on the underlying Pleistocene sediments. In particular, examples of the root systems of the saw palmetto (*Serenoa repens*) and cabbage palm (*Sabal palmetto*) (fig. 5.7A) have their full subsurface architecture defined above and on the outcrop. In brief, these palms have 5–10 mm roots that radiate outward from a much thicker trunk (in the case of the cabbage palm) or rhizome (saw palmetto). The cabbage palm (Wade and Langdon, 1990) has a root system similar to that of the more fully described date palm (Zaid and de Wet, 2002). In contrast, the saw palmetto has a reclining, shallowly buried to emergent rhizome whose roots radiate from the rhizome's lower half (Fisher and Jayachandran, 1999). Accordingly, the two local palms are readily distinguished both from other plants and also from one another. The roots have a pervasive effect through their numerous downwardly oriented and radial penetrations of nearly

5 vertical m of strata in the outcrop.

Other considerations are of modern infauna mixing their traces with trace fossils in the outcrop, alluded to earlier with regard to modern *Ocypode quadrata* burrows. One of us (Martin) also noted that sphecids wasps (tentatively identified as *Stictia signata*) were actively burrowing into sandy slopes of eroded sand and vertical faces of the outcrop (fig. 5.7B), presumably constructing brooding chambers. We also wonder about the depth of bioturbation by modern infaunal insects toward the top of the stratigraphic section, and the amount of overprinting that may occur between modern meniscate burrows and fossil ones.

#### COMPARISON OF MODERN AND ANCIENT STORM-WASHOVER FANS

Keeping in mind Tobler's first law of geography, "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970), we examined some washover fans on St. Catherines Island (fig. 5.8), as well as some on Sapelo Island (fig. 5.8A). Some of the best-developed modern washover fans on St. Catherines are distributed along Seaside Spit, south of Yellow Banks Bluff (compare with fig. 5.1), behind a beach flanked with a narrow strip

of low dunes. Washovers consist of an apron of partly coalesced fans extending into Seaside Marsh; the apron makes up about 80% of Seaside Spit, which is 1.7 km long (Bishop et al., 2007: 51). These washovers are active during the same storms that erode Yellow Banks Bluff. The shoreline has retreated at rates ranging from 6.5 to 21 m a<sup>-1</sup> from 1979 to 2005, averaging 3.8 m a<sup>-1</sup> over the past 50 years (Goodfriend and Rollins, 1998; Prezant et al., 2002; Bishop et al., 2007). As sand is washed over protected intertidal marsh, relict marsh mud is exposed along the beach (Morris and Rollins, 1977). Bishop et al. (2007) reported that waves sort and deposit denser, dark heavy minerals over lighter quartz sand in the fans.

The surfaces of the washover fans are nearly smooth, gentle slopes that merge westward into sandy marsh and shallow sandy channels (fig. 5.9). These surfaces, particularly on their edges, are moist and are microbially bound, which subdues erosion by wind or water. The lower parts of the fans are the wettest, and these areas are inhabited by dense populations of fiddler crabs, either *Uca pugilator* or *Uca pugnax*, depending on whether the substrates are muddy or sandy, respectively (fig. 5.9B, C). The adjoining marsh is dominated by cordgrass (*Spartina alternifolia*) but higher sand flats are dominated by black rush (*Juncus roemerianus*). Washover fans support

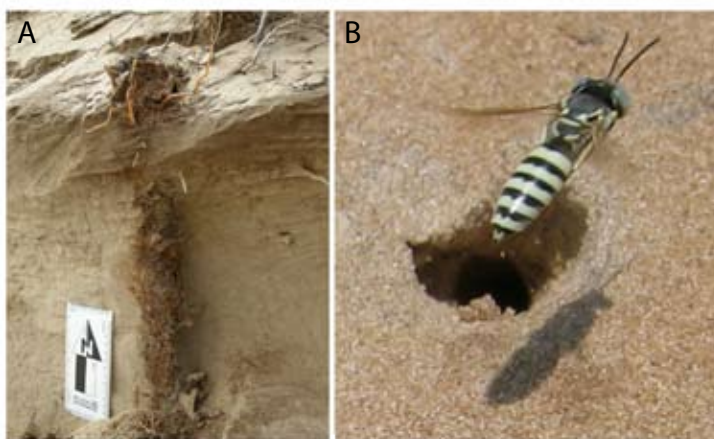


Fig. 5.7. Modern tracemakers associated with Yellow Banks Bluff. **A**, modern roots of cabbage palm (*Sabal palmetto*), imparting darker coloration around roots and staining nearby trace fossils; **B**, Vespoidean (tentatively identified as *Stictia signata*) burrowing into sand talus on eroded face of Yellow Banks Bluff.



Fig. 5.8. Aerial view of modern washover fans, St. Catherines Island, Georgia. **A**, overall view of northern third of St. Catherines, with Seaside Spit area (south of Yellow Banks Bluff) containing prominent washover fans; **B**, close-up of inset area showing fans (arrows) and characteristic fan morphology; note overlapping (coalescing) fans in places. Base maps from Google Earth™.

only a few species of plants and animals. The dominant organism is the sand fiddler crab, *Uca pugilator* (Prezant et al., 2002: 24). Accordingly, fiddler-crab tracks, scrape marks, feeding pellets, feces, and burrows are the most voluminous traces on fans. In addition, during our visit on June 1–6, 2007, we noted the presence of trackways of feral hogs (*Sus scrofa*), raccoons (*Procyon lotor*), great blue herons (*Ardea herodias*), sandhill cranes (*Grus canadensis*), and, closer to the shore, burrows of ghost crabs (*Ocypode quadrata*; fig. 5.9D–G). All of these animals can feed on fiddler crabs, which represent an abundant food source. Raccoons were responsible for numerous excavations of fiddler crab burrows; these ranged considerably in outline and depth, but represented significant disruptions of surface and subsurface sediments of the fan deposits, some as much as 20 cm deep and 30 cm wide (fig. 5.9E). Other potential vertebrate tracemakers on or adjacent to washover fans that are, or historically were, present on the Georgia coast include canids, felines,

otter, skunk, black bear, beaver, rabbit, opossum, bison, alligator, tortoise, terrapin, and rattlesnake, as well as numerous species of birds (Larsen, 1982: 164–165; Laerm et al., 1999). A newcomer to Sapelo Island is the armadillo, which may have come over to the island in the 1970s (fig. 5.9G). On the proximal side of fans (abutting coastal dunes), sea turtle nests might also be incorporated in the proximal portions of washovers.

Trackways are common on the surface of the fans. Vertebrate trackways are dominant on the distal part of the fan, and invertebrate trackways on the proximal part. Microbial binding of fan surfaces (fig. 5.9C) also may aid in preserving trackways, which can be identified to species for several days or weeks after their formation. As mentioned earlier, vertebrate trackways include those of great blue heron (*Ardea herodias*), raccoon (*Procyon lotor*), feral hog (*Sus scrofa*), and other birds and mammals. In marked contrast to their behavior in other environments, all the animals tend to forage in straight lines while on the

relatively featureless parts of the washover fans (fig. 5.9G). Raccoons and feral hogs typically follow established paths in the dunes and marsh edges, fanning out to forage nocturnally in more open areas of the marsh and washover fans. In contrast, herons are solitary and stalk their prey diurnally.

Raccoons (*Procyon lotor litoreus*) have been intensively studied on St. Catherines Island (Harman and Stains, 1979; Anderson and Hudson, 1980). These omnivores have extremely varied diets, but feed largely on fruits when available (Harman and Stains, 1979). In the winter and spring, as plant foods such as acorns and fruits become scarce, their diet shifts to small invertebrates, including marsh crustaceans. Sand fiddler crabs (*Uca pugnator*) are the raccoons' most important food item during these seasons (fig. 5.8E); other marsh crabs ("*Eurytium depressum*," *Panopeus herbstii*, *Sesarma reticulatum*, and probably *Uca minax*) are eaten as well, but mainly along marsh creeks and oyster beds. The brown squareback crab, *Sesarma cinereum*, is available in high marsh areas but is present (and eaten) only in low numbers. Harman and Stains (1979) observed groups of as many as six raccoons foraging in the marsh on relatively warm days in the coldest months (January and February); the fiddler crabs become active when their burrow temperatures reach 16°C (Teal and Teal, 1969), and this is when the raccoons prey upon them. Raccoons on St. Catherines tend to forage within ranges that may exceed 100 ha, but ranges shift seasonally with food availability (Harman and Stains, 1979; Anderson and Hudson, 1980). The animals are basically nocturnal but are sometimes active during the day as well.

In terms of invertebrate trackways, ghost crabs (*Ocypode quadrata*) dominate the upper (proximal) part of a fan, whereas the lower (distal) fan would primarily contain sand-fiddler crab tracks (*Uca pugnator*). We expect that other invertebrates may also leave tracks on washover surfaces, but we currently have no information on which taxa. Ghost crabs (*Ocypode quadrata*) are most common in back-beach and foredune facies on Georgia islands, but also live on washover fans within a short distance of the sea; these decapods require seawater for reproduction, respiration, and hydration (Martin, 2006). Furthermore, Duncan (1986) found that: (1) the more inland ghost crab burrows are particularly large; (2) burrows made on gently sloping surfaces, such as washovers, dip relatively steeply; and (3) burrow

apertures tend to point downslope. As mentioned earlier, the fossil burrow *Psilonichnus* is often ascribed to ghost crabs (Frey, Curran, and Pemberton, 1984; Frey and Pemberton, 1987), but also could have been formed by other ocypodids (such as fiddler crabs) and other decapods (Nesbitt and Campbell, 2006).

The tracemaking activities of the sand fiddler crab (*Uca pugnator*) have been documented on St. Catherines washover fans (Frey, Curran, and Pemberton, 1984: figs. 3a–c), and more extensively on Sapelo Island (Frey, Basan, and Scott, 1973: fig. 1a; Basan and Frey, 1977). These fiddlers walk and burrow sideways as well as grazing on the substrate as surface-deposit feeders, and all of these activities create distinctive traces with some potential for preservation in the geological record. As described above, these are simple, L- to J-shaped burrows having a circular to oblate cross section about 1–2 cm in diameter (Basan and Frey, 1977). Deery and Howard (1977) also point out how washover fans on Ossabaw Island had thin layers of eolian sands on their top surfaces, which we observed as well on St. Catherines and Sapelo Island fans. These windblown sands then can passively fill concavities, such as fiddler crab burrows, which one of us (Martin) documented on Sapelo Island (fig. 5.6).

*Uca pugnax* digs complex burrow systems, though they start out as simple burrows similar to those of *Uca pugnator* (Frey, Basan, and Scott, 1973: fig. 1d; Basan and Frey, 1977). Simple L- to J-shaped burrows may be indistinguishable from those of *Uca pugnator* in form and size, but (as described above) *Uca pugnax* can proceed to construct a U-shaped burrow, or even a complex system consisting of U-shaped components. The basal part of the burrow of *U. pugnax* tends to be curved, while that of *U. pugnator* tends to be more level (Frey and Basan, 1977). Burrows of both may be present in high marsh environments, and one or both are probably present at Yellow Banks Bluff.

Presumably, washover fans during Silver Bluff time and today share a common biota; sea level, forest vegetation, and hence climate may have been similar. The Pleistocene network burrows we interpret here are morphologically similar to modern fiddler crab burrows, and were probably made by *Uca pugnax*, perhaps accompanied by *Uca pugnator* in a mostly barren high marsh environment atop a washover fan. Pleistocene *Taenidium* resembles the burrows



of modern cicada nymphs (Gregory, Martin, and Campbell, 2004), and attests to the freshening of the high marsh. Evidently the washover fan surface was eventually buried and covered by a backdune meadow; today it is the site of a modern maritime forest. Pleistocene trackways, if present, would not be readily seen in vertical exposures of unconsolidated sand, but might be visible on bedding planes after consolidation to sandstone. Slight lithologic differences, for instance, in heavy mineral concentration or microbial consolidation, might result in bedding planes being more easily split in the distant future. The species list would have been markedly different before the Pleistocene mass extinction, which eliminated most of the larger animals. Pigs were introduced in historical times; they commonly forage along beaches and in marshes as well as in the forests. The only known Pleistocene hooved mammals (artiodactyls) that may have inhabited Georgia barrier islands, and thus made trackways analogous to those of hogs, would have been deer and bison (Kurtén and Anderson, 1980; Laerm et al., 1999). Other traces of hogs, particularly their extensive root-

ing and excavation of deep subterranean nests (e.g., those of sea-turtle eggs) have no known Pleistocene equivalent.

#### SUMMARY OF WASHOVER FAN ICHNOLOGY

In summary, we propose that ancient storm-washover fans, such as those interpreted here from the Silver Bluff Formation, may contain distinctive and diagnostic suites of plant, invertebrate, and vertebrate trace fossils that can be applied to interpreting similar ancient deposits on the Georgia barrier islands and elsewhere. Discerning such suites requires a thorough knowledge of the behavioral ecology of modern tracemakers and their traces in washover fans, the latter of which can then be reasonably compared to trace fossils in ancient deposits. As a result, the geological histories of these islands can be more accurately assessed; in some instances, the smallest macroscopic evidence (e.g., fiddler crab burrows) can be the most important in discerning large paleoenvironmental changes in the Georgia barrier islands.

Fig. 5.9 (left). Modern washover fans and their ichnology. **A**, washover fan immediately adjacent to (west of) Cabretta Beach, Sapelo Island; photograph is digital composite of three successive, lateral shots (left to right) from same vantage point; **B**, distal end of same washover fan showing transition between sandy substrates of fan and muddy marsh, including abundant burrows of *Uca pugnax* at transition; **C**, organic-rich muddy zone in transition of same washover fan with algal films (shiny area to the right), presenting a probable model for Yellow Banks washover-fan strata; **D**, typical vertebrate tracks of modern washover fans: tridactyl tracks of sandhill crane (*Grus canadensis*) and artiodactyl hoofprints of feral hog (*Sus scrofa*); note abundant burrows and feeding pellets of *Uca pugilator*, and how some of the pellets fill the tracks of both vertebrates: St. Catherines Island; scale = 10 cm. **E**, excavation trace of raccoon (*Procyon lotor*) predation on *Uca pugilator*, plus dead fiddler crab (left): St. Catherines Island; scale = 10 cm. **F**, raccoon trail in proximal part of washover fan: St. Catherines Island; **G**, raccoon and armadillo (*Dasypus novemcinctus*) trackways crossing edge of washover fan depicted in A, with *Spartina alterniflora* (tall grass) and groundcover of *Salicornia virginica* denoting marsh: Sapelo Island, Georgia.





## CHAPTER 6

### QUATERNARY VEGETATION AND DEPOSITIONAL HISTORY OF ST. CATHERINES ISLAND

FREDRICK J. RICH AND ROBERT K. BOOTH

The Quaternary vegetation history of the southeastern United States has not been well studied, particularly in comparison to more northerly regions of North America, and this is even more apparent on the coastal plain of Georgia (e.g., Watts, 1971; Rich and Spackman, 1979; Rich 1984a, 1984b, 1996; Rich and Pirkle, 1998). The coastal region of Georgia is characterized by a string of barrier islands that formed during the late Pleistocene and have been continually modified during the Holocene through depositional and erosional processes. These processes continue to shape the geomorphology and hydrology of the barrier island region, resulting in a dynamic mosaic of salt, brackish, and freshwater marshes and sandy, well-drained upland soils dominated by southern pine and oak forests.

St. Catherines Island is one of the least disturbed of the barrier islands along the Georgia coastline, and has been the subject of a suite of studies over the past several decades aimed at better understanding its geological development, current vegetation, and vegetation history. For example, maps and descriptions of the principal plant communities currently on the island have been developed (Somes and Ashbaugh, 1972; Coile and Jones, 1988; Reitz et al., 2008) and ethnobotanical studies have revealed information on the composition of plant communities prior to European disturbance (Thomas, 2008). However, a longer-term perspective on the vegetation and developmental history of the island has been provided by lithostratigraphic studies of pollen preserved in a range of depositional environments. The following report is a distillation and summary of the palynological work performed on St. Catherines Island

over the past decade. The distribution of sites is scattered, the ages of deposits are not systematically distributed, and the available records are discontinuous, so this compilation cannot be seen as the result of a comprehensive study. However, the accumulation of data of different ages from many localities shows that the sediments of St. Catherines Island contain a wealth of palynological and paleoecological information that bears on our understanding of ancient terrestrial ecosystems of the Georgia coastal plain.

#### SITE NETWORK

Palynological samples from St. Catherines Island have been collected from various locations and include exposed dune sections as well as sediment cores; our site network includes areas within the northern portion of the island, which is Pleistocene in age, as well as sites within the accretionary complex of the southern, Holocene-aged portion of the island (fig. 6.1). In addition to samples from St. Catherines Island, we discuss samples of probable late Pleistocene age collected from Gray's Reef, located about 32 km southeast of St. Catherines Island. Data from some localities have been published elsewhere (Booth and Rich, 1999; Booth, Rich, and Bishop, 1999; Booth et al., 1999; Russell et al., 2009), and others are presented here for the first time.

#### METHODS

In some cases, sediments were collected merely as grab samples (e.g., South Beach samples); in other cases, sediment cores were col-

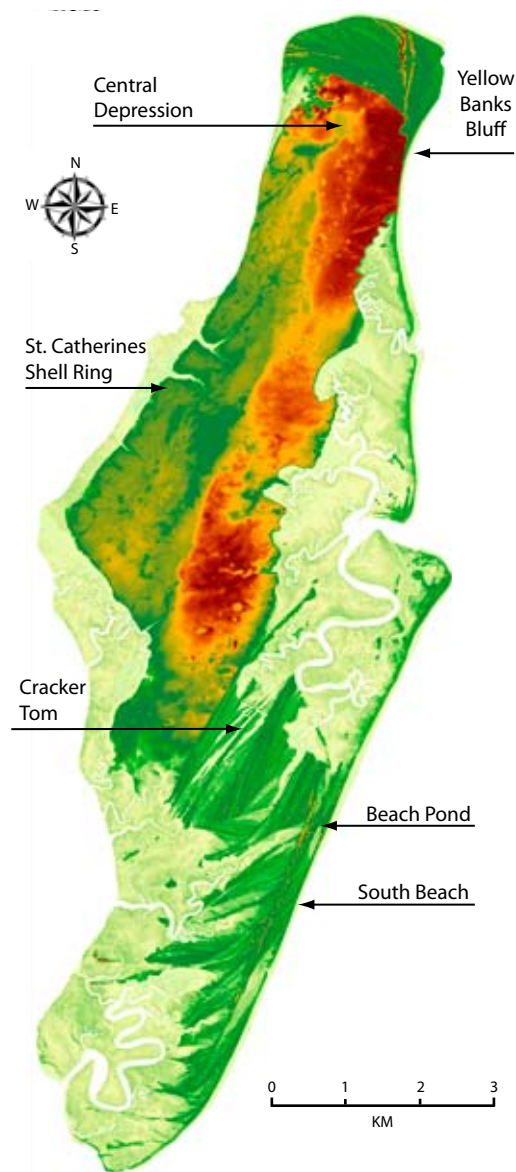


Fig. 6.1. Contrast-enhanced aerial photograph of St. Catherine's Island showing the location of sites where palynological samples have been collected and analyzed.

in each sample, and for most samples more than 500 grains were counted. Percentages for arboreal taxa were calculated using a total arboreal sum, and percentages for other taxa were calculated using a total sum. To facilitate comparison of pollen samples analyzed from the island, and particularly to compare the composition of late Pleistocene and Holocene samples, pollen data were subjected to hierarchical cluster analysis (flexible- $\beta$  linkage method,  $\beta = -0.25$ ) using Sørensen's distance measure (McCune and Grace, 2002).

Ages of Holocene sediments discussed in this chapter are presented in both radiocarbon years and calendar years, following the conventions set out in the preface (see also appendix 1).  $2\sigma$  ranges for calendar-year ages were determined using the INTCAL 2004 calibration curve (Reimer et al., 2004). Ages of Pleistocene samples are reported in radiocarbon years only.

A note concerning nomenclature is also appropriate at this point. Taxonomists periodically change the names we use to identify plant families or even species. Thus, to the extent that the works we have compiled here span a period of years, and because some of those names have changed with time, there are differing names that are actually synonyms. A good case in point is the grasses, known earlier by the familial name Gramineae, but more recently as Poaceae. Both terms will be found in this text, depending upon when the data were collected, which name was used at the time, and when a particular publication appeared. Families such as the composites are so large and complex that the nomenclature dealing with them is equally complex. You will see Compositae, Tubiflorae, and Asteroideae appearing in this text. These all refer to plants that are related to daisies, sunflowers, or dandelions. We have tried to identify synonymies where they do occur. Additionally, scientific names and common names appear, and we have attempted to include the common name in the first use of every scientific name.

## RESULTS AND DISCUSSION

We discuss the vegetational and developmental history of the island by first presenting the results obtained from the individual sites and then concluding with a more synthetic discussion of the geological and vegetation development of the island.

lected using a vibracorer (Bishop et al., chap. 10). Standard techniques were used to isolate pollen, spores, and other palynomorphs from collected samples (Traverse, 2007). A minimum of 300 palynomorphs were identified and tallied

#### YELLOW BANKS BLUFF

A sample of humate-bearing sand was collected from just above the active beach at Yellow Banks Bluff (fig. 6.1), and given its location and stratigraphic context, it is probably late Pleistocene in age. The preservation of pollen in the sample was not ideal, as the grains were all unusually small, suggesting anomalous conditions during deposition and/or diagenesis of the deposit. Likewise, many pollen grains were nondescript in appearance and difficult to identify, perhaps representing poorly preserved *Alnus* (alder) or Tubuliflorae (composites) grains that had lost part of the external pollen wall (ektexine). Among the numerous identifiable grains, the most abundant arboreal taxa were *Carya* (hickory and pecan) and *Pinus* (pine); however, a very large amount of pollen from herbaceous plants and woody shrubs characterized the sample, including abundant Tubuliflorae (41% of the palynoflora), *Alnus* (17%), Poaceae (grasses, 10%), and *Ambrosia* (ragweed, 5%; table 6.1).

The palynoflora of the Yellow Banks Bluff sample suggests the local presence of an alder–composite grass community unlike anything that occurs on the island now. This community appears to have been deposited in or near an alder-dominated wetland, perhaps similar to the tag alder wetlands of the upper Midwest, which are commonly dominated by *Alnus rugosa*, species of the composite *Eupatorium*, and several species of grasses. Additionally, there is little or no indication of halophytic species in the Yellow Banks Bluff sample; there were no Chenopodiaceae/Amaranthaceae (lamb's quarters, goosefoot, etc.), and *Iva* (marsh elder, a common seaside inhabitant) constituted less than 1% of the pollen/spores.

#### GRAY'S REEF

The palynological composition of three samples from Gray's Reef National Marine Sanctuary illustrates yet another aspect of the coastal flora as it probably appeared during the Last Glacial Maximum (table 6. 1). Russell et al. (2009) noted that the transient cooccurrence of “warm-” and “cool-climate” taxa may have been common in the Southeast during the Late Glacial Maximum. A coastal/maritime forest appears to have occupied the vicinity of Gray's Reef National Marine Sanctuary, east of the Georgia mainland in an area currently submerged beneath about 18 m of seawater. Sediment cores from the reef in-

cluded medium gray clay with shell fragments; palynological samples were recovered 5–10 cm below the tops of two sediment cores. Pollen/spore recovery was excellent, and included such common taxa as *Pinus*, *Quercus* (oak), *Carya*, and *Liquidambar* (sweet gum). Other taxa, however, including *Alnus*, *Picea* (spruce), and *Tsuga* (hemlock) typically occur today in more northerly latitudes (Rich and Pirkle, 1994), or higher altitudes, such as the Piedmont.

#### ST. CATHERINES SHELL RING

The St. Catherines Shell Ring (aka Long Field Crescent, Long Field Shell Ring; Bishop et al., 2007; Thomas, 2008; Sanger and Thomas 2010; Bishop et al., this volume, chap. 10) is on the western margin of the island (fig. 6.1), and is the location of a large shell ring of Native American construction. In chapter 10 (this volume), Bishop and colleagues illustrate the stratigraphy of six cores collected from the site and inferred stratigraphic correlations (see fig. 10.6). Several samples from these cores have been analyzed palynologically, including a sample from a shell bed located at 322 cm below the surface and dated at  $>44,800$   $^{14}\text{C}$  yr B.P. (Beta-217823). Several peat samples from just over 4 m deep were recovered from shell ring vibracore #2, and two radiocarbon dates were obtained from these peat samples. These dates indicate that deposition of the peat occurred at  $39,130 \pm 660$   $^{14}\text{C}$  yr B.P. (Beta-217824) and  $29,440 \pm 260$   $^{14}\text{C}$  yr B.P. (Beta-217825 (fig. 10.6).

The pollen assemblage from the deep shell bed was dominated by *Pinus* (common names have already been given) and *Quercus*; these occurred in approximately equal percentages (table 6.1). Other arboreal types that were likely present in the region include *Carya*, *Liquidambar*, *Nyssa* (black gum/tupelo), *Betula* (birch), Cupressaceae/Taxodiaceae (probably cypress), and *Ulmus* (elm). Abundant nonarboreal types included Chenopodiaceae/Amaranthaceae type (probably salt marsh chenopods) and Poaceae, consistent with deposition in or near a salt marsh environment. The palynology of the sample is quite similar to that of the lowermost sample from a core from Cracker Tom Hammock (CTH559; discussed in the next section), which is also presumably late Pleistocene in age and characterized by codominance of *Pinus* and *Quercus*, and significant amounts of *Carya*, *Liquidambar*, Cupressaceae/Taxodiaceae, Poace-

ae, and Chenopodiaceae/Amaranthaceae type. Trace amounts of *Fagus* (beech) also occurred in both the shell bed sample and the lowermost Cracker Tom Hammock sample.

The lowermost peat captured in St. Catherines Shell Ring core #2 was dominated by *Pinus* (table 6. 1). Other common arboreal types include *Quercus*, Cupressaceae/Taxodiaceae, *Carya*, *Betula*, *Fagus*, *Liquidambar*, and *Nyssa*. The relatively high *Fagus* percentage (3%) suggests the local presence of beech populations. Beech currently does not occur in coastal Georgia, except for some disjunct populations on north-facing bluffs of the Savannah River. The nonarboreal pollen of the peat indicates deposition in a freshwater peatland environment, dominated by ferns (*Osmunda*, *Woodwardia*-type), grasses, and sedges.

Additional analyses of subsamples of the St. Catherine Shell Ring peat collected from core 2 (location indicated on fig. 10.2) revealed similar results. These samples came from 4.06–4.13 m below land surface, and consisted of subsamples of a single piece of dense, brittle, grayish black (N2) sediment. Grasses were the most abundant pollen type in these three subsamples, and these were associated with abundant cypress-type (Cupressaceae/Taxodiaceae/*Taxodium*), royal/interrupted/cinnamon fern (*Osmunda*), and monolete fern spores likely attributed to Virginia chain fern-type (*Woodwardia*). The peculiar abundance of grape (*Vitis*) in one subsample is also notable. The palynoflora suggests a fern-and-grass-dominated wetland with nearby cypress trees that hosted grape vines. Similar landscapes can be seen in the eastern Okefenokee Swamp, particularly in areas of Chesser and Coward Lake prairies where vast grassy wetlands (locally referred to as prairies) are dotted with groves of cypress. An otherwise significant taxon in the Okefenokee (*Nymphaea*, the white water lily) is absent from the St. Catherines Shell Ring peat, a condition that might indicate shallow, or completely absent standing water at the time of its deposition.

#### CRACKER TOM TRANSECT

The area of Cracker Tom Hammock/Cracker Tom Causeway contains some of the oldest accretionary ridges on the island (see chap. 10: fig. 10.7), as it is directly adjacent to the northern Pleistocene-age island core. Cores have been collected from this area and studied on three occasions, by different investigators, and the results of these analyses appear to be central to our un-

derstanding the Pleistocene and Holocene depositional histories of St. Catherines Island.

A core was collected from the Cracker Tom Bridge locality in 1990 by Gale Bishop, and a small sample of a basal peat was radiocarbon dated (UGA-6267) and determined to be  $28,370 \pm 340$   $^{14}\text{C}$  yr B.P. (fig. 6.2). The palynological composition of the samples was dominated by monolete spores (spores resembling microscopic kidney beans) of what could most easily be attributed to a common wetland fern of the southeastern United States, *Woodwardia* spp. Two species, *W. virginica* and *W. areolata*, are common in the Southeast. Though Gleason and Cronquist (1963) identify both species as living in "swamps," Rich (personal obs.) has seen *W. virginica* to be more common in extensive flooded wetland situations, while *W. areolata* seems to prefer occupation of cypress knees, other areally limited exposed surfaces within freshwater wetlands, and mainland areas that lie upslope of perennially flooded locations. *W. virginica* forms large communities (probably clones) that occupy emergent vegetative mats in the Okefenokee Swamp. These mats are most common in open, sunny areas where there is little competition from any other species; Coward Lake Prairie in the Okefenokee is a characteristic site. The coincidental appearance of other herbaceous species such as the Chenopodiaceae/Amaranthaceae, Compositae, Gramineae, and Cyperaceae (sedges) is fully consistent with the presence of *Woodwardia*. The sample was almost certainly derived from a fern-dominated freshwater wetland.

Booth (1998) collected and analyzed three cores for their palynological content from the Cracker Tom area, and recovered what appears to represent the same peat deposit at the base of a core from Cracker Tom Bridge (CTB). The peat from this core was dated to  $47,620 \pm 2500$   $^{14}\text{C}$  yr B.P. (USGS WW 1197), and if this radiocarbon date is accurate, the peat is considerably older than the peat collected from the same area by Bishop in 1990. However, the pollen assemblage in the peat of the Cracker Tom Bridge core was essentially the same as the sample analyzed from the 1990 core (table 6. 1). Monolete fern spores dominated the sample, and other taxa in the sample included insect-pollinated composites (aka Asteroideae), the Chenopodiaceae/Amaranthaceae, grasses, the Cyperaceae, *Polygonum* sp. (common freshwater herbs, generally known as knotweed), *Sagittaria* sp. (arrowhead, also com-



mon in freshwater), and *Sambucus* sp. (elderberry). A detailed morphological analysis of the fern spores suggested that they were most similar to spores produced by the Virginia chain fern (Booth and Rich, 1999), *Woodwardia virginica*. The pollen and spore composition of the peat sample indicated the presence of a terrestrial hydrophytic community that is common in southeastern Georgia today. Even extralocal taxa, including pine, oak, sweet gum, cypress, and wax myrtle (*Myrica*) are typical of freshwater wetlands; there was no indication of northern taxa in the peat.

Booth's (1998) analysis of his three cores resulted in the identification of 50 taxa among the cores. The general characteristics of the three cores were similar; *Pinus* and *Quercus* dominated every sample, except for the ancient peat from CTB. High percentages (40%–55%) of broken pine pollen were common in all samples. Though broken pines (i.e., grains broken in halves) are not unusual in samples of any provenance, the clear abundance of them in some samples has been related to deposition in nearshore coastal environments (Rich and Pirkle, 1998). Strata above the peat in the CTB core included a sequence of clastic sediments; fortuitously, immediately above a clear disconformity (i.e., a depositional break separating sedimentary units) on the upper surface of the peat lay unconsolidated sand with abundant shells. One *Americardia media* L. valve was removed from the core, and it bore beneath it a small cluster of charcoal fragments. Both the shell and the charcoal were sent to the USGS for radiocarbon analyses. The shell was determined to have a radiocarbon age of  $4060 \pm 50$   $^{14}\text{C}$  yr B.P. (USGS WW1198: 4420–4810 cal B.P.) while the charcoal was dated at  $6020 \pm 50$   $^{14}\text{C}$  yr B.P. (USGS WW1262: 6740–6990 cal B.P.).

Linsley and Rollins (in Bishop et al., 2007) conducted sedimentological investigations of four additional cores from the same vicinity and their paleoenvironmental interpretations are discussed in chapter 10, this volume (esp. fig. 10.7). The peat illustrated at the base of the Linsley and Rollins Cracker Tom Bridge core is almost certainly the same peat that was recovered in the previous cores from the area, and was dated by  $22,600 \pm 310$   $^{14}\text{C}$  yr B.P. (Pitt-831). This age is more similar to the age obtained from the peat collected by Bishop in 1990 than it is to the older radiocarbon date obtained by Booth (1998). However, the relationships that the Bishop and Linsley/Rollins peats described above have to the

sample described by Booth (1998) and Booth and Rich (1999) have yet to be determined with certainty. The great differences in dates must be reconciled, though the range of ages over a 10,000 year period are similar to the range of ages determined for the deeply buried peat samples from the St. Catherines Shell Ring (see above).

#### BEACH POND

Beach Pond is one of the remaining freshwater enclaves that lies close to the coast on the eastern shore of St. Catherines Island. Booth (1998) and Booth et al. (1999) provided an analysis of a core recovered from Beach Pond that represents a record of Holocene deposition in that area of the island. The core was 4.5 m long, and consisted of sand, clay, and peat. Palynostratigraphy revealed dynamic changes in environments of deposition and plant communities during the time of sediment accumulation. The lower portion of the core accumulated under nearshore marine conditions, and probably represents deposition in a shallow lagoon that would have been located south of the island at that time.

The pollen composition of the lower sediments in the Beach Pond core was characterized by abundant pollen of *Pinus*, and, similar to the Cracker Tom results, many broken grains were encountered (fig. 6.3). A wood fragment was recovered from the uppermost portion of the lagoonal facies, and was dated at  $1210 \pm 40$   $^{14}\text{C}$  yr B.P. (1010–1260 cal B.P.; Beta-115910). Tidal-flat strata overlay the wood-bearing unit, and were in turn overlain by a thin peat layer derived from what was probably an interdunal swale community dominated by *Myrica*. A return to brackish marsh conditions subsequently occurred, as indicated by the peculiar presence of the pollen of *Limonium* (sea lavender) and species common to upper areas of the salt marsh environment. Pollen possibly attributable to *Salicornia* (glasswort, or a similar member of the Chenopodiaceae or Amaranthaceae) and abundant grass pollen accompanied the *Limonium*, consistent with a brackish marsh community. The freshwater pond community that stands at the site now was established as the salinity at the site decreased over time and was indicated by the abundance of freshwater taxa, including *Typha* (cattail), sedges, and the very distinctive megaspores of the floating fern *Azolla*. Fluctuations in sea level, the advent of erosional episodes and storm overwash events, and anthro-

**TABLE 6.1**  
**Relative Abundances of Pollen and Spores from Late Pleistocene-Age Samples at**  
**Yellow Banks Bluff, Gray's Reef, Long Field (near St. Catherines Shell Ring), and**  
**Cracker Tom Bridge Collected in 1990**

	Yellow Banks Bluff <sup>a</sup>	Gray's Reef <sup>a</sup>	Gray's Reef <sup>a</sup>	Gray's Reef <sup>a</sup>	Long Field shell <sup>b</sup>	Long Field peat <sup>b</sup>	Long Field core 2, sample 1 (4.06– 4.13 m) <sup>a</sup>	Long Field core 2, sample 2 (4.06– 4.13 m) <sup>a</sup>	Long Field core 2, sample 3 (4.06– 4.13 m) <sup>a</sup>	Cracker Tom Bridge, 1990 core, basal peat
<i>Acer</i>	0	0	0	0	0	0	0.5	0.6	0.8	0
<i>Betula</i>	0	0.9	1.3	1.1	0.8	2.9	2.1	0	0.8	0
<i>Carya</i>	25.3	5.3	2.6	1.4	4	7.6	1.6	3.1	1.5	0
<i>Castanea</i>	2.3	0.4	2.2	0.7	0	0	0.5	0.6	1.5	3.6
<i>Fagus</i>	2.3	0.9	0.4	0	0.4	2.9	3.8	4.4	5.4	0
<i>Fraxinus</i>	1.1	0.4	0.4	0.7	0	0	0.5	0	0	0
<i>Liquidambar</i>	0	2.6	0	0.4	2.0	1.1	2.2	1.3	0.8	3.6
<i>Nyssa</i>	0	0	0	0	0.7	0.7	0	1.3	0.8	0
<i>Pinus</i>	62.1	61.7	75.0	78.6	45.2	57.8	22.6	40.6	20.0	82.1
<i>Quercus</i>	4.6	19.8	16.8	15.2	42.8	19.1	7.5	8.8	10.8	7.1
<i>Taxodium</i>	1.1	3.1	0	1.1	3.6	8.7	58.1	39.4	57.7	3.6
<i>Ulmus</i>	1.1	0.9	1.3	0.7	1.2	0	0.5	0	0	0
<i>Alnus</i>	19.3	2.0	0.7	1.7	0	0.5	1.5	0	0.3	0
<i>Ambrosia</i>	5.3	0.8	0.6	0.5	1.6	0.7	0	0.3	0.6	0
Apiaceae	0	0	0	0	0	0.2	0	0.6	0	0
Caryophyllaceae	0	0.3	0	0	0	0	0.3	0	0	0
Chenopodiaceae / Amaranthaceae	0	12.8	4.8	4.3	5.2	2.4	0.6	0.6	0.3	6.7
<i>Corylus</i>	0	0	0.2	0.5	0.7	0.5	0	0	0	0
Cyperaceae	0	1.0	0.2	0	0.3	2.6	0	0	0	2.1
Ericaceae	0.1	0	0	0	0	0	0	0	0	0
<i>Ilex</i>	1.4	0	0	0	0	0.2	0	0.6	0	0
<i>Iva</i>	0.3	0.5	0.4	0	0.3	0	0	0	0	0
<i>Myrica</i>	0.8	1.0	0.2	0.2	0.3	0.2	1.5	1.8	0.3	0
<i>Osmunda</i>	0.3	0.5	0.2	0	0.3	7.5	6.4	9.1	5.8	0
<i>Ostrya-Carpinus</i>	0.3	0	0.2	0	0	0	0.3	0.3	0.3	0
Poaceae	11.2	2.3	4.0	0.7	5.2	19.2	25.0	30.0	28.4	5.0
<i>Polygonum</i>	0	0.5	0	0	0	0	0	0	0	0
<i>Salix</i>	1.7	0.5	0	0.5	0	0.2	0	0	0.6	0.8
<i>Sphagnum</i>	0	0.2	0.2	0	0.7	0	0	0	0	0
Tubiflorae	45.1	1.3	0	0	0.7	0	0.3	0	0.3	3.3
<i>Typha</i>	0	0	0	0	0	0	0	0	0.3	0
<i>Typha latifolia</i>	0	0	0	0	0	0	0	0	0	0
<i>Vitis</i>	0	0	0	0	0	0	0	0.9	10.3	0
Woodwardia type	1.9	1.7	0.6	0	1.0	19.7	7.3	7.0	9.4	70.0
Microforaminifera	0	17.8	42.4	25.1	1.3	0	0	0	0	0

<sup>a</sup>Analyst F.J. Rich.

<sup>b</sup>Analyst R.K. Booth.

pogenic changes such as road building and well drilling have probably all influenced the development of communities at Beach Pond by altering hydrological flow patterns and the relative influence of saltwater and freshwater at the site.

#### SOUTH BEACH PEAT

Three samples of sediment were recovered from shells that were entombed in peat that was exposed on South Beach, St. Catherines Island (Rich and Pirkle, 1998). The shells were articulated and were removed from their original points of burial, so the sediments are believed to faithfully represent the nature of the vegetation at the time of burial, at least as it is represented by pollen and spores.

Shells of *Mercenaria mercenaria* (quahog), *Crassostrea virginica* (eastern oyster), and *Geukensia demissa* (Atlantic ribbed mussel) are very common in modern-day salt marshes on the Atlantic coast of Georgia. These genera are also common in the South Beach deposit, and radiocarbon dates on shells revealed ages of  $500 \pm 80$   $^{14}\text{C}$  yr B.P. (*Crassostrea*, UGA-6161),  $670 \pm 90$   $^{14}\text{C}$  yr B.P. (*Mercenaria*, UGA-6162), and  $580 \pm 90$   $^{14}\text{C}$  yr B.P. (*Geukensia*, UGA-6163). A sample of wood was removed from the deposit as well and yielded an age of  $430 \pm 90$   $^{14}\text{C}$  yr B.P. (UGA-6160). All four radiocarbon dates are statistically indistinguishable at the 95% level (t-test), and the calibrated range of the pooled mean indicates an approximate age of cal A.D. 1310–1440 (2 $\sigma$  range). In cultural terms, this falls within the latest Irene phase, immediately prior to establishment of the mission Santa Catalina de Guale (Thomas, personal commun.).

The vegetation existing on or near the island during the time of shell and peat deposition at South Beach was essentially the same as current vegetation. The pollen/spore content of the shell fillings (see Rich and Pirkle, 1998) consisted of trace amounts of monolete fern spores, *Alnus*, and *Castanea* (American chestnut) and minor amounts of *Corylus* (hazelnut), *Fraxinus* (ash), *Nyssa*, *Salix* (willow), and *Ulmus* (table 6.2). *Carya*, Poaceae, *Liquidambar*, and *Myrica* were also present in small amounts, with the latter three taxa being most consistently present. Chenopodiaceae/Amaranthaceae, Tubuliflorae, and *Taxodium* were all common in the samples, with *Taxodium* being the most consistently abundant of these three taxa. Finally, *Quercus* and *Pinus* clearly dominated the samples (table 6.2). Re-

sults indicate that at the time of deposition of the shells and peat, sources of abundant pollen that could accumulate in an intertidal setting were the same plants that occur in such a setting on the island now. Clearly this is not surprising given the young age of the deposit; however, the fact that an intertidal salt-marsh occurred in an area where there is now open beach and pounding surf highlights the dynamic nature of the surficial processes that continually modify barrier island environments.

Beach retreat on South Beach was dramatically demonstrated in March 1993 when Flag Pond (a former freshwater marsh on South Beach) was made a saltwater lagoon by breaching of the sand ridge that had separated it from the ocean (Bishop et al. 2007). Since that date, the development of a tidal channel, known as Flag Inlet, and the continuing retreat of the beach ridge have changed the former cattail marsh to a system of tidal flats and salt marsh. Thus the shoreline retreat we have witnessed in the recent past appears to have been a factor in island development nearly 600 years ago.

#### THE CENTRAL DEPRESSION

The Central Depression is an enigmatic topographic feature of St. Catherines Island that has only been recently investigated from a geological perspective. Bishop et al. (2007) illustrate its general location on the island, and Reitz et al. (2008) relate the Central Depression to both the hydrologic characteristics and soil types of the island. According to the latter authors, accounts written by Jonathan Bryan (1753, as reported in Thomas, 2008) describe a “perfect Meadow being a large Savanna of about a Mile or Mile and half wide and four or five Miles long, and finely water’d with Springs.” Additionally, “cristial [crystal] Streams in winding rills proceeds the rising Mounts and flow the verdant meads....” It does not take much imagination to construct a vision of well-watered wetlands that lay over a large portion of the middle of St. Catherines Island. Reitz et al. (2008) note that the “perfect Meadow” was drained by the construction of dragline ditches in the 1930s. The legacy of the meadow is now preserved in the subsurface, if it exists at all, and recent attempts have been made to recover strata from the Central Depression that might tell us something of its history.

In the spring of 2008, R.K. Vance and three students from Georgia Southern University

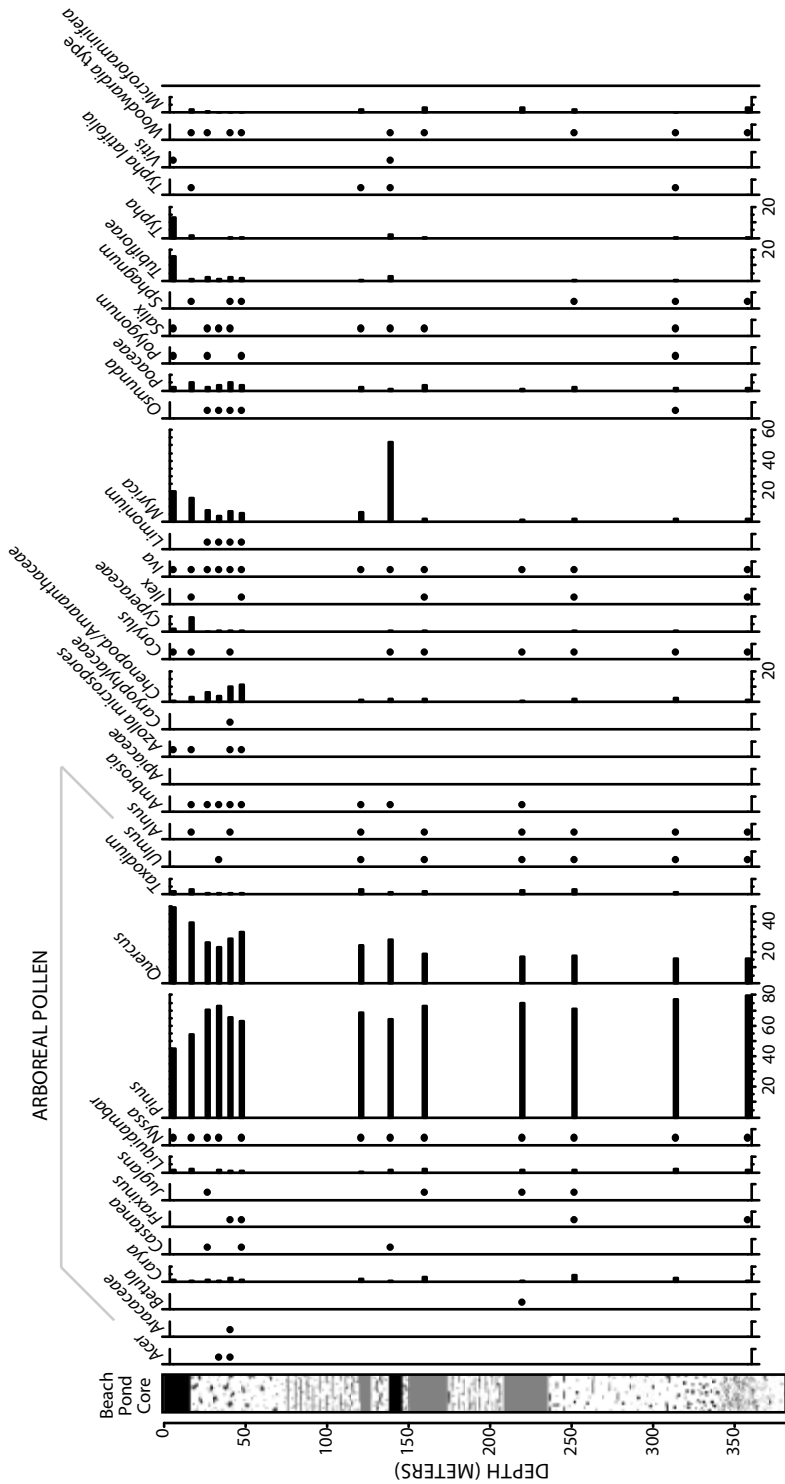


Fig. 6.3. Relative abundance of pollen and spores from three cores collected from the Beach Pond area (modified from Booth et al., 1999). Core stratigraphy and stratigraphic position of the samples are shown to the left.

TABLE 6.2  
**Relative Abundances of Pollen and Spores  
from Peat Exposed on South Beach**  
Analyst: F.J. Rich.

	South Beach <i>Geukensia</i> infilling	South Beach <i>Crassostrea</i> infilling	South Beach <i>Mercenaria</i> infilling
Aracaceae	0	0.6	0
<i>Betula</i>	0	0	0.5
<i>Carya</i>	1.0	1.2	0.5
<i>Castanea</i>	1.0	0.6	0
<i>Fraxinus</i>	0	0	1.5
<i>Liquidambar</i>	2.6	1.8	2.0
<i>Nyssa</i>	0.5	0.6	1.0
<i>Pinus</i>	69.1	59.3	68.7
<i>Quercus</i>	17.8	26.7	17.2
<i>Taxodium</i>	7.9	9.1	7.6
<i>Ulmus</i>	0	0	1.0
<i>Alnus</i>	0.4	1.0	0.9
Chenopodiaceae / Amaranthaceae	4.3	2.9	2.6
<i>Corylus</i>	0.4	1.0	0
Cyperaceae	0.4	0	0
<i>Ilex</i>	0	0	0.9
<i>Myrica</i>	3.8	7.1	2.2
<i>Osmunda</i>	0	0.5	0.4
<i>Ostrya-Carpinus</i>	0	0.5	0
Poaceae	3.8	6.7	6.1
<i>Salix</i>	0.4	0	0.4
Tubiflorae	4.2	1.9	0.4
Woodwardia-type	0.4	0	0
Microforaminifera	4.5	8.6	6.1

went to the island and recovered nine vibracores from the Central Depression and surrounding ridges, mostly at the northern end of the island (see chaps. 10 and 11). The desirability of obtaining cores from the depression was suggested not only by the written historical record, but by a profile of the feature that Vance had earlier recovered using ground penetrating radar (GPR); GPR provided unmistakable evidence that a substantial synformal sag structure existed in the subsurface. The purposes of the coring were several, among them a desire to reconstruct a vegetational and developmental history of the

Central Depression based on palynological analyses of the sediments, sedimentological analyses, and geophysical interpretations of the GPR data. Preliminary results were described by Ferguson et al. (2009).

Sediments recovered from the Central Depression using a soil bucket auger show that dark, humic acid- or humate-rich sediments can be recovered to a depth of at least 2 m; below that depth the water is high enough to preclude recovery of meaningful auger samples. However, vibracore samples taken toward the northern terminus of the Central Depression were recovered from the ground intact, and core #2 produced productive pollen samples to a depth of 85 cm. Palynological data from 50–55 cm revealed a dominance of *Myrica*, with the typically accompanying taxa *Pinus*, *Quercus*, *Liquidambar*, and the Ericaceae (heaths, such as blueberry). Other components of the pollen flora suggest the presence of a typical southeastern wetland flora, with one notable exception. *Tsuga* was present in more than trace amounts. This typically northern, or Piedmont species occurs rarely in samples from St. Catherines Island. *Tsuga* pollen is wind-borne, so its presence in the Central Depression does not necessarily indicate local presence of the plants, but it suggests that the plants probably grew on the coastal plain. *Tsuga* and other indicators of cooler climatic conditions provide substantive evidence that cool temperate vegetation grew on or near the core of the island, probably during the Pleistocene. Further results from Ferguson and her co-workers will hopefully provide a significant body of knowledge relating to the ancient history of the Central Depression.

QUATERNARY VEGETATION HISTORY  
AND THE DEVELOPMENT  
OF ST. CATHERINES ISLAND

Although our picture of the vegetation history of the island is still incomplete, collectively the palynology of the various core and grab samples that have been analyzed provide some insights. Vegetation and depositional changes on the island can also be linked to changes that occurred on the broader coastal plain and provide information on the potential effects of Quaternary sea level and climatic changes in this understudied region. Although many of the species that are found on the island today are present in Holocene and late

Pleistocene sediments, there are subtle differences between the palynological composition of older and younger sediments (fig. 6.4).

The consistent presence, in both Holocene and late Pleistocene age sediments, of characteristically southeastern plant taxa such as *Pinus*, *Quercus*, *Taxodium*, *Nyssa*, and *Liquidambar* attests to the stability of these plants on the coastal plain during the late Pleistocene and Holocene (fig. 6.4). Most taxa present even in trace amounts in the records from the island are still found in the Southeast. Even considering the extent of late Pleistocene and Holocene sea level changes, when the island was alternately incorporated onto the mainland, or separated from it by tidal waters (see chap. 3, fig. 3.3), many elements of the southeastern flora we are familiar with on the island remained largely in place. However, there is some evidence of small amounts of northern species that probably cooccurred with southeastern species on the coastal plain (fig. 6.4). For example, the occurrence of *Tsuga* pollen in the Central Depression, along with abundant *Pinus*, *Quercus*, and *Liquidambar*, suggests that these taxa likely cooccurred in the region. Similarly, relatively abundant *Fagus* and *Taxodium* pollen was found in the peat from below the St. Catherines Shell Ring as well as other late Pleistocene age samples from the island (fig. 6.4), suggesting a similarly unique association of plants.

The occurrence of some characteristically north-temperate species has become a hallmark of floras of the southeastern United States during the late Pleistocene (Russell et al., 2009). Rich et al. (2000) found *Alnus*, *Liquidambar*, *Pinus*, *Picea*, *Quercus*, *Taxodium*, and *Gordonia* (loblolly bay) cooccurring in a beaver pond deposit from Deepstep, Georgia, dated  $>47,470$   $^{14}\text{C}$  yr B.P. (Beta-98688). Since that time a number of additional sites (including vertebrate sites) have demonstrated the extent to which northern and southern elements were mixed on the Georgia coast during the Late Glacial Maximum. For example, Booth, Rich, and Jackson (2003) identified southern pines from needle macrofossils in 37,000 year old peat recovered from Skidaway Island; interestingly, small amounts of both *Picea* and *Fagus* pollen were found in the same sediments.

For the most part, late Pleistocene sediments from the island are dominated by freshwater, terrestrial assemblages. These include sites from Cracker Tom and the St. Catherines Shell Ring

(fig. 6.4). The occurrence of freshwater peatland deposits on the island during the late Pleistocene is not surprising, given that sea level is estimated to have been as much as 120 m below its current position (Adams and Faure, 1998; Delcourt, 2002; Russell et al., 2009). Even a conservative estimate of the position of the Late Glacial Maximum shoreline places it well to the east of the island, probably as far as Gray's Reef (Russell et al., 2009). St. Catherines Island would have been a part of the mainland, not unlike Yamacraw Bluff, the present-day ridge that lies in the heart of Savannah and well inland of the Atlantic Ocean. There is the suggestion that late Pleistocene sea level changes along the Georgia coast may have been quite dynamic, and/or the coastline has experienced episodes of tectonic activity; a marine shell bed was deposited at a depth of 322 cm below the surface of the St. Catherines Shell Ring, but well above the expected sea level of its age. The anomalous appearance of intact marine shells at elevations on the Georgia coast where one might not expect to find them is not a new phenomenon (Pirkle et al., 2007). Oyster beds standing at 2 m elevation on the St. Marys River, and reliably dated at about 36,000  $^{14}\text{C}$  yr B.P. (Pirkle et al., 2007; Rich and Pirkle, 1994), suggest that the influence of regional tectonics needs to be considered in any discussion of the topographic and geographical placement of coastal features in Georgia.

Pollen records from Florida indicate that the late Pleistocene of the Southeast was likely much drier than the Holocene, although it was also extremely dynamic at millennial timescales (Watts and Hansen, 1988, 1994; Jackson et al., 2000). Depositional hiatuses caused by low water brought on by increased aridity and/or the regional drop in sea level are also present throughout much of the region (Watts, 1971; Watts and Hansen, 1988; Rich, 1996; this volume, chap. 3). Late Pleistocene sediments on St. Catherines Island appear to be separated from Holocene age sediments by a depositional hiatus spanning at least 15,000 years, suggesting that the regional drop in sea level that accompanied the Late Glacial Maximum is manifest on the island.

Bishop et al. (2007; see also chap. 3, this volume) provide an excellent synopsis of the development of St. Catherines Island through time. In very general terms, the core of the island is of Pleistocene age, though it is unclear just when the island first took form, or if it developed over a

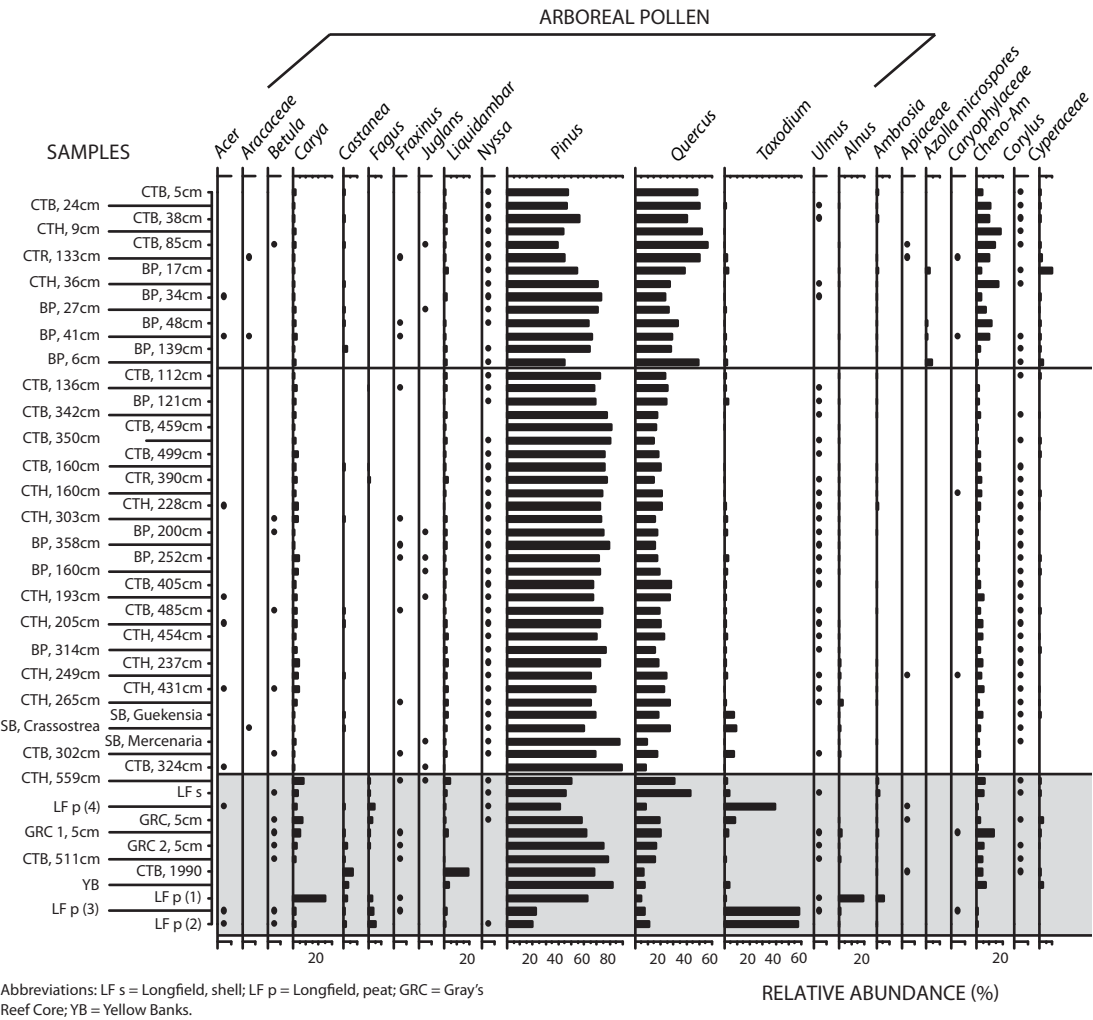
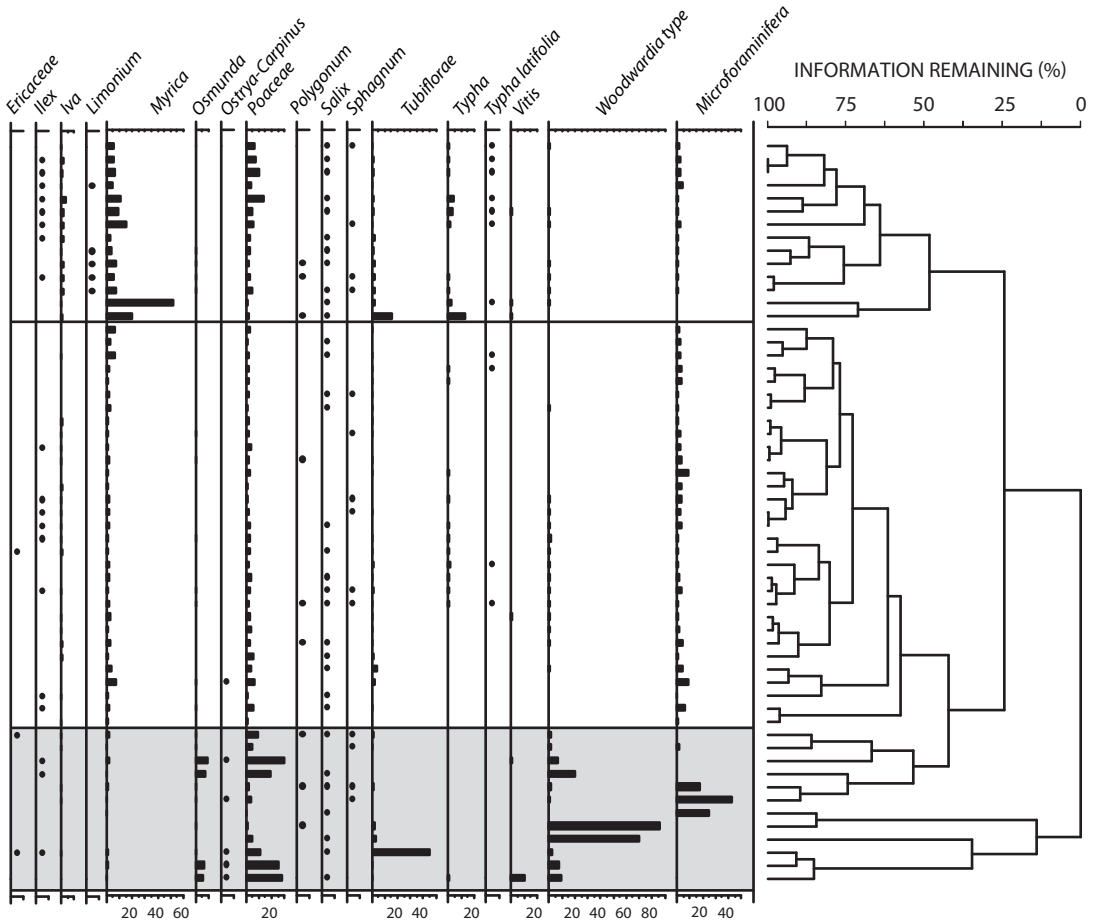


Fig. 6.4 (above and on opposite page). Palynological composition of all samples from St. Catherines Island, comparing late Pleistocene (gray shading) and Holocene samples. Sample names are given as a core number/abbreviation followed by the depth (cm), or sample number from table 6.1. The samples are arranged according to the results of cluster analysis, which is shown to the right and objectively groups samples that are similar in composition. Arboreal pollen percentages are based on an arboreal pollen sum and all other percentages are based on the total palynomorph sum.



long period of time and intermittently. The oldest floras from that ill-defined period of island development appear to come from Yellow Banks Bluff and the greatest depths at Cracker Tom and the shell ring. Between about 6000 and 4000 years ago, the island began to flood, and the now-vanished island known as Guale Island (Bishop et al, 2007) disappeared as rising sea levels brought the forces of erosion and longshore drift to the eastern margin of St. Catherines Island (see this

volume, chap. 3, fig. 3.3). The establishment of current hammock and marsh plant communities at the Cracker Tom locality occurred some time after 3200 <sup>14</sup>C yr B.P. The southern end of the island (south of the Cracker Tom locality) subsequently developed, and the flora that was discovered by Spanish explorers arose. The rapidity of the physical and biological changes that occurred during that episode of island development probably cannot be overstated.





## CHAPTER 7

### RECENT SHORELINE EROSION AND VERTICAL ACCRETION PATTERNS, ST. CATHERINES ISLAND

DONALD B. POTTER, JR.

Significant erosion rates on the north and east sides of St. Catherine's Island have long been evident, most notably shown by standing dead trees and patches of relict marsh mud on the beaches. McClain (1980) began a series of measurements in 1974 at markers located at prominent and accessible places on the island, particularly in the northern and northeastern areas. In a few locations, notably at the north end of Engineers Road (East) and at Picnic Bluff (fig. 7.1), his rusty metal rebar stakes are still present. Since the initiation of the University of the South's Island Ecology Program in 1987, the distances from the bars to erosional scarps have been annually monitored by Sewanee students and professors. Additional stakes have been installed over the past two decades in an effort to more precisely monitor rates of scarp retreat near the western extension of Engineers Road (West) in the northwestern part of the island, along the northern shore between Engineers Road (East), and the now-eroded USGS benchmarks along the northeast shore, along the Yellow Banks Bluff from the Picnic Area to the Ramp, and along South Beach from Beach Pond to the southern tip of the island. In addition to these Atlantic shoreline areas, two marsh-edge areas inland from the shoreline but subject to cut-bank erosion of tidal inlets have also been monitored, one on Wamassee Creek south of the mission site (fig. 7.2) and one at Seaside Inlet north of Seaside dock (fig. 7.3). The important long-term role of tidal creek cut-banks in eroding marsh-edge bluffs is particularly evident in aerial photographs and even USGS 7.5 minute quadrangles of St. Catherine's eastern marsh

drained by Seaside and McQueen inlets (along King New Ground Scarp of Bishop et al., 1997); large arcuate boundaries up to 1 km long such as the forest edge north of King New Ground dock (fig. 7.1) are obvious and appear by the regularity of their shape to indicate relatively young (Holocene) meander scars.

Monitoring along the periphery of St. Catherine's Island has been expanded in the past 12 years, particularly along the Yellow Banks Bluff north of Seaside ramp and along the stretch of beach from South Beach entrance to Flag Lagoon, a freshwater pond formerly situated west of the beach, that was breached in March 1993 and now is inundated by daily tides, forming the lagoon.

In addition to shoreline and scarp retreat we have documented three areas that show various aspects of erosion and accretion: the bluff along the south margin of St. Catherine's Sound in the northeast portion of the island where a recently eroded benchmark appeared on maps (fig. 7.4), the small hammock in Seaside Marsh 0.5 km southwest of the ramp entrance on North Beach, and the roughly circular marsh immediately south of McQueen Inlet that is bordered by dunes on the north, east, and south. The benchmark location shows vertical accretion between the installation of 1913 and 1933 benchmarks by the U.S. Coast and Geodetic Survey. Our interest in the Seaside Marsh hammock has been the relative timing of hammock sand deposition versus marsh formation. In the dune-ringed marsh at McQueen Inlet the volume of fresh groundwater has increased and the water table has risen as eolian sand has accumulated on its outer edges.

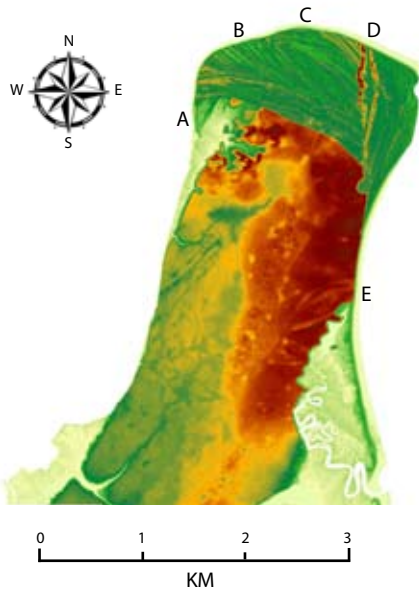


Fig. 7.1. Lidar map of the northern end of St. Catherine's Island, with measurement sites (A–E) documenting shoreline retreat. Image created by Brian K. Meyer.

## METHODOLOGY

The method of monitoring retreat has been to install PVC pipe driven ~45.7 cm (18 in.) into the sand at known locations, to be used as reference points from which distance to the erosional scarp may be measured along a given bearing. Latitude and longitude are recorded and the stakes are labeled with a letter and number (i.e., SB 1 for South Beach #1). Notable landmarks are also occasionally used and are typically large trees that can be identified on aerial photographs. For example, a tall magnolia with striking bronze-colored leaves standing 7.9 m from the bluff in 1996 (and the namesake of Magnolia Bluff, the current picnic site) was used as a reference along Yellow Banks Bluff north of Seaside ramp until it eroded onto North Beach in 2000.

Aerial photographs have been an important resource for establishing historical rates of erosion. Careful scaling from the photograph gives a reasonable estimate of distance between the shore and known locations that include small hammocks, the edge of Flag Pond, and identifiable large trees. Comparison of the map distance

from a given year with the present distance (determined with a tape measure) allows calculation of yearly erosion averages.

A more recent method involves walking the erosional scarp or high tide line with a high-accuracy GPS unit. These tracks are compared to those of subsequent years.

The first method, installing PVC pipes and monitoring the locations regularly, is the most precise and labor-intensive. Relatively frequent replacement of lost pipes is an inevitable consequence of natural erosion, heavy equipment use near roads and the human use of nearshore areas. The installation of backup PVC markers, typically 10 m farther from the scarp than the original markers, has allowed fewer interruptions in data collection in several of our most critical sites.

Study of the vertical accretion at the northern benchmark has included measurement of charcoal horizon elevations with tape and auger. Fresh erosion scarps have been photographed, measured, and sketched. Increment borings in pines have yielded minimum ages of both trees and corresponding forest floors, and have also provided growth-disturbance patterns. Metal probes have been used to determine whether trees are rooted at the present land surface or a lower surface. Typically the pines have a set of horizontal roots along the surface on which they grow, and buried trees can be identified by trunks without this set of roots.

At Seaside Marsh south of the ramp, vibro-coring from dune sands to below marsh level has given a clearer understanding of the relative ages of marsh and hammock. In the McQueen Marsh immediately south of the inlet, observation of water table height, salinity, and freshwater flora have helped to monitor yearly variation.

## RESULTS

Erosional retreat rates are presented here for locations in the northwest, north, and eastern portions of the island, working in a clockwise direction. The overall pattern in the northern part of the island, with the exception of 1.5 km north of Yellow Banks (Picnic) Bluff, is retreat. Four representative locations, listed clockwise from the northwest, define the pattern for the northern tip of the island (fig. 7.1): a large dune immediately north of the northwest marsh (fig. 7.1, location A), dunes at the western extension of Engineers Road (B), the shore at the northern extension of



Fig. 7.2. Aerial photograph of the southwestern side of St. Catherines Island. Wamassee Creek forms an active cut bank immediately south of Mission Santa Catalina de Guale. Photograph by Digital Globe, March 8, 2008.

Engineers Road (C), and the 1933 benchmark (D) (see table 7.1).  
Rates for North Beach were measured along the 4 m high Pleistocene Yellow Banks Bluff (Bishop et al., 2007) extending 800 m north from the North Beach ramp (fig. 7. 1, location E). Table 7.2 shows the average rates of retreat from 1996 through 2008 from north to south along this stretch. Average retreat for the 12 markers in this

area was 1.82 m/yr (Potter, Padgett, and Trimble, 2007; Potter, fieldnotes, 2008).  
Eight markers were installed on South Beach between Beach Pond and Flag Pond in 2000. Yearly erosion rates for this stretch range from 0.9 to 2.9 m/yr, with an average rate of 1.63 m/yr. Single yearly rates measured over the span from 1987 to the present are as high as 10.4 m/yr, recorded in the winter of 1992–1993 when

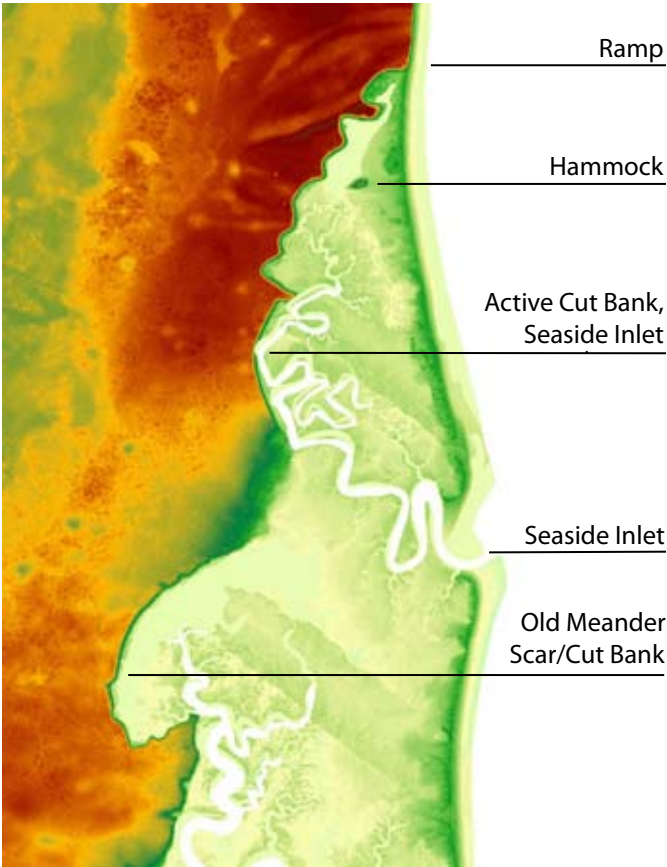


Fig. 7.3. Lidar map of the Seaside Marsh portion of St. Catherine's Island. Note the large meander scar south of Seaside Inlet. A new scar is shown where the present inlet cuts the Pleistocene bluff. The small hammock south of the ramp predates the marsh that surrounds it. Image created by Brian K. Meyer.

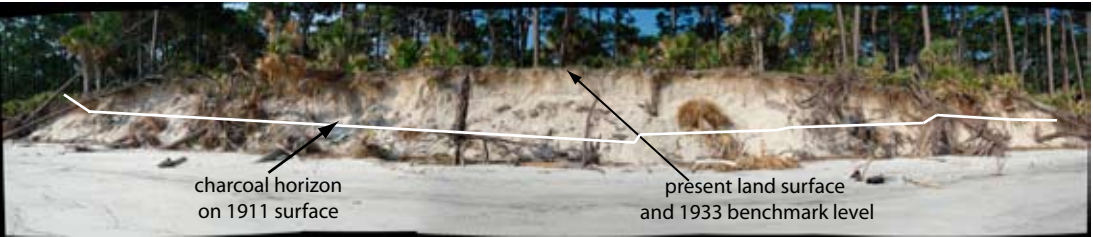


Fig. 7.4. View of Benchmark Bluff, looking southward. The bluff is 4–5 m in height. The white line represents the surface on which the 1911 benchmark was placed; it is now marked by a charcoal-rich horizon. A pine with horizontal roots at the 1911 level is left of center. The 1933 benchmark was placed on the present wooded surface and was undercut and eroded in the summer of 2007. Several of the living trees in this view are rooted at the lower horizon (photograph by Mike Brady, taken June 2007).

the 1.22 m high narrow forested ridge of sand between North Beach and Flag Pond was eroded (Potter, fieldnotes, 1992 and 1993).

The highest erosion rates on St. Catherines Island are south of Flag Pond. At least 10 of our markers have been eroded over the period since 1987, and retreat has been estimated using 1951 and 1972 aerial photographs. Erosion rates based on the photographs are 2.3 m/yr from 1972 to 2008 in the Flag Pond area and 5.4 m/yr from 1951 to 2008 in the marsh immediately south of the last large forested hammock on South Beach at latitude 31°33'50"N.

Measurements and observations of the three selected vertical accretion study areas are briefly summarized here.

(1) The bluff at the 1933 benchmark site is more than 120 m long in an E-W direction and approximately 5 m high. A charcoal-rich horizon 0.75 to 1 m above high tide level marks the level of land surface at the time the 1913 benchmark was placed on the island. A longleaf pine rooted at this horizon 3.6 m downward from the modern forested dune surface was exposed in the erosion scarp in the summer of 2007. Increment boring 4.5 m above the charcoal layer and base of the tree showed a burn scar on rings 9 and 10; there were 93 rings in total. Probing with a steel bar to depths of 0.5 m around the circumference of pines within 3 m of the bluff showed several to be rooted below the present forest horizon.

(2) At the Seaside Marsh hammock located 0.5 km SW of the North Beach ramp a vibracore was taken in the west slope about 1.5 m above marsh level. No marsh mud or other indications of marsh sedimentation were identified in a 3 m core. Sand samples from the hammock and Yellow Banks Bluff 0.16 km to the west compare closely in texture and in their light brown color (Iralu, Serene, and Potter, 2008).

(3) Informal observations in the past few summers at the marsh immediately south of McQueen Inlet indicate increasing freshwater and higher water tables in the past few summers on the inner-facing slopes of the dune-ringed depression.

DISCUSSION

Significant erosion of the northern and eastern shore of St. Catherines Island is a long-standing reality evidenced by dead standing trees on the beach, steep erosional scarps where dunes or more ancient sands are adjacent to the beach,

TABLE 7.1  
Erosion Rates at the Northern End of St. Catherines Island, 1977–2008

Marker Location	Year Measurements Began	Average Retreat, m/yr
Northwest Marsh	1977	0.20 m/yr
W. End Engineers Rd.	1999	2.38 m/yr
N. End Engineers Rd.	1979	1.65 m/yr
1933 Benchmark	1993	1.03 m/yr

TABLE 7.2  
Erosion Rates on Yellow Banks Bluff, North Beach, 1996–2008

Location on bluff	Retreat, m/yr <sup>a</sup>
Northern third	0.53
Middle third	1.61
Southern third	2.69

<sup>a</sup>Average rate.

conspicuous washover fans in the eastern-facing salt marshes, and cohesive marsh deposits exposed on the beach face. For island residents and visitors, the retreat has also been made obvious by the rerouting of Seaside Road near Yellow Banks Bluff and the multiple relocations of Seaside ramp, and by bounding scarps around the periphery of St. Catherines Island, including the cut banks in Wamassee Creek, south of Mission Santa Catalina de Gualé (fig. 7.2).

Measurement of this retreat would appear to be a simple matter of installing and monitoring fixed markers, but the process has been complicated by irregular monitoring and the lack of anticipation of rapid erosion rates that have caused the loss of many markers. In the past 12 years we have been more vigilant in our monitoring and in the placement of backup markers. This time-consuming process is more precise than aerial

photograph scaling and GPS measurements, although the latter may soon offer enough precision to be a standard method. For calculating erosion over longer spans of time the aerial photographs methods are indispensable.

For calculating erosion of the north tip of St. Catherines, the older McClain markers established three decades ago are the most reliable for longer-term trends. Given the protection of the northern tip of the island, it is no surprise that the dune 0.7 km south of the western extension of Engineers Road (fig. 7.1, location A) exhibits an erosion rate of 0.2 m/yr (table 7.1). Engineers Road (West) on St. Catherines Sound shows a corresponding increase in erosion; the 2.38 m/year rate is anomalously high in comparison to other north shore sites, but only 10 years of data are available. The marker here was in a clump of five tightly clustered live oaks that were undermined by storm waves in the winter of 2006–2007, and the relatively horizontal rooting pattern allowed the entire mass to tip seaward. Erosion at the northern end of Engineers Road (East) (fig. 7. 1, location C) has been relatively steady over the years. McClain established the marker at 62 m from the scarp in 1979 (McClain, 1980); it was at 38.1 m in 1990, 27.2 m in 2004, and 14.1 m in 2008 (Potter, fieldnotes, 1997–2008).

Although erosion has been relatively constant at the northernmost part of the island at Engineers Road (East), the bluff in the benchmark area has varied from a fresh scarp in the late 1980s to an inactive slope bordered to the north by low dunes and young pines formed as accretion occurred below the bluff in the 1990s. There was no measured retreat of the benchmark bluff area from 1992 to 1996 (Potter, fieldnotes, 1992, 1996). A renewed cycle of erosion in the past five years resulted in retreat of the bluff that resulted in erosion of the 1933 and 1913 benchmarks onto the beach in 2007. The more recent benchmark, a brass cylinder in a concrete cube (labeled “U.S. Coast and Geodetic Survey, no.2, 1913 1933; 22.242”), was found in the surf below the high-tide mark in June 2007. Smaller concrete blocks found within a few meters may have been parts of the 1913 marker eroded from the charcoal horizon.

The charcoal horizon with the live pine rooted along it approximately halfway up the present 5 m bluff has shed light on a long-standing discussion among the University of the South

faculty members. In 1987, founding staff members Keith-Lucas, Ramseur, Toll, and Potter found two closely spaced live oaks at the top of the highest dune on the island, 200 m south of the benchmark. These appeared to be branches of a single buried tree, and the discussion centered around the tree’s potential ability to keep growing when buried to a significant depth. Erosion in early 2007, exposing the charcoal layer and its living pine with a lower trunk buried 3.6 m deep, confirmed the two-decade-old speculation that St. Catherines Island’s highest dunes formed in at least two stages.

The accretion of new dune lines north of Yellow Banks Bluff beginning in the early 1990s has coincided with the growth of a large bar (part of St. Catherines Sound ebb delta) off the northeast tip of the island, now protected by the Georgia Department of Natural Resources for nesting birds. Growth of the bar has lessened the erosional effect of storm waves and caused an eastern extension of the beach between the bar and Sand Pit Road. Modest vertical accretion in the northernmost portion of Yellow Banks Bluff has stabilized erosion at what had been one of McClain’s more active sites from 1974 to 1979 (McClain, 1980). Increasing rates of erosion farther south along North Beach and Yellow Banks Bluff, with the highest rates of 2.69 m/year occurring in the area of Seaside ramp correspond to increasing distance from the protective influence of the bar.

Nowhere else on the island is the march of erosion more obvious than along South Beach. Active washover fans into low-relief palm and live oak forests, as well as east-facing marshes, are the rule. The loss of so many naively placed markers in the Flag Pond area and farther south was due in part to erosional rates ranging from 2.3 m/year to 5.4 m/year that are best measured by markers established far back from the beach or by the use of historical aerial photographs. Corps of Engineers (1971) studies indicate that the recession of the southernmost part of South Beach is “greater than 2,400 feet” in the period from 1857–1860 to 1951–1952.

In the case of the small hammock in Seaside Marsh south of the ramp, the lack of marsh sediments correlative with the marsh deposits of Seaside Marsh in the vibracore taken there suggests that the hammock is a remnant of the nearby Pleistocene sands exposed in the bluff to the west and that the hammock was isolated by inlet migration.

Very preliminary work on vertical accretion in the small marsh south of McQueen Inlet has been done, with recent GPS data providing a framework that was lacking in earlier student studies. If windblown sand from nearby dunes continues to accumulate in this erosion-vulnerable area, we may be able to document the transition to a more freshwater-dominated marsh.

### CONCLUSIONS

The documentation of shoreline retreat along the St. Catherine's coast is more system-

atic than in the earliest years of the University of the South's Island Ecology Program but is in the process of being expanded and refined. Studies of further change in established study areas will be augmented by denser arrays of markers, and the areas south of Flag Pond characterized by high historical rates of erosion will receive renewed attention. As the accuracy of GPS systems improves, they will become a more important component of data collection. Documentation of the erosion of the island will remain important as sea level continues to rise.





## CHAPTER 8

### ROLE OF STORM EVENTS IN BEACH RIDGE FORMATION, ST. CATHERINES ISLAND

HAROLD B. ROLLINS, KATHI BERATAN, AND JAMES E. POTTINGER

There is obvious correlation between storm frequency and intensity, and rates of erosion and deposition along barrier islands, and there have been several demonstrations of how single storms can affect temporal patterns of erosion and deposition.<sup>1</sup> Sexton and Hayes (1983), for example, described downdrift beach accretion following repositioning of an inlet channel during Hurricane David in 1979. The sedimentary dynamics of ebb-dominated inlet systems along the southeastern United States have been investigated in some detail and models have been developed that are applicable to various temporal scales (Oertel, 1977; Kana, Hayter, and Work, 1999). In this chapter, we document how a single storm, Hurricane Hugo in 1989, helped to catalyze an ongoing depositional pattern and led to the formation of a set of three distinct beach ridges along the northeast end of St. Catherines Island over an interval of five years. This provides evidence that single storm events might trigger cascading deposition of beach ridges and we suggest that clusters of violent storm events might have long-term effects on the geomorphic configuration of barrier islands.

Causal links between individual beach ridges and storms have been assumed since the earliest work on beach ridges by Redman (1852, 1864) and by Johnson (1919). Storm events have most commonly been invoked for genesis of coarse clastic beach ridges, sometimes complemented by fair weather accumulation of sediment in the nearshore (Ting, 1936; Thom, 1964; Psuty, 1967). On the other hand, many models of beach ridge formation downplay the role of storm events, emphasizing instead various combinations of such

processes as ocean swells, emergent bars, swash, berm construction, vegetational construction, and eolian activity (Taylor and Stone, 1996). In some cases, these processes have been assumed to operate in concert with sea level change (see discussion by Thomas, chap. 1). Some of these processes are thought to act gradualistically, slowly building individual beach ridges; others are considered to operate catastrophically in a manner similar to that of storm events. However, the construction of multiple beach ridges (beach ridge sets) has always, to our knowledge, been viewed as gradual, the product of fusion of individual ridges (by whatever process) over decades or even millennia.

#### ST. CATHERINES ISLAND

St. Catherines Island is one of a string of barrier islands (the Sea Islands) along the southeastern coast of the United States, stretching from Cape Fear in North Carolina along the Georgia Embayment to northern Florida (see fig. 1.1). Unlike the barred coasts farther north, or those along the Gulf of Mexico, many of the Sea Islands are complexes of older Pleistocene cores with aggraded sets and subsets of erosionally truncated Holocene beach ridges at their northern and southern ends. Individual Sea Islands are separated from one another by tidal inlets (sounds) from the mainland by vast expanses of coastal salt marsh (Leatherman, 1979; Frey and Howard, 1988; Bishop et al., 2007; among others).

Several of the Sea Islands are actually “double islands,” consisting of Pleistocene cores with Holocene companions that accreted against the

northeastern portions of the cores during Holocene stabilization of sea level some 4000–5000 years ago. Examples of this double configuration include Sapelo Island and its Holocene partner, Blackbeard Island, and St. Simons Island with its Holocene counterpart, Little St. Simons Island. Although St. Catherines Island retains no Holocene attachment, evidence of a former companion (named Guale Island) is provided by the presence of extensive sea-facing relict salt marsh muds along the eastern North and Middle beaches (Morris and Rollins, 1977; West, Rollins, and Busch, 1990; Rollins, West, and Busch, 1990; Linsley, 1993; Bishop et al., 2007; Thomas, Rollins, and DePratter, 2008). Following the erosional destruction of Guale Island there has been very rapid erosion of the eastern margin of the island core (Oertel and Chamberlain, 1975; Goodfriend and Rollins, 1998; Bishop et al., 2007). The greatest intensity of washover activity in the Georgia embayment occurs along this stretch of unprotected shoreline (Deery and Howard, 1977). Also, the absence of a Holocene companion has meant that the northern end of St. Catherines Island has received the brunt of unbuffered sedimentary impact associated with St. Catherines Sound, the inlet separating St. Catherines Island from Ossabaw Island to the north (but see Chowns et al., 2008 and Chowns, this volume, chap. 9, for alternative scenarios). Thus, it is not surprising that some of the best-developed beach ridge sets to be found along the southeastern coast of the United States occur at the northern end of St. Catherines Island (Oertel, 1975b; fig. 8.1).

## METHODOLOGY

Two approaches were used to assess the effects of Hurricane Hugo on the geomorphology of the northern end of St. Catherines Island: (1) analysis of aerial and ground-based photographs, and (2) detailed topographic mapping of the newly deposited beach ridges (fig. 8.2).

Panchromatic and natural color aerial photographs ranging in scale from 1:10,000 to 1:60,000 were analyzed. To minimize effects of differences in tidal cycles, the aerial photographs were standardized by locating the High Water Line (HWL) on each photograph. The HWL “appears as a tonal change on the beach face due to differences in the water content of the sand” (Smith and Zarillo, 1990: 29). This approach is not applicable for photographs taken in

rainy conditions or during storms because there would be little contrast of brightness above and below the HWL (Shoshany and Degani, 1992). All aerial photographs used in this study clearly displayed the HWL.

The following enhancement strategies were applied to the aerial photographs for analysis and interpretation of features:

- (1) Photographs were scanned using Adobe Photoshop and a flat bed scanner at 300 dots per inch resolution.

- (2) The scanned photographs were imported to ENVI, an image processing software program.

- (3) Removal of geometric distortion (except that due to topography) was accomplished by registration (warping) of an image to a base photograph. In ENVI, the images were warped using a polynomial transform and nearest-neighbor resampling method. Warping was accomplished by identifying and matching common points (ground control points) on the base photograph and the photograph selected to be warped. At least 12 ground control points were selected on each photograph. Some common features that made excellent ground control points were isolated trees, sand pits, tree/sand lines, swamps, sloughs, and dirt road intersections.

- (4) Once the images were warped, they were enhanced to emphasize the targeted marginal ramp shoal features. Aerial photographs record the amount of sunlight reflected by the surface of the earth. In this case, beach sand tends to have the highest reflectivity (albedo). A gray-scale image is broken down into 255 shades, with category 255 being pure white and category 0 pure black. The range of values for beach sand is from 195 to about 255. A density slice was produced by selecting the values of beach sand and assigning a color to the range (in this case, green). This resulted in an almost three-dimensional image, allowing us to easily distinguish beach sand from the other island surface features.

During the fall of 1995 and late spring, 1996, detailed field mapping of beach ridges was conducted at two specific locations along preselected baselines: the beach ridge field at North Beach and the Picnic Point beach ridge set (fig. 8.3) (Pottinger, 1996). The North Beach site baseline was oriented north-south and base stations were selected by optimizing the overlap of splay transects. Picnic Point stations were spaced 100 ft apart and unsplayed transects orthogonal to

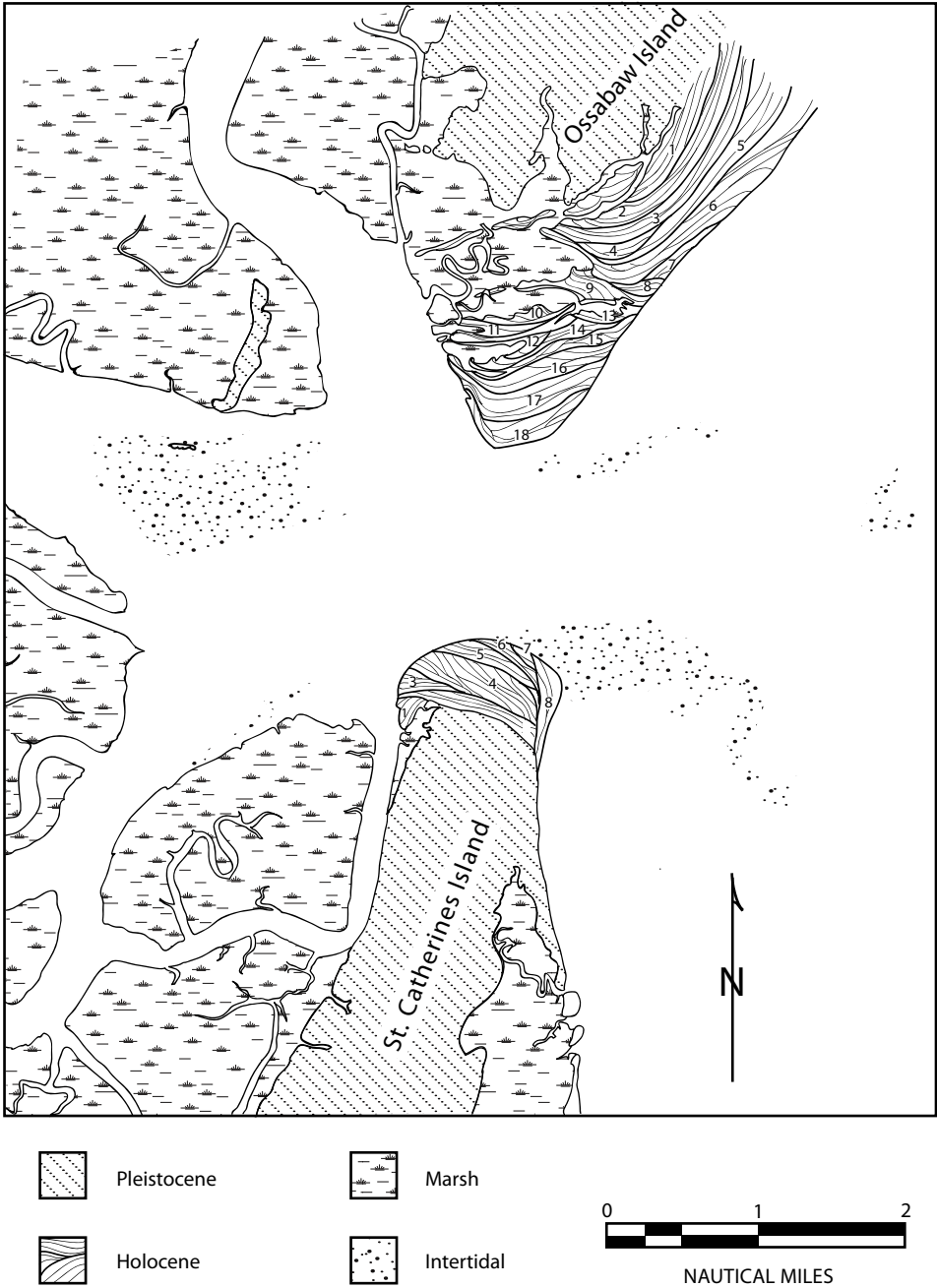


Fig. 8.1. Pattern of truncated Holocene beach ridge sets (numbered) at north end of St. Catherines Island (after Oertel, 1975).



Fig. 8.2. Location of Picnic Point and North Beach study areas. Google Earth™ image, 2010.

the baseline were used to provide detailed mapping of the beach ridges. The northernmost base station was tied into a Coast and Geodetic Survey benchmark located at the north point of the island. Mapping was carried out with the use of a Total Station Theodolite.

#### BEACH RIDGE CONSTRUCTION FOLLOWING HURRICANE HUGO

In the fall of 1989, Hurricane Hugo, a Category 5 hurricane, reached landfall off Charleston, South Carolina. Significant amounts of sediment flushed through St. Catherine's Sound as a result of inland rainfall. The ebb-tidal delta oceanward of St. Catherine's Sound is asymmetrically enlarged downdrift to the south. Export of surplus sediment through St. Catherine's Sound following Hugo led to increased enlargement and detachment of this southern ramp-margin shoal and it quickly moved shoreward blocking

the southward transport of ebb-tidal sediment through normally deeper spillover channels. This converted the largely subaqueous marginal shoal to a shallow and extensively emergent wave-dominated bar. In effect, this acted, metaphorically, to create a shield-trapping sediment moving northward on the flood tide before it could enter the main ebb channel to be flushed seaward and swept away by dominant ebb flow. The trapped sediment was subsequently moved southward by wave action and longshore drift to become engaged in beach ridge construction (a phenomenon known as "shoal bypassing") (Sexton and Hayes, 1983). This was accomplished without significant modification of the main tidal inlet channel (fig. 8.4).

The sequence of events outlined above closely follows the scenario of inlet-related mixed energy dynamics described by Hayes (1975), Oertel (1975b, 1977), and Kana, Hayter, and Work (1999). For at least two decades prior to 1989,

the exposed portion of the shoal at the south end of St. Catherines Sound had been diminished in overall size and was semidetached. Picnic Point, an erosional scarp cut into the Pleistocene core about 0.75 mi south of the northern end of the island, had been actively wave-cut until the 1980s when the southern ramp-margin shoal became more emergent and created what Oertel (1977) termed a “shield” confining tidal flow to the main axis of the inlet channel. This pattern was enhanced by Hurricane Hugo, in 1989, and by 1990 the first of three nascent beach ridges had begun to form in front of Picnic Point bluff. A progression of beach ridge development can be seen over the subsequent multiyear evolution of this beach ridge subset, and is reflected in a seaward to landward transect over the beach ridges. The de-

velopment of the beach ridges followed the morphogenetic pattern outlined by Frey and Howard (1988). Straw dunes (small isolated dunes that formed by the entrapment of windblown sand around wracks of beach-drifted marsh grass (*Spartina alterniflora*) accumulated in the upper backshore and evolved into sparsely vegetated foredunes and eventually coalesced into highly vegetated primary dune ridges (fig. 8.5). Over just a few years three dune ridges formed and the more landward ridge became heavily vegetated with dense bushes and small trees. The topographic maps (figs. 8.6 and 8.7) depict the three beach ridges, oriented north-south, ranging in elevation from 0.1 ft to 1.25 ft above the high water line (HWL) (in 1996), and extending the entire length of the Picnic Point mapping site.

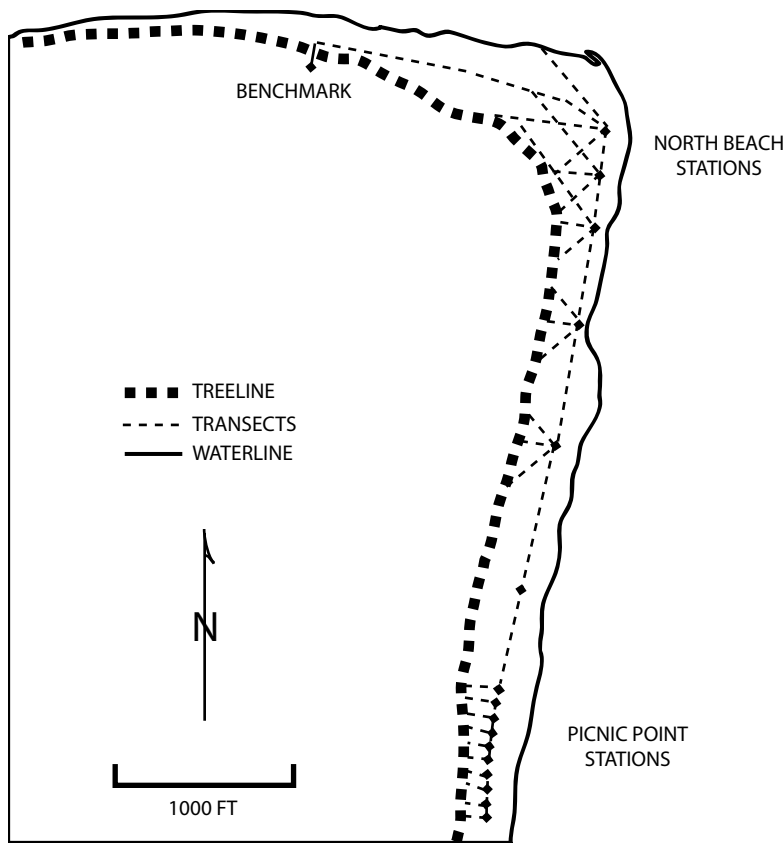


Fig. 8.3. Distribution of Picnic Point and North Beach mapping stations.

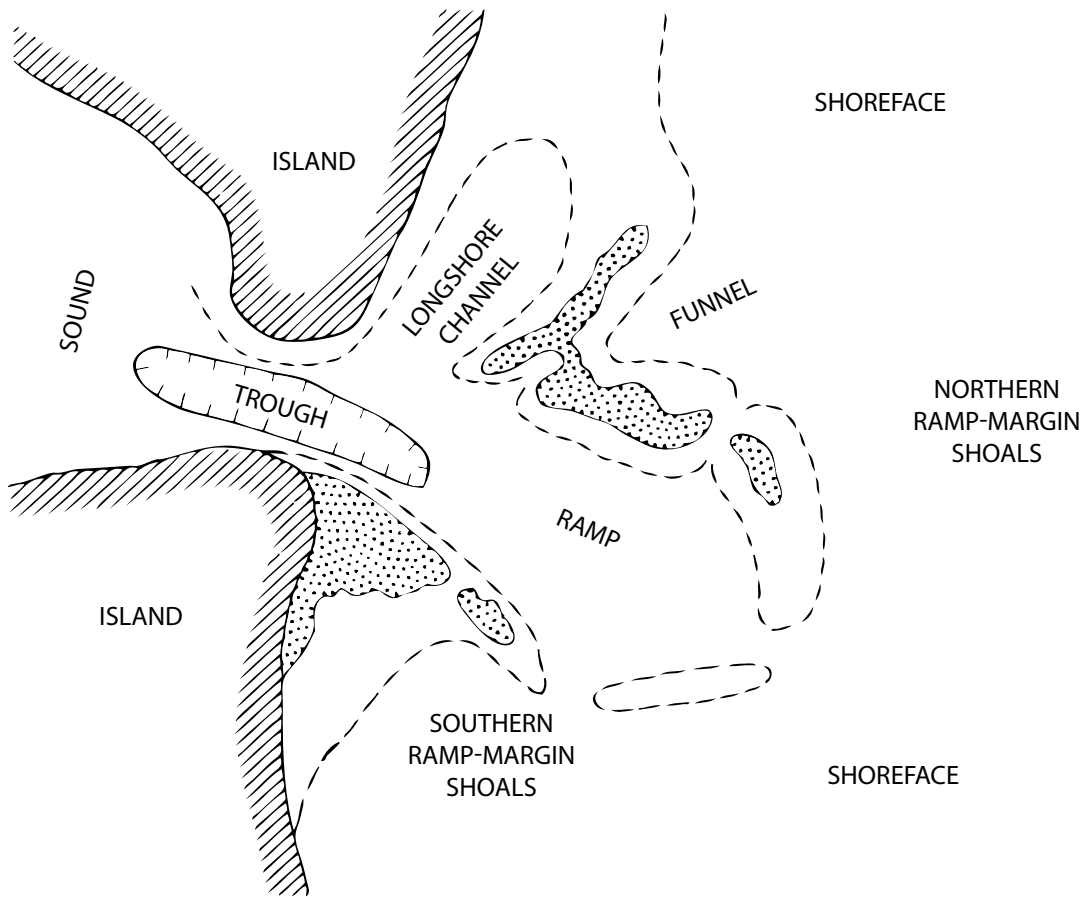


Fig. 8.4. Geomorphic features associated with a Georgia inlet shoal system (after Frey and Howard, 1988).

## DISCUSSION

It appears that, in the context of models proposed by Oertel (1975b, 1977) and Kana, Hayter, and Work (1999), Hurricane Hugo likely initiated a bypassing event along the northeastern margin of St. Catherines Island by isolating the downdrift shoal from the inlet ramp and moving it shoreward. The shoreward proximity of this extensively emergent and shallow shoal sealed off much of the southward ebb flow normally coursing through shallow spillover channels. As stated by Oertel (1977: 1127), "When shoals are attached to the shore they function as shields which confine flow to the main axis of the channel." "However, in the lee of a marginal shoal,

the tidal circulation is restricted and forms a slack zone that is only effected by refracted waves." In the ebb-dominant tidal systems of the Georgia coast, wave currents are nevertheless important during major storms and, as noted by several workers (Oertel, 1975b; Chowns et al., 2008), sediment transport along this coast tends to exhibit seasonality, with dominant southward progradation during the fall and winter and a northward transport during spring and summer.

Oertel (1975b) proposed a complex scenario to explain the mosaiclike pattern of truncated sets of beach ridges found at the north end of St. Catherines Island (fig. 8.1), and some of the other Sea Islands. He hypothesized that historical changes in the sedimentary dynamics associ-



Fig. 8.5. Photograph of beach ridges adjacent to Picnic Point. View to the north.

ated with the inlets (sounds) and marginal ramp shoals bordering the inlets led to sequential aggradation and degradation (truncation) of beach ridge sets related to Holocene constriction of inlet throats. The wedgelike beach ridge sets at the northern end of St. Catherines Island, Oertel (1975b) noted, are oriented divergent to the Pleistocene shoreline and, he surmised, a result of depositional influence of “deltaic barriers of the early Holocene Savannah River system.” Oertel (1975b, 1977) attributed the multiple sets and subsets of truncated beach ridges at the north end of St. Catherines Island to intervals of attachment and detachment of the ramp-margin shoal through the Holocene. Subsequent workers (Chowns et al., 2008, and this volume, chap. 9; Bishop et al., 2007) have also noted the anomalous pattern of beach ridge accretionary morphology at the northern ends of St. Catherines Island and some of the other Sea Island (e.g., Jekyll Island), suggestive of ongoing inlet adjustment or even migration.

The models of Kana, Hayter, and Work (1999) and Oertel (1975b, 1977) are quite similar in terms of microscale dynamics, and only differ in terms of macroscale focus. Kana, Hayter, and Work emphasized the impact of shoal bypassing on shoreline configuration and Oertel was mainly concerned with origin and evolution of beach set ridges. Our observations along Picnic Point bluff following Hurricane Hugo highlight the role of single storm events in triggering rapid construction of beach ridge sets. These three beach ridges formed so rapidly because

postattachment shoal spreading, with a dominant southerly vector, occurred between Picnic Point bluff and the shoreface. The cause of deposition of multiple sequential beach ridges is less clear, although it may reflect separate, but weaker, storm events. Intervals of truncation, following either Kana, Hayter, and Work (1999) or Oertel (1975b, 1977) would appear to indicate erosion during longer, somewhat stable intervals, when spillover ebb flow could pass southward due to a more detached marginal shoal.

Storm events, if demonstrable as precursors to the genesis of earlier beach ridge sets, present an unexpected complement to Oertel’s model. We surmise that the extensive mosaic of truncated beach ridge sets north of Picnic Point possibly formed in a manner similar to the post-Hugo set—that is, they were triggered by storm events. Of course, aerial photograph coverage is not available for the late Holocene to directly test this hypothesis. We wondered, however, whether the last 50 or so years of available photographs might be adequate to evaluate longer-term trends of beach ridge set formation caused by storm events. Continuous single-year aerial photograph coverage is not available even for the last 50 years. However, sufficient photographs exist to evaluate the effects of clusters of violent storms upon ramp-margin shoal deposition and beach ridge set formation, and to determine whether the cascading pattern observed after Hurricane Hugo is scalable upward to longer intervals of alternating storm violence and quiescence. A significant cyclicity in Atlantic coastal storm activity has been demonstrated by Davis and Dolan (1993). The interval between the mid-1940s and mid-1960s was particularly stormy, and a noticeable decline in storm activity occurred between the mid-1960s and mid-1970s, followed by a variable intensity pattern since then (Pottinger, 1996). Figure 8.8 presents a summary of this temporal variation in storm intensity.

A temporal comparison of aerial photographs of the marginal shoal at the northeastern margin of the island indicates that a surplus of sediment debouched through St. Catherines Sound during the stormy interval between the mid-1940s and mid-1960s, apparently represented by the extensive low-tide exposure of a marginal shoal that was diminutive and barely emergent during the 1940s (fig. 8.9). By 1951, the blunted but arcuate adjacent shoreline sug-

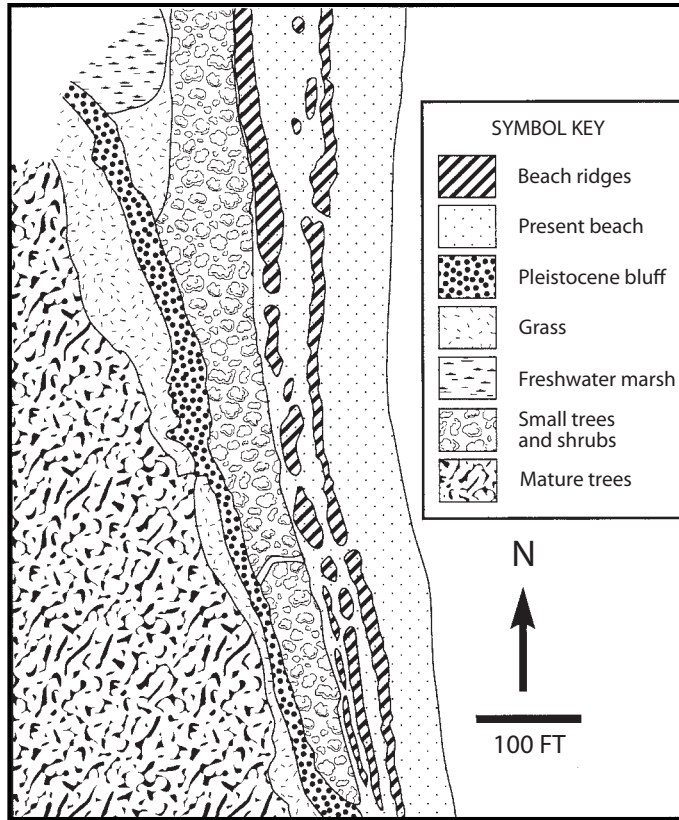


Fig. 8.6. Schematic map of vegetational zones, Picnic Point beach ridges.

gests that either (1) a previously detached bar had grounded and was subject to downdrift sediment dispersal by wave and flood attack, after the model proposed by Kana, Hayter, and Work (1999), or (2) an ebb-tidal spillover channel was shunted to the south, erosionally beveling the shoreface. The several small emergent bars scattered in the marginal flood channel suggest that the first explanation may be more likely. Another arcuate bar appears nearly detached and isolated. Renourishment in the form of beach ridges is just visible in the Picnic Point area (fig. 8.10). By 1963 the shoal has moved oceanward and has reduced low tide exposure, suggesting diminished sediment supply (fig. 8.11).

A comparison of the 1963 inlet margin with that of 1972 indicates a period of overall stability

and the exposed shoal had moved offshore (fig. 8.12). Short-term variability was more complex, however, as indicated by the presence of an attached bar in 1972, which becomes erosionally dispersed over the ensuing decade.

Relative stability continued between 1972 and 1980 (fig. 8.13). The exposed shoal increased in size, but maintained the same relative offshore position. Between 1980 and 1990 the shoal again moved shoreward, creating a shallow flood tidal and wave platform, which supplied sediment to beach ridges opposite Picnic Point (fig. 8.14). The entire sequence of photographs is summarized in figures 8.15 and 8.16, and appears to demonstrate several years of shoal bypassing, followed by more than two decades of relative stability, and then, additional years of bypassing continuing to the present.

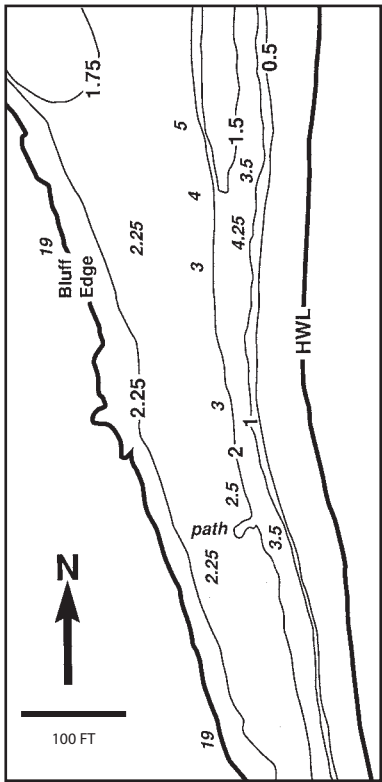


Fig. 8.7. Topographic map of Picnic Point beach ridge set. Elevations in feet about the high water line (HWL).

CONCLUSION

Our study demonstrated that a single storm event (Hurricane Hugo) was correlated with the construction of a set of three beach ridges adjacent to Picnic Point, near the north end of St. Catherines Island. The storm event apparently represented the initiation of an interval of net import of sediment shoreward in this area, interrupting the normal ebb-dominant export of sediment to a more offshore marginal shoal. This reversal of inlet dynamics appears noticeable over mesoscale intervals of time correlating with fluctuating intervals of violent and quiescent Atlantic coastal storm activity.

NOTES

1. This research was supported by grants from the E.J. Noble Foundation, administered by the American Museum of Natural History. We thank N.J. DeLillo, R.G. Kyshakevych, and J.C. Rollins for assistance in field mapping. R. Hayes, St. Catherines Island Foundation, provided valuable logistic support and advice.

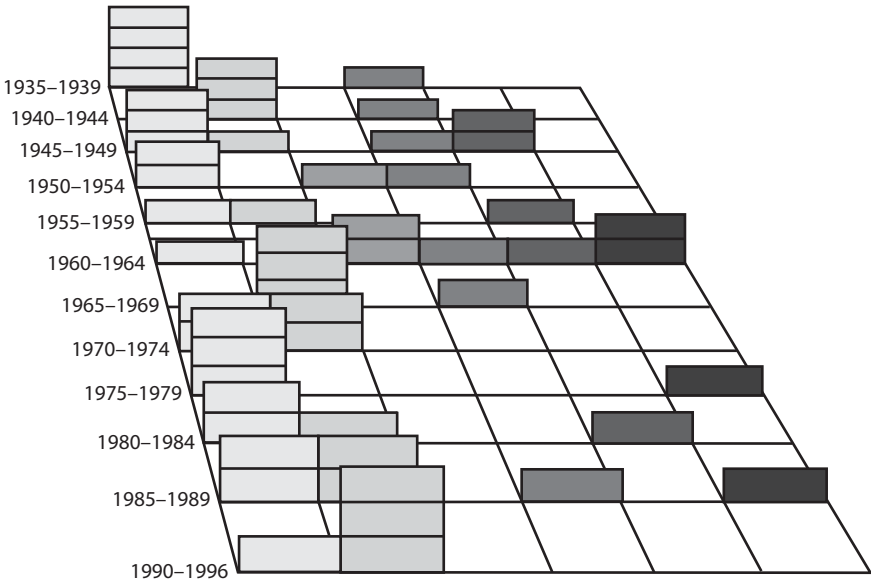
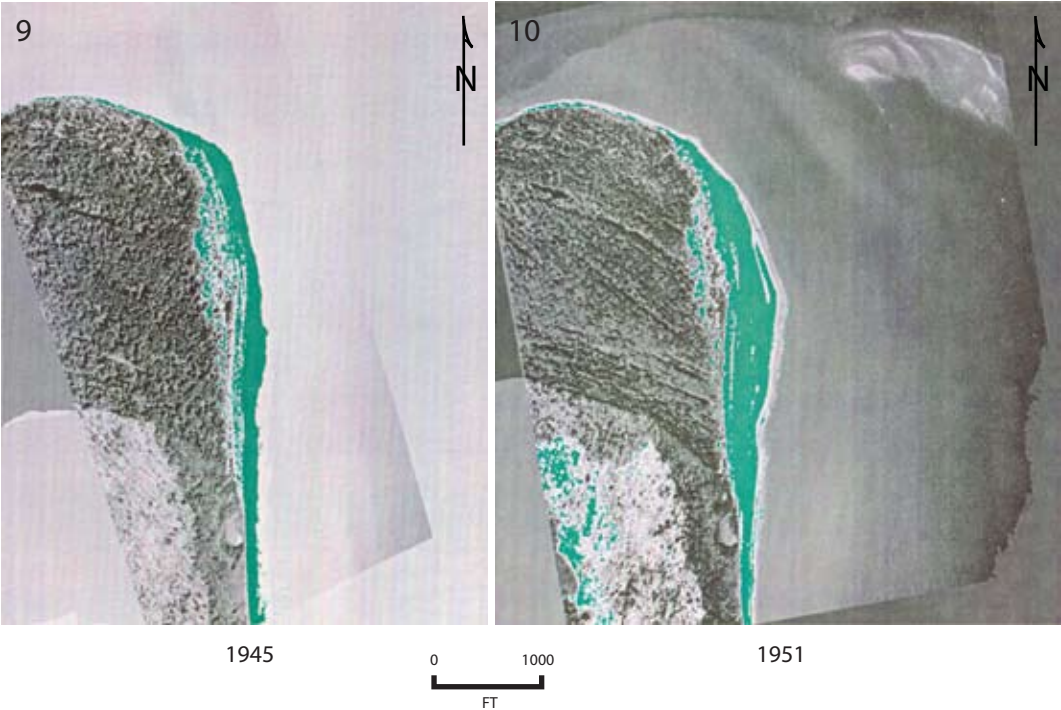
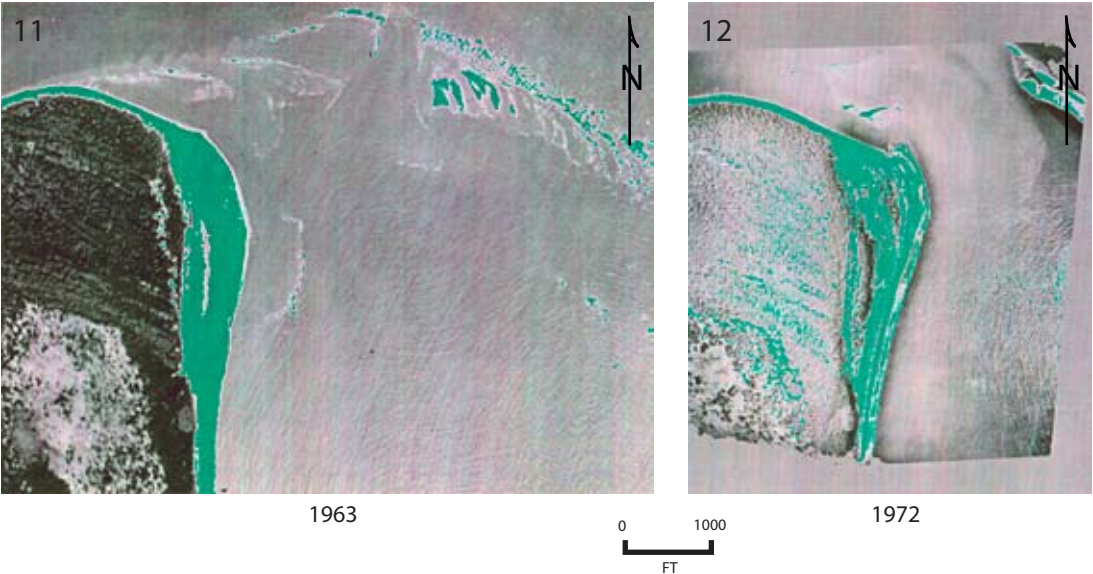


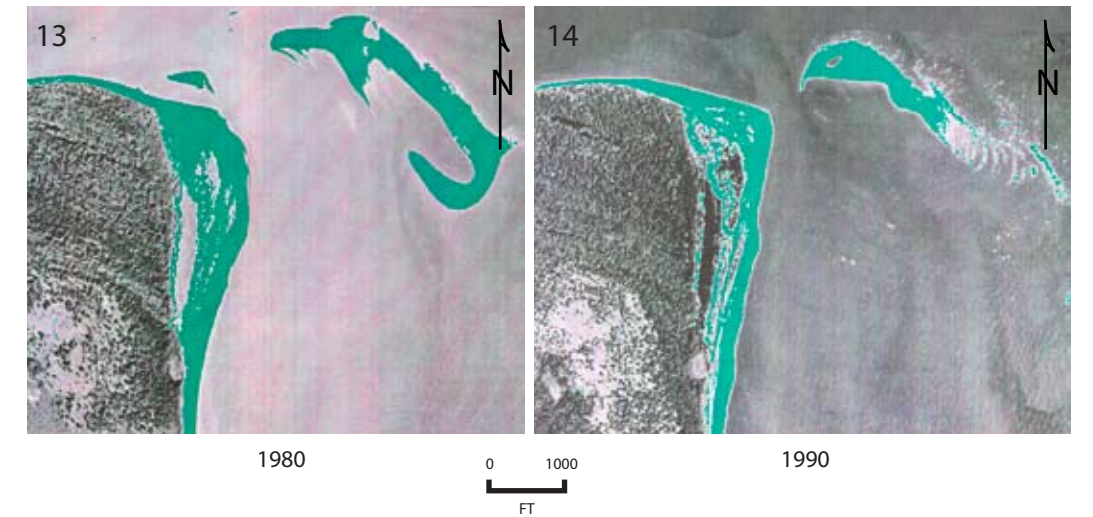
Fig. 8.8. “Cash register” diagram portraying storm intensity and frequency (data from Davis and Dolan, 1993). Intensity ranged, left to right, from tropical storm to Category 5 (Saffir-Simpson scale) hurricane.



Figs. 8.9–8.10. Enhanced aerial photographs of the northern portion of St. Catherines Island, with green color indicating beach sand: **9**, 1945 enhanced photograph (note that photographic coverage may not have included marginal shoal); **10**, 1951 enhanced photograph of northern portion of St. Catherines Island. Green color indicates beach sand (see text).



Figs. 8.11–8.12. Enhanced aerial photographs of the northern portion of St. Catherines Island, with green color indicating beach sand: **11**, 1963 enhanced aerial photograph of northern portion of St. Catherines Island. Green color indicates beach sand (see text); **12**, 1972 enhanced aerial photograph of northern portion of St. Catherines Island. Green color indicates beach sand (see text).



Figs. 8.13–8.14. Enhanced aerial photographs of the northern portion of St. Catherines Island, with green color indicating beach sand: **13**, 1980 enhanced photograph; **14**, 1990 enhanced photograph.

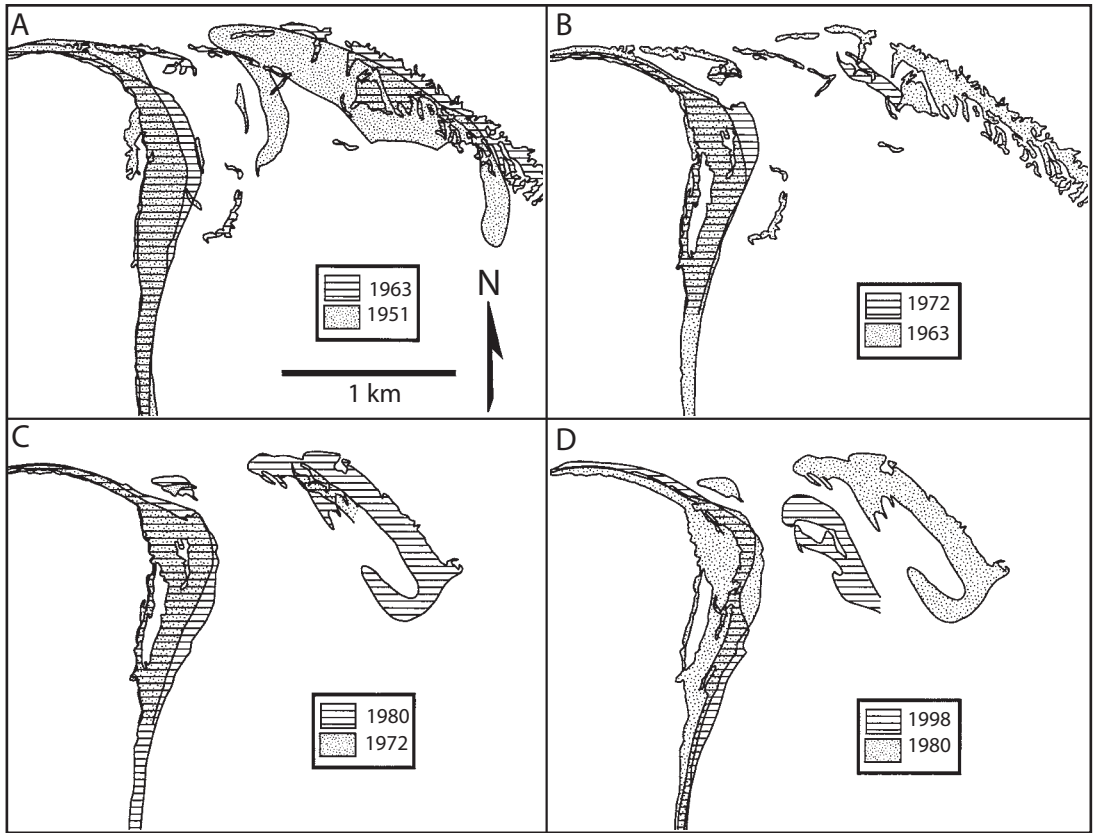


Fig. 8.15. Schematic overlays showing temporal sequence (A–D) of geomorphic changes along the southern marginal ramp shoal area, northern end of St. Catherines Island.





## CHAPTER 9

### DRAINAGE CHANGES AT OSSABAW, ST. CATHERINES, AND SAPELO SOUNDS AND THEIR INFLUENCE ON ISLAND MORPHOLOGY AND SPIT BUILDING ON ST. CATHERINES ISLAND

TIMOTHY M. CHOWNS<sup>1</sup>

In a recent paper, Chowns and others (2008) suggest that estuaries on the Georgia coast have recently been straightened as a consequence of the Holocene transgression. Abandoned channels preserved beneath Holocene marsh show that inlets formerly debouched south of their present locations, presumably in response to southerly longshore transport. Ossabaw, St. Catherines, and Sapelo sounds are prime examples of inlets that appear to have been modified during this process. All these inlets are fed by tidal distributaries and marshes that may be subject to avulsion when large volumes of water are trapped behind the barrier islands by a combination of storm runoff, onshore winds, and high tides. Circumstantial evidence for changes in inlet location is mainly geomorphic (fig. 9.1) including evidence of:

- (1) Breaching supplied by truncation and cross-cutting relations adjacent to modern channels,

- (2) Abandoned channels preserved beneath modern marsh,

- (3) Detached spits that originally formed the northern, seaward margin of abandoned inlets,

- (4) New spits formed by rapid progradation into abandoned inlets.

All four criteria were documented in the diversion of Brunswick River from the south to the north end of Jekyll Island and proved by vibracoring and radiometric dating (Chowns et al., 2008).

In the present case Ossabaw Sound provides the clearest evidence of recent breaching, Blackbeard and Guale marshes are possible abandoned channels, Blackbeard and Guale islands are good candidates for dissected spits, and St. Catherines Spit represents abandoned inlet fill. In order to assess the evidence, relative timing is critical.

The breaching of an inlet, dissection of a spit, abandonment of a former channel, and growth of a new spit are clearly related events. Thus a program of vibracoring, and dating by <sup>14</sup>C and optically stimulated luminescence (OSL) using quartz sand, has been initiated to establish the age of the inlets, dates of abandonment and infilling, and the ages of dune ridges that make up the spits (table 9.1). All new <sup>14</sup>C dates are conventional ages corrected for isotopic fractionation by Beta Analytic and are based on plant debris (confidence limit 1σ). Calendar dates are calibrated according to conventions cited in the preface to this volume (Bishop, Rollins, and Thomas). Only preliminary results are available so far but they generally support the hypothesis and provide a provisional time line.

The study area lies at the center of the Georgia Bight subject to a mixed wave and tidal regime, although dominated by tidal processes (Davis and Hayes, 1984; Davis, 1994; Hayes, 1994). Currently, tidal energy increases toward the head of the Georgia Bight, while wave energy decreases. In response to mesotidal conditions and suppressed wave energy the Georgia Sea Islands are relatively short drumstick-shaped islands separated by deep inlets formed by strong tidal currents (especially ebb tidal currents; Oertel, 1975b, 1977; Oertel, Henry, and Foyle, 1991). By contrast, in the Carolinas the combination of larger waves and microtidal conditions leads to longer islands with inlets that tend to close as a result of longshore transport (Davis and Hayes, 1984; Davis, 1994; Hayes, 1994). The processes by which barrier islands form and migrate have been described by Hoyt (1967) and Hoyt and Henry (1967). The

most important origin is through the flooding of dune ridges during transgression, but a secondary cause is the dissection of spits.

Although eustatic sea level has risen progres-

sively during the Holocene (Fleming et al., 1998, Peltier, 2002) the relative rate of rise varies locally as a consequence of vertical land movements. On the U.S. Atlantic coast, variations are primari-

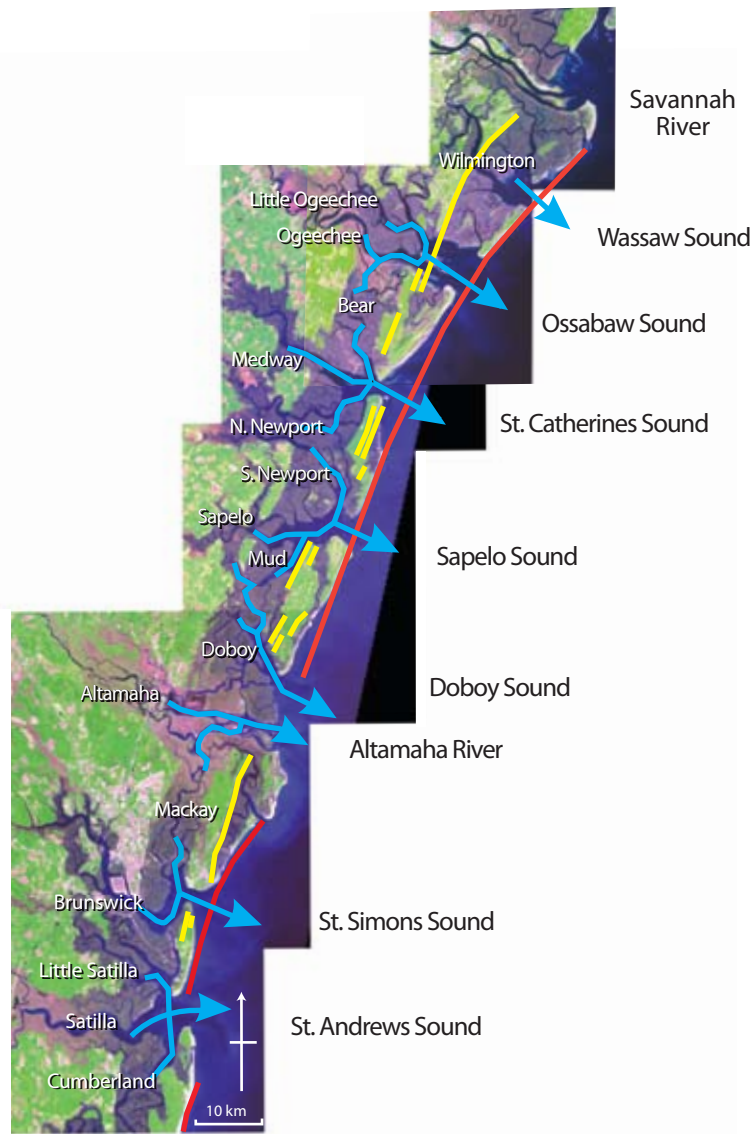


Fig. 9.1. Satellite image of the Georgia coast showing the location of modern estuaries and their principal distributaries. Yellow lines show the continuity of strand lines that make up the Silver Bluff barrier. Red lines suggest the Holocene strand prior to the beaching of major inlets. Note the progradation of the modern strand immediately south of the Savannah and Altamaha, the largest rivers. All inlets take relatively direct routes to the Atlantic without evidence of displacement due to longshore transport and spit building. This configuration is believed to be a consequence of the modern marine transgression, which favors tidal over wave processes.

TABLE 9.1  
**Preliminary Ages for Dune Lines on St. Catherines Spit Based  
on Optically Stimulated Luminescence and <sup>14</sup>C Dates**

Locations <sup>a</sup>	OSL ka	<sup>14</sup> C yr B.P.	cal B.P.
Southern tip of spit (XVI–XVII) (Irene phase and later)	(9) 0.5 ± 0.3	—	—
Beach Pond–Flag Pond (XIII– XV), St. Catherines phase	(10) 1.0 ± 0.1	(Beta-217246) 1010 ± 50	830–570
	—	(Beta-217245) 1170 ± 50	960–720
	(11) 0.7 ± 0.1	—	—
	—	(Beta-115910) 1210 ± 40	1260–1010
Jungle Road ridge (X–XII) (Wilmington phase)	(7) 0.3 ± 0.1	—	—
	(6) 0.9 ± 0.1	—	—
	(5) 1.2 ± 0.1	—	—
	(8) 0.5 ± 0.1	—	—
	(3) 1.5 ± 0.3	—	—
Western spit, older part (V–IX) (Refuge–Deptford phases)	—	(Beta-183630) 1350 ± 60	1190–910
	—	(Beta-183629) 1390 ± 50	1120–950
	—	(Beta-183637) 1500 ± 50	1290–1060
	(4) 1.2 ± 0.3	(Beta-20829) 1700 ± 60	1520–1310
	(2) 1.3 ± 0.5	(Beta-262151) 1720 ± 50	1780–1520
Cracker Tom Hammock (I–IV) (St. Simons phase)	—	[(UGA 6442) 3590 ± 50	3820–3490
	—	(USGS #WW-1260) 4450 ± 50	4950–4620

<sup>a</sup>For locations, see figures 9.5 and 9.9. Beta-262151 is reported here for the first time; all other <sup>14</sup>C dates are from Thomas (2008, tables 29.1. and 15.2; see also appendix 1, this volume). Paired OSL and <sup>14</sup>C dates are from related beach ridges and should be of similar age. OSL dates provided by Dr. George Brook, University of Georgia Luminescence Dating Lab, based on assumed water content of 20 ± 5% and cosmic rate 150 ± 30 (μGY/yr).

ly related to glacial isostatic adjustments. The depression created by the Laurentide Ice Sheet was matched by the development of a forebulge that is currently collapsing concomitant with deglaciation and isostatic uplift in Canada (Engelhart et al., 2009). On the Georgia–Carolina coast, several workers (DePratter and Howard, 1981; Gayes et al., 1992; Scott et al., 1995; Colquhoun, Brooks, and Stone, 1995) identify a relative lowstand of sea level (estimated around 3600 cal B.P.) that may be related to the presence of this bulge. It has important implications for the evolution of the coast and its aboriginal inhabitants.

Chowns, Schultz, and Griffin (2006) and Chowns et al. (2008) argue that marine transgression tends to favor tidal over wave processes by trapping sediment in the estuaries and also flooding the marshes, thereby increasing the volume of the tidal prism. On the other hand, stillstand (or minor regression) is expected to release more

sand into the longshore transport system and decrease the volume of the tidal prism, thus favoring wave over tidal processes. In other words, stillstand favors spit building and the diversion of inlets while transgression encourages inlet straightening and the dissection of spits.

This chapter investigates the evidence for breaching at Ossabaw, St. Catherines, and Sapelo sounds, the possible timing of the breaches, and their influence on the distribution of erosion and accretion, especially on St. Catherines Island.

# SILVER BLUFF STRANGLINES

During the Pleistocene with sea levels down around 100 m, the coastline lay close to the shelf edge (Hoyt, Henry, and Weimer, 1968; Hoyt and Hails, 1974; Fleming et al., 1998; Rollins and Thomas, this volume, chap. 16). Radiometric ages from buried marsh sediments and cypress

swamps indicate that sea level first reached the modern shoreline between 5500 and 4500  $^{14}\text{C}$  yr B.P. (DePratter and Howard, 1977, 1980, 1981; Thomas, Rollins, and DePratter, 2008: chap 29), reoccupying an earlier Silver Bluff strandline, questionably dated between 35 and 50  $^{14}\text{C}$  ka (Hoyt, Henry, and Weimer, 1968; Hoyt and Hails, 1974; Vento and Stahlman, this volume, chap. 4). In this process, the old dunes were converted to barrier islands, the low country behind the dunes was inundated to form marshes, and inlets opened at river mouths (Hoyt, 1967). St. Catherines Island was isolated from the mainland around 4000 B.P. (Linsley 1993; Linsley, Bishop and Rollins, 2008; Thomas, 2008: chap 4; Rollins and Thomas, this volume, chap. 16). As sea level rose with deglaciation, barrier islands initiated on the shelf migrated landward, and presumably southward with longshore transport, and eventually merged with the old Silver Bluff dunes to form the modern Sea Islands with a Pleistocene core fronted by dunes and marshes accreted during the Holocene (Bishop et al., chap. 3, this vol.). Satellite images of the Silver Bluff islands show lineations representing old wave-cut strandlines that form a rather continuous arc between the Savannah and Altamaha rivers (fig. 9.1). In spite of intervening inlets, lineaments project from one island to another as if the islands were once continuous. This continuity is especially obvious across Wassaw and Ossabaw sounds leading to the crosscutting relationship illustrated by Alexander and Henry (2007). These same lineaments may also project to St. Catherines Island, raising the possibility that the scarp that forms the southeastern boundary of the Silver Bluff barrier on Ossabaw Island is the same feature as the King New Ground Scarp on St. Catherines (Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008). There is a long gap between Silver Bluff deposits on St. Catherines and the north end of Sapelo Island but the trends are similar. The first noticeable change occurs at the south end of Sapelo where the trend that extends from Wilmington and Skidaway islands is truncated by a younger set of cusped beach lineaments. Overall, beach ridges on the Silver Bluff barrier seem to be more continuous than the Holocene beach ridges. If inlets were present between Skidaway, Ossabaw, and St. Catherines islands they must have been relatively small. The only possible interruption for a larger inlet along this stretch of coast during Silver Bluff

time was at Sapelo Sound. The implication is that Wassaw, Ossabaw, St. Catherines, and possibly even Sapelo Sound, all postdate the Silver Bluff shoreline and were thus breached or significantly enlarged during the Holocene transgression. One possibility, which needs further investigation, is that the low country between the Silver Bluff and Princess Anne beach ridges represents the former valley of the Ogeechee at a time when it was tributary to the Altamaha.

## OSSABAW SOUND

Ossabaw Sound seems to be the most recent breach within the Georgia Sea Islands (fig. 9.2). The inlet is relatively narrow and clearly transects both Silver Bluff strandlines and Holocene marshes seaward of this barrier (Alexander and Henry, 2007). At first inspection it appears that marshes and sand hammocks dated by archaeological artifacts (DePratter and Howard, 1981) and OSL (Alexander and Henry, 2007) to be as young as 1.5–1.0 ka are truncated. However, peat associated with inlet fill close to Torreys Landing on the south side of Ossabaw Sound (fig. 9.3) shows that this part of the inlet is older than  $1880 \pm 40$   $^{14}\text{C}$  yr B.P. (Beta 263588; 1900–1710 cal B.P.;  $2\sigma$  interval; see appendix 1; i.e., Deptford or older). Nevertheless, Ossabaw Sound still appears to be one of the youngest inlets between the Sea Islands with no sign of abandoned channels as in the case of older inlets at St. Catherines and Sapelo sounds and only a small spit intruding from Wassaw Island.

Because the Holocene marsh is almost 5 km wide, the Silver Bluff barrier cannot have been breached by erosion from the seaward margin. Rather it must have resulted from erosion by the Ogeechee. In fact, aerial photographs suggest the possibility of a large meander in the vicinity of the confluence of the Little Ogeechee with the main trunk of the Ogeechee, which may have initiated the breach (fig. 9.2). Erosion on the outside cut-bank of such a meander would be expected to eat away the western margin of the Silver Bluff barrier, ultimately allowing communication with the marsh west of the Holocene barrier. Most likely the avulsion occurred as a consequence of excess discharge and flooding on the lower reaches of the Ogeechee. Combinations of storm rainfall (hurricane or nor'easter), onshore winds, and high spring tides are precisely the kinds of conditions required.

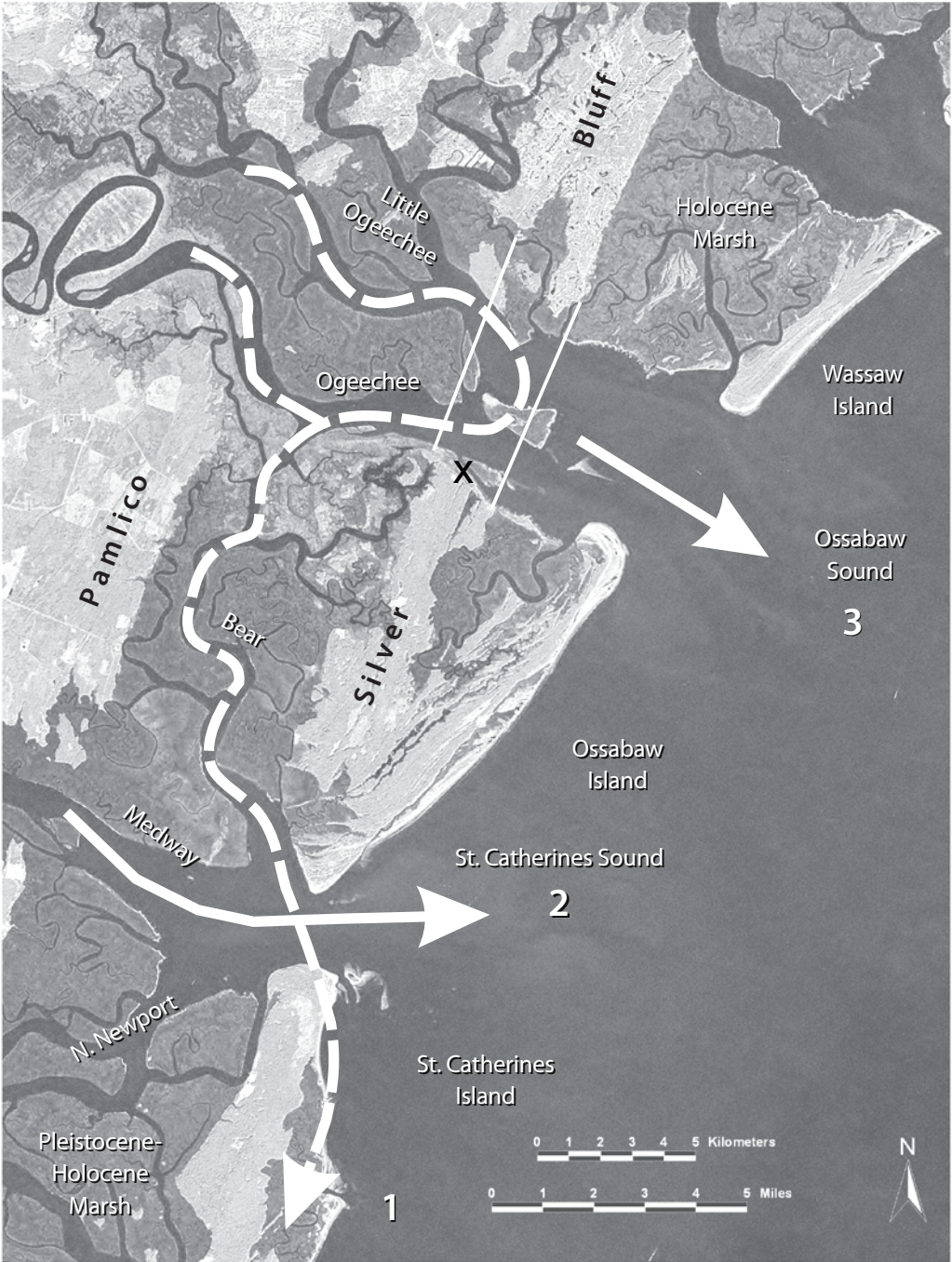


Fig. 9.2. Satellite imagery of Ossabaw Island showing the proposed displacement in the mouth of the Ogeechee from St. Catherines Sound to Ossabaw Sound resulting from erosion and avulsion at an old meander at the confluence with the Little Ogeechee. Numbers indicate the relative ages of inlets based on crosscutting relations. Number 1 is Guale Inlet. Cross marks the location of Torreys Landing (fig. 9.3) (updated from Chowns et al., 2008).

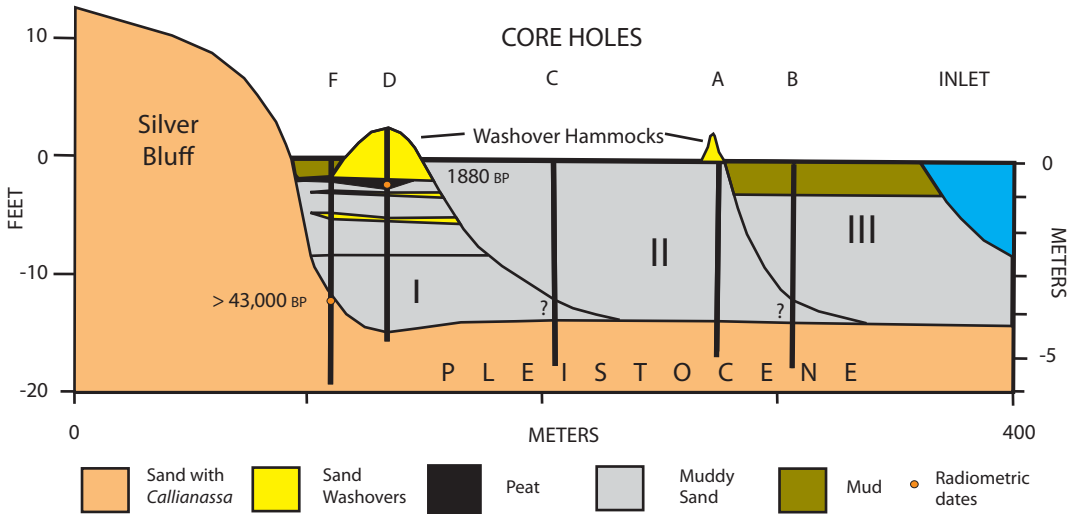


Fig. 9.3 Stratigraphic cross section constructed from vibracores (A–D, F) across channel bars (I, II, and III) near Torreys Landing on the south side of Ossabaw Sound (see fig. 9.2 for location). Radiometric dates show that the inlet predates  $1880 \pm 40$   $^{14}\text{C}$  yr B.P. (1900–1710 cal B.P.;  $2\sigma$  interval).

### SAPELO SOUND AND BLACKBEARD ISLAND

The original location of Sapelo Sound is known from the development of beach ridges at the south end of St. Catherine's Island (figs. 9.4 and 9.5). The oldest Holocene beach ridges in the vicinity of Cracker Tom Hammock (terrains I–IV) were evidently shaped by wave action on the Atlantic strand. They are concave toward the ocean, having accreted against a bulwark of Pleistocene deposits along Back Creek Scarp. Figure 9.5 illustrates the major accretionary terrains that make up St. Catherine's Spit south of Cracker Tom Hammock. In addition to progradation (purple lines) there were periodic episodes of wave erosion from the Atlantic beach (green lines) and the tip of the spit was frequently trimmed by storm waves crossing Sapelo Sound (yellow lines). The red line labeled Zapala Scarp indicates dissection by a tidal channel and is interpreted as the original limit of Sapelo Sound (Bishop et al., 2007).

The first evidence of a spit (terrain V) occurs immediately south of Zapala Scarp, which truncates Cracker Tom Hammock seaward of South Newport River (Bishop et al., 2007). While Cracker Tom Hammock overlies Pleistocene de-

posits at shallow depth (Booth and Rich, 1999; Booth, Rich, and Bishop, 1999), south of Zapala Scarp the spit rests on inlet fill (Linsley, Bishop, and Rollins, 2008). Radiometric dates from roots in a paleosol within terrain V suggest that the spit was initiated sometime before  $1720 \pm 50$   $^{14}\text{C}$  yr B.P. (Beta 262151; 1780–1520 cal B.P.; fig. 9.6) possibly around 2700 cal B.P. or even 3000 B.P., based on the occurrence of early Refuge ceramics on terrain VII (Thomas, Rollins, and DePratter, 2008: chap. 29). A small composite sample of plant debris deposited with the sand of terrain V was submitted for dating (Beta 261351;  $6330 \pm 60$   $^{14}\text{C}$  yr B.P.; 7420–7160 cal B.P.) but proved excessively old probably as a result of contamination with reworked fossil wood.<sup>2</sup>

The southern shore of Sapelo Sound is formed by Blackbeard Island and the question then arises as to whether, prior to the erosion of Zapala Scarp, this island may have been a part of St. Catherine's Island. The suggestion that Blackbeard Island originated as a spit at the southern end of St. Catherine's Island rests on similarities to the beach ridges on Cracker Tom Hammock and overall morphology (figs. 9.5 and 9.7). Like Cracker Tom Hammock, Blackbeard Island consists mainly of beach ridges that are concave to the Atlantic and quite unlike

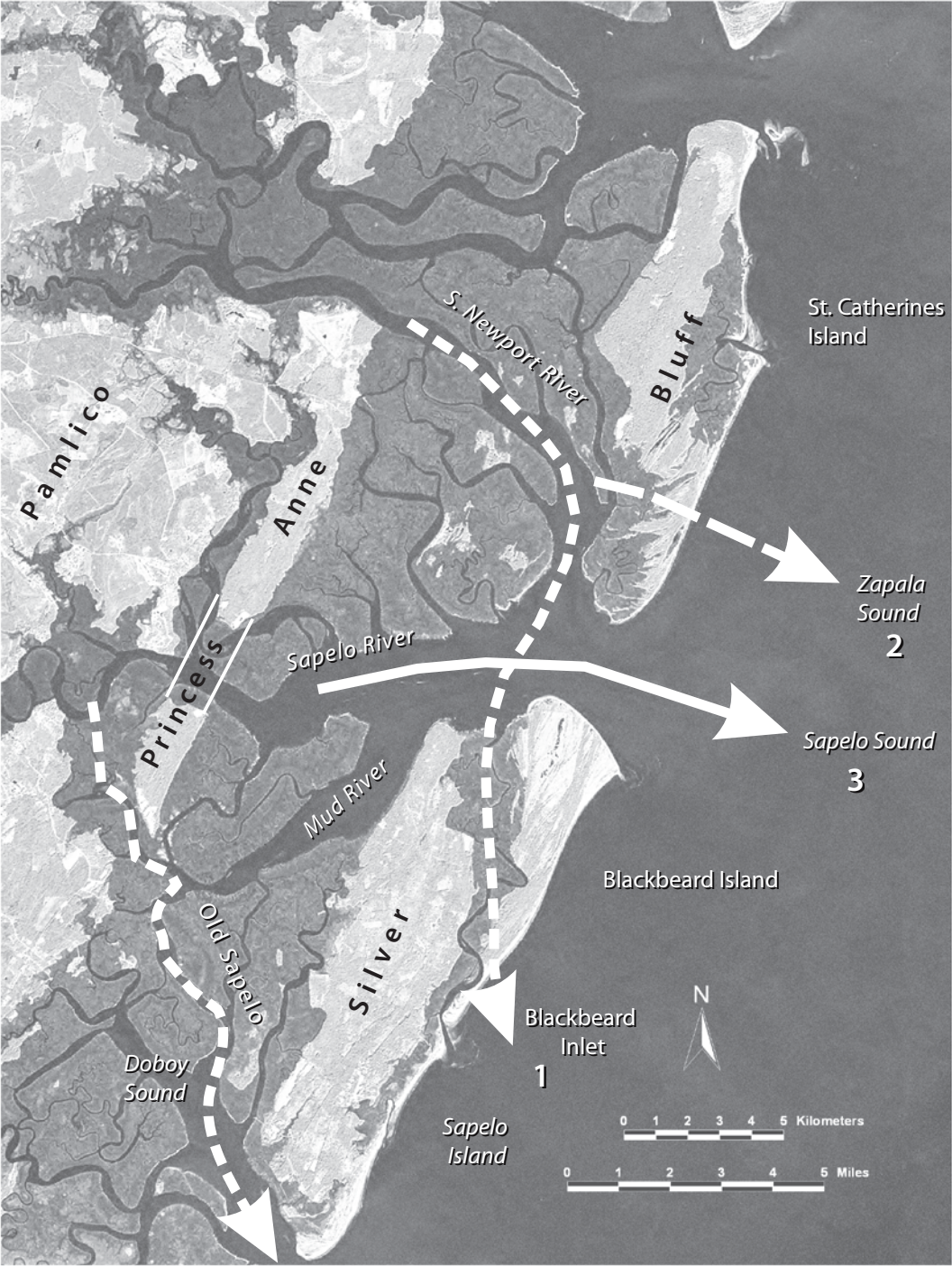


Fig. 9.4. Satellite imagery of St. Catherines and Sapelo islands suggesting the original course of S. Newport River prior to the breaching of Zapala (Sapelo) Sound and isolation of the southern part of St. Catherines Spit to form Blackbeard Island. Based on crosscutting relations Blackbeard Inlet (1) predates Zapala Sound (2) and Sapelo Sound (3). Sapelo River originally drained into Doboy Sound (updated from Chowns et al., 2008).

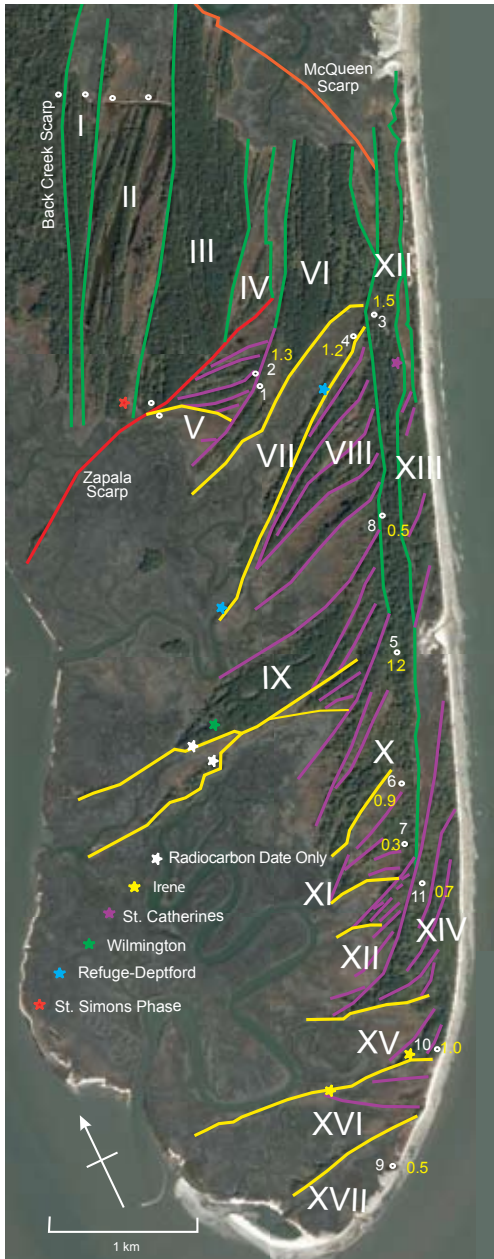


Fig. 9.5. Beach ridges that make up St. Catherine's Spit illustrating episodes of progradation (purple lines) interrupted by erosion; wave erosion on the Atlantic beach (green), and southern tip of the spit (yellow) as well as erosion by tidal inlets (red). Numbered circles show the locations of sample sites providing OSL dates (table 9.1). Asterisks, color coded to date, represent archaeological sites from Thomas (2008): Irene (yellow), cal A.D. 1300–1580; St. Catherine's (violet), cal A.D. 800–1300; Wilmington (green), cal A.D. 350–800; Refuge-Deptford (blue), cal 1000 B.C.–A.D. 350; and St. Simons Phase (red), cal 3000–1000 B.C.

the convex dune lines that form the modern tip of St. Catherine's. Both sets of beach ridges are similarly aligned and generally prograde to the east except at the southern end of Blackbeard where progradation is to the south, culminating in the spit at Cabretta Inlet (Oertel, 1975b). If we assume for the sake of argument that Sapelo Sound has maintained a constant width during the progradation of St. Catherine's Spit, then the north end of Blackbeard Island may have lost around 6 km to erosion since about 2700 cal B.P. This is sufficient to span the modern sound and overlap the southern third of the spit (fig. 9.8). Blackbeard Marsh is entirely consistent with an abandoned tidal inlet. At the northern end it matches the dimensions and alignment of South Newport River while to the south it narrows as a result of overwash from the younger part of Blackbeard Island.

It is clear that Blackbeard is a late addition to Sapelo Island. Depending on the development of inlets, it must have originated as an independent island or as part of St. Catherine's Island. If it is a segment of St. Catherine's, the older parts of Blackbeard should match (or postdate) terrains around Cracker Tom Hammock and predate terrains south of Zapala Scarp. Once again, radiometric dating is necessary to test which hypothesis is feasible. Current archaeological sites and limited  $^{14}\text{C}$  dating indicate that Cracker Tom Hammock predates 4000  $^{14}\text{C}$  yr B.P. (4480 cal B.P.; St. Simons phase or older) while St. Catherine's spit is younger than ~2700 cal B.P. (Refuge and younger, per Thomas, 2008: table 15.3). The oldest archaeological sites on the west side of Blackbeard Island date to the Deptford period (C. DePratter, V. Thompson, personal commun., 2008), which ranges from 2180 to 1690  $^{14}\text{C}$  yr (2300–1600 cal B.P.) in the St. Catherine's Island chronology (Thomas, 2008: chap. 15; this volume, table 1.1); the island, of course, may be much older. Preliminary  $^{14}\text{C}$  dates from the west side of the island range from  $3090 \pm 40$  B.P. (3330–2750 cal B.P.; Beta-282469) to 2110  $\pm 40$  B.P. (2290–2270 and 2160–1990 cal B.P.; Beta-

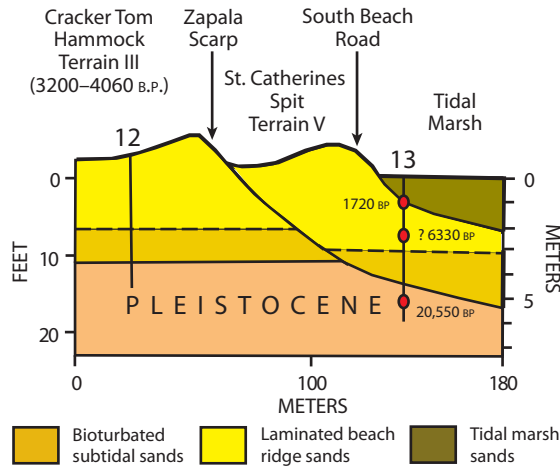


Fig. 9.6. Stratigraphic cross section across Zapala Scarp showing locations of dated samples (all expressed in  $^{14}\text{C}$  yr B.P.). Dates prove that terrain V predates  $1720 \pm 50$   $^{14}\text{C}$  yr B.P. (1780–1520 cal B.P.). Estimate of  $6330 \pm 60$   $^{14}\text{C}$  yr B.P. (7420–7160 cal B.P.) was from a composite sample of plant debris and is most likely contaminated by fossil material. See figure 9.9 for location of vibracores. Dates for Cracker Tom Hammock are based on Booth, Rich, and Bishop, 1999.

282468) (St. Simons to Deptford) as predicted.

The alignment of Blackbeard Marsh with South Newport River suggests that the location of Sapelo Sound was formerly controlled mainly by the South Newport and that it was the breaching of Zapala Scarp that led to the abandonment of the inlet beneath Blackbeard Marsh. This also suggests that formerly Sapelo and Mud rivers may have debouched further south at Doboy Sound.

#### ST. CATHERINES SOUND AND GUALE ISLAND

According to Linsley (1993), Linsley, Bishop, and Rollins (2008), and Bishop et al. (2007), St. Catherines Island was, until recently, accompanied by a doublet similar to the Blackbeard-Sapelo doublet. The reconstructions of those authors show an unusual geometry with a seaside marsh protected by north and south prograding spits. As an alternative interpretation, it is possible that, as in the case of Blackbeard Island, “Guale Island” originated as a spit at the southern end of Ossabaw Island and was dissected due to a change in the position of St. Catherines Sound. In this case Seaside-McQueen (Guale) Marsh, like Blackbeard Marsh, is the remnant of the old inlet (fig. 9.8).

Prior to the breaching of Ossabaw Sound the Ogeechee probably entered St. Catherines Sound via Bear River and possibly occupied the channel beneath Guale Marsh. Bishop et al. (2007) record more than 9.1 m of marsh mud at the northern end of Seaside (Guale) Marsh, a minimum depth for the channel. Radiocarbon dates from other cores in the same vicinity indicate an active channel between 4290 and 3100  $^{14}\text{C}$  yr B.P. (4840–3350 cal B.P.) giving way to tidal marsh around 1720  $^{14}\text{C}$  yr B.P. (1580 cal B.P.; Linsley, 1993; Linsley, Bishop, and Rollins, 2008; Thomas, Rollins, and DePratter, 2008: table 29.1; see also this volume, appendix 1). Guale Inlet may have been abandoned with the loss of discharge from the Ogeechee or possibly earlier as a result of other drainage changes or erosion at the shoreline. Loss of the Ogeechee would increase the importance of the Medway and South Newport rivers and change the trajectory of the inlet, possibly leading to abandonment of Guale Inlet and the breaching of a spit attached to Ossabaw to form Guale Island. This is a similar scenario to that described at St. Simons Inlet following a change in trajectory due to the capture of Brunswick River (Chowns et al., 2008). Accretion north and south of the modern inlet (Oertel, 1975b) is most likely a response to the loss of discharge and

narrowing of the channel, which is now controlled mainly by the Medway.

ST. CATHERINES SPIT

Any changes in inlet geometry, and especially those involving the Ogeechee, would have a major effect on sand supply to Ossabaw, St. Catherines, and Sapelo islands. In the case of Sapelo

and St. Catherines, a recent displacement in the Ogeechee would remove the islands from a proximal to a distal position relative to sand supply from this river. It is very likely that changes in erosion and progradation both on Gualie Island and the southern spit may be related to such changes in sand supply (Bishop et al., 2007). Figure 9.9 shows estimated ages of the accretionary terrains that make up the spit. Approximate ages



Fig. 9.7. Pattern of beach ridges on Blackbeard Island showing progradation to the east and south over time. Green lines between major terrains mark intervals of wave erosion on the Atlantic foreshore; yellow lines indicate erosion at the tip of a spit, and red lines are channel margins. Note the overall cuspate geometry (similar to Cracker Tom Hammock) formed by deposition against a bulwark of older deposits.

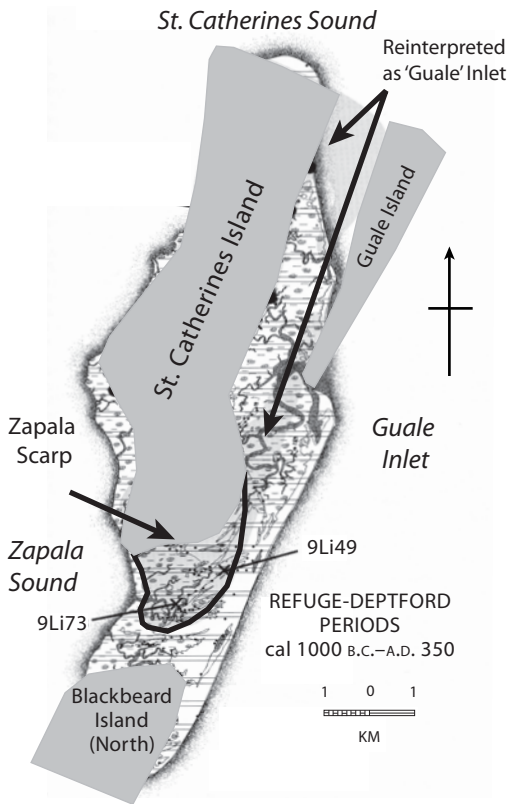


Fig. 9.8. Reconstruction of St. Catherines Island around 2700  $^{14}\text{C}$  yr B.P. (2770 cal B.P.; early Refuge Period) showing Guale Island, Guale Inlet, and Zapala Scarp with the inferred location of Blackbeard Island (modified from Linsley, 1993; Thomas and others, 2008). Timing is shortly after the breaching of both Zapala (Sapelo) and St. Catherines sounds. Sites 9Li49 and 9Li73 are Refuge sites (9Li49 early Refuge) on the spit south of Zapala scarp showing that the scarp must have been eroded prior to 2500 B.P.  $^{14}\text{C}$  yr B.P. (2610 cal B.P.).

are given based on  $^{14}\text{C}$  dates and archaeological sites, mainly from Thomas (2008: tables 13.4 and 29.1), supplemented by preliminary dates from optically stimulated luminescence (OSL) of quartz sands making up the dune ridges (table 9.1). Since beach ridges may have been reoccupied over a considerable range of time, it is clearly the older archaeological ages that are most significant for dating the progradation of the spit. In general the OSL dates fall in the correct order and

are consistent with  $^{14}\text{C}$  dates but younger than expected from archaeological determinations. There are no radiometric ages older than 1720  $^{14}\text{C}$  yr B.P. (1580 cal B.P.) and yet archaeological sites date back to the early Refuge period (2850–2500 cal B.P.). This is a problem previously noted by Thomas (2008, chap. 16, and personal commun., 2010). Some OSL dates are anomalously young, possibly as a result of exposure to blowouts, superposition of younger dunes, or bioturbation after original deposition.

The spit may be divided into four distinct sectors characterized by different styles of accretion and separated by pronounced erosional discontinuities (fig. 9.9). The oldest sector includes terrains I–IV and lies immediately east of Back Creek Scarp. It is bounded on all sides by erosional discontinuities but evidently formed due to eastward progradation of the Atlantic beach. The beach ridges are distinctly cusate because sand accumulated against a bulwark of older beach ridges. Radiometric ages from Cracker Tom Causeway (Booth, Rich, and Bishop, 1999; Thomas, 2008: table 29.1) indicate that deposition commenced sometime before  $4450 \pm 50$   $^{14}\text{C}$  yr B.P. (4950–4620 cal B.P.), which is in accord with the occurrence of St. Simons period artifacts resting on terrain II.

The second sector includes terrains V–IX with the first evidence of an inlet and recurved spit in terrain V. The resulting discontinuity with terrains I–IV is identified as Zapala Scarp (Bishop et al., 2007) and appears to connect with the Atlantic beach to the north (between intervals IV and VI) and with the remnants of an overwash hammock further west. Terrain VI also records the southern tip of the island with a recurved spit turning north into Atlantic beach ridges. This is the last unit that progrades markedly to the east. Terrain VII consists of Long Marsh and an associated overwash-sand hammock to the southeast. The sand hammock is especially significant because two archaeological sites (9Li49, and 9Li73 of Thomas, 2008, chaps. 20 and 28; Thomas, Rollins, and DePratter, 2008, chap. 29: fig. 9.8) have yielded Refuge artifacts (early Refuge in the case of 9Li49). This would indicate that the shoreline must have prograded south of terrain VII by the end of Refuge times (around 2300 cal B.P.; see table 1.1) and that  $^{14}\text{C}$  ( $1720 \pm 50$   $^{14}\text{C}$  yr B.P.; 1780–1520 cal B.P.) and OSL ( $1.3 \pm 0.5$  ka) dates from terrain V are too young. Subsequent to terrain VII, progradation was mainly southward, periodically interrupted

by erosion from waves crossing Sapelo Sound. The position of the Atlantic beach was apparently stationary through terrains VIII–IX with  $^{14}\text{C}$  dates ranging from  $1500 \pm 50$  (1290–1060 cal B.P.) yr B.P. to  $1350 \pm 60$  yr B.P. (1190–910 cal B.P.). One archaeological site dates to the Wilmington period (9Li 164), but terrains VIII–IX might be older, possibly even Refuge.

Terrains X–XII continue to build to the south but an important discontinuity is evident at the north end. Here X–XII are amalgamated into a single ridge that truncates older terrains, in particular terrain VI and McQueen Scarp. Evidently, the remnant of Guale Inlet north of McQueen Scarp was blocked at this time. OSL dates within this sector show a scatter ranging from  $0.3 \pm 0.1$  to  $1.5 \pm 0.3$  ka possibly due to the superposition of younger dunes on top of the X–XII ridge. There is only one significant archaeological site (9Li128) yielding sherds of St. Catherines age (Thomas, 2008: chap. 20; Thomas, Rollins, and DePratter, 2008: chap. 29). Most likely this ridge dates to the Wilmington period but, once again, may be older. The last important break (along Jungle Road Scarp) occurs between terrains XII and XIII immediately east of Jungle Road. Terrains X–XII were abandoned at this stage and a new foreshore XIII–XVII was constructed further east. It was the progradation of this new succession of beach ridges that impounded first Beach Pond (1210  $^{14}\text{C}$  yr B.P.; 1260–1010 cal B.P.; Booth et al., 1999) and later Flag Pond. Radiometric ages indicate the southern tip of the island at terrain XV by 1090  $^{14}\text{C}$  yr B.P. (cal 1000 B.P.;  $1.0 \pm 0.1$  ka OSL). To the north terrains XIII–XV are mainly St. Catherines age while further south (XVI–XVII) they are probably Irene. The Jungle Road hiatus between units XII and XIII is probably late Wilmington (prior to  $1210 \pm 40$   $^{14}\text{C}$  yr B.P.; 1260–1010 cal B.P.).

The southern tip of the island has been undergoing rapid erosion for at least 150 years (Griffin and Henry, 1984) and the location of the strandline is currently controlled by the position of the headland at McQueen Inlet.

#### AGE RELATIONS

More work is needed to prove the ages of Ossabaw, St. Catherines, and Sapelo sounds but some idea of relative age may be gained from existing dates and from geomorphic preservation (table 9.1; figs. 9.9 and 9.10). The relative ages of these inlets as well as of Blackbeard and Guale inlets are critical to the question of the

segmentation of the Ogeechee, which will be discussed later.

The breaching of Sapelo Sound along the line of Zapala Scarp probably occurred during the early Refuge archaeological period (perhaps around 2700 cal B.P.) or sometime around the St. Simons–Refuge boundary (3000 cal B.P.) and has since been obscured by the renewed progradation of St. Catherines Spit. Prior to the Refuge period, between about 4300 and 3600 cal B.P. or perhaps a little later (Gayes et al., 1992; Scott, Gayes, and Collins, 1995), sea level fell by around 2 m leading to a significant gap in the archaeological record. This may have been due to abandonment of the island or to the drowning and erosion of Refuge sites during subsequent sea level rise (DePratter and Howard, 1981; Thomas, 2008; this volume, chap. 4; chap. 1, this vol.). The eastward progradation of Cracker Tom Hammock (I–IV) may be a record of higher sedimentation rates during the lowstand, while Zapala Scarp was cut during the early stages of transgression. Eastward progradation was resumed in terrains V–VII possibly due to the proximity of the Ogeechee at Guale Inlet.

In the case of St. Catherines Sound, a presumed doublet, Guale Island, has apparently been consumed by wave erosion and the inlet has been narrowed both to the north and south by accretion. The age of breaching of the modern inlet may be approximated from the date that Guale Inlet was abandoned; sometime before 1720  $^{14}\text{C}$  B.P. (Pitt-723; 2200 cal B.P.) during the Deptford period based on vibracores (Linsley, 1993; Linsley, Bishop, and Rollins, 2008).

Although St. Catherines Spit continued to advance southward, apparently during the Deptford and/or Wilmington periods (2180–1170 cal B.P.), the Atlantic shoreline remained fixed through terrains VIII–XII, as the sedimentation rate was balanced by the creation of accommodation space. Terrain XII crosscuts and is superposed on McQueen Scarp, indicating that Guale Inlet was closed, allowing sand from the erosion of Guale Island to pass directly along the strand to feed the spit. Prior to this time the location of the southern strandline was controlled by the promontory south of Guale Inlet whereas afterward it was controlled by Guale Island. As an apparent result the shoreline was twice trimmed by erosion (prior to XII and again prior to XIII) and then repaired (during XII and later during XIII–XIV). Erosion may have occurred with the

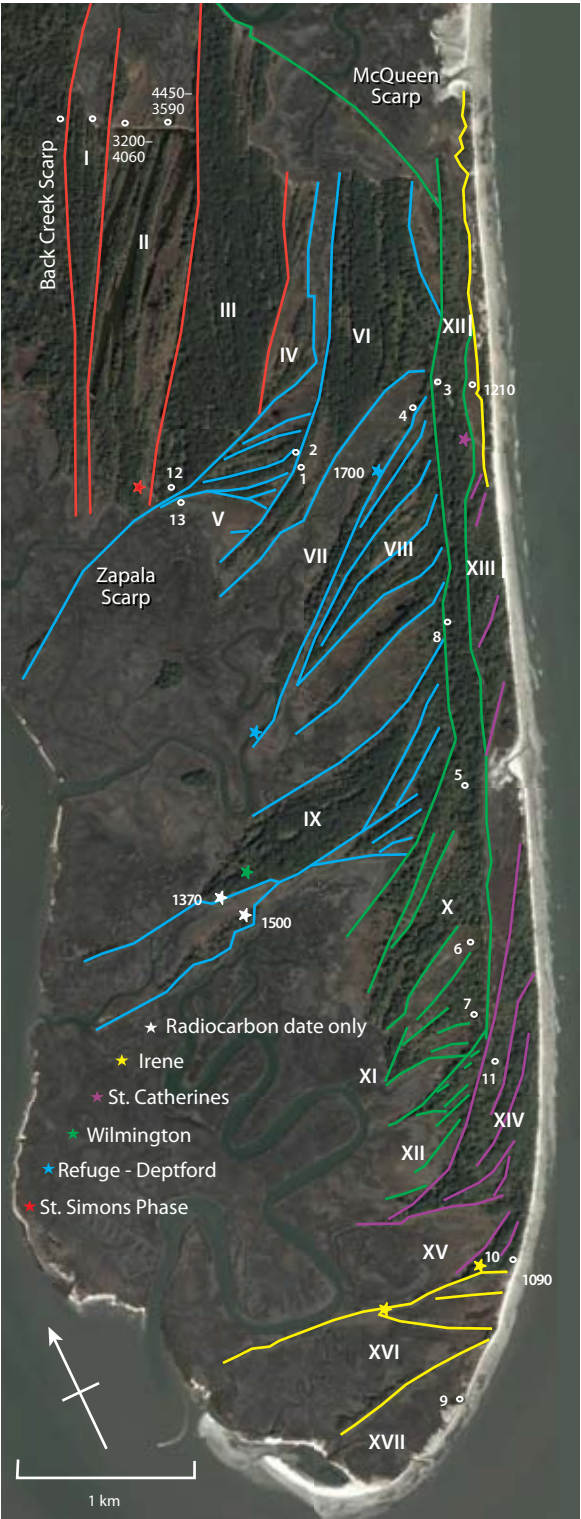


Fig. 9.9. Tentative subdivision by age of accretionary terrains on St. Catherines Spit, based mainly on <sup>14</sup>C dates (expressed in cal B.C./A.D. estimates) as well as the distribution of archaeological sites and dated artifacts: Irene (yellow), cal A.D. 1300–1580; St. Catherines (violet), cal A.D. 800–1300; Wilmington (green), cal A.D. 350–800; Refuge-Deptford (blue), cal 1000 B.C.–A.D. 350; and St. Simons Phase (red), cal 3000–1000 B.C. Numbered circles show the location of sample sites including vibracores where <sup>14</sup>C dates were obtained. Asterisks represent archaeological sites from Thomas (2008).

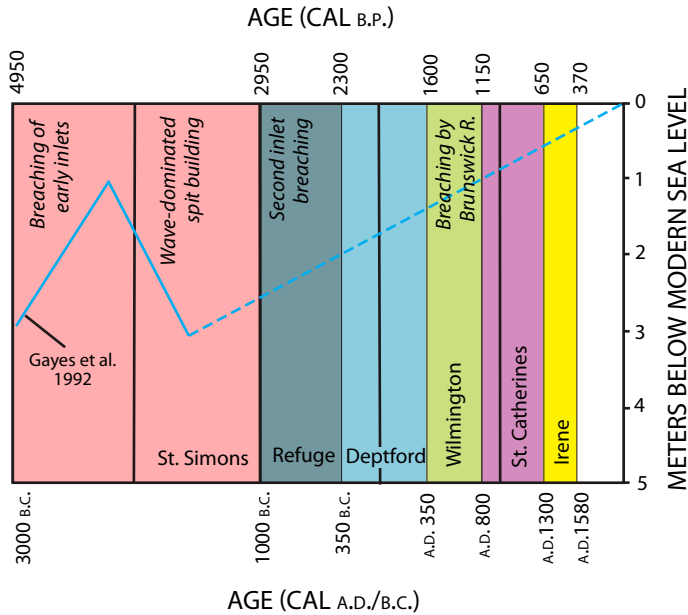


Fig. 9.10. Chronostratigraphic diagram showing relationship between archaeological phases, sea level, and breaching of inlets. Archaeological boundaries are approximate and based on Thomas (2008, chap. 15). Early inlets include the ancestral Blackbeard and Guale inlets. Sapelo Sound, St. Catherine's Sound, and Ossabaw Sound are secondary inlets. Blackbeard and Guale islands are relics of spits constructed during an interval of wave dominance related to a minor regression.

loss of sand supply from Guale Inlet and repair occurred when supply was reestablished from St. Catherine's Sound or even Ossabaw Sound.

Ossabaw Sound was breached sometime before  $1880 \pm 40$   $^{14}\text{C}$  yr B.P. (Beta-263588: 1900–1710 cal B.P.; see appendix 1) and appears to be the youngest of the three major inlets. As noted earlier, it is markedly crosscutting and without evidence of old abandoned channels. If there is a record of this breach preserved as a hiatus in the progradation of St. Catherine's Spit, it should appear somewhere in the Deptford section. The discontinuities between terrains IX and X and XII and XIII most likely date to the Wilmington period, too young to support a connection. However, there is much uncertainty in the assignment of radiometric dates and a correlation remains a possibility. It is possible that these discontinuities record the relocation of the Ogeechee first to St. Catherine's Sound and later to Ossabaw Sound. In each case erosion was repaired once sand supply was reestablished by longshore

transport. Alternatively, they may merely reflect changes in erosion on nearby Guale Island.

Within the limitations of the available radiometric ages, it seems that all three inlets, Sapelo (Zapala), St. Catherine's, and Ossabaw may have opened around the same time (fig. 9.10), sometime around 2700 cal B.P. in the case of Zapala, between 3100 and 1720  $^{14}\text{C}$  yr B.P. (3350–1570 cal B.P.) for St. Catherine's, and perhaps shortly before 1880  $^{14}\text{C}$  yr B.P. (1870 cal B.P.) in the case of Ossabaw Sound. All may date to the Refuge-Deptford period and be attributable to rising sea levels following a forced regression during late St. Simons time. Further south, the breach at St. Simons Sound occurred around 1480  $^{14}\text{C}$  yr B.P. (1390 cal B.P.), during the Wilmington period (Chowns et al., 2008). At all of these localities southeasterly flowing inlets were abandoned and infilled by marsh: Blackbeard Marsh on Sapelo, Guale Marsh on St. Catherine's, and Clam Creek Marsh on Jekyll. While Blackbeard Marsh is still protected by the spit that formed

its seaward boundary, both Guale Marsh and Clam Creek Marsh are currently exposed to wave erosion.

### BLACKBEARD AND GUALE INLETS

The abandoned inlets beneath Blackbeard and Guale marshes predate younger inlets at Sapelo, St. Catherines, and Ossabaw sounds. Evidently they originated prior to the lowstand responsible for the construction of the spits that eventually gave rise to Blackbeard and Guale islands. This is confirmed in the case of Guale Inlet by inlet facies giving radiometric dates between  $4290 \pm 80$  (Pitt-734) and  $3100 \pm 50$  (Pitt-736)  $^{14}\text{C}$  yr B.P. (3440–3170 cal B.P. and 5210–4570 cal B.P.; Linsley, Bishop, and Rollins, 2008, Thomas, 2008: 835–858, table 29.1). They are therefore the earliest inlets preserved, remnants of older breaches in the Silver Bluff barrier, perhaps dating to the 4300  $^{14}\text{C}$  cal B.P. highstand identified by Gayes et al. (1992) and Scott, Gayes, and Collins (1995). Of course, these radiometric dates record the final positions of these inlets at the time they were abandoned; the inlets probably originated further north up the longshore transport system and migrated south over time.

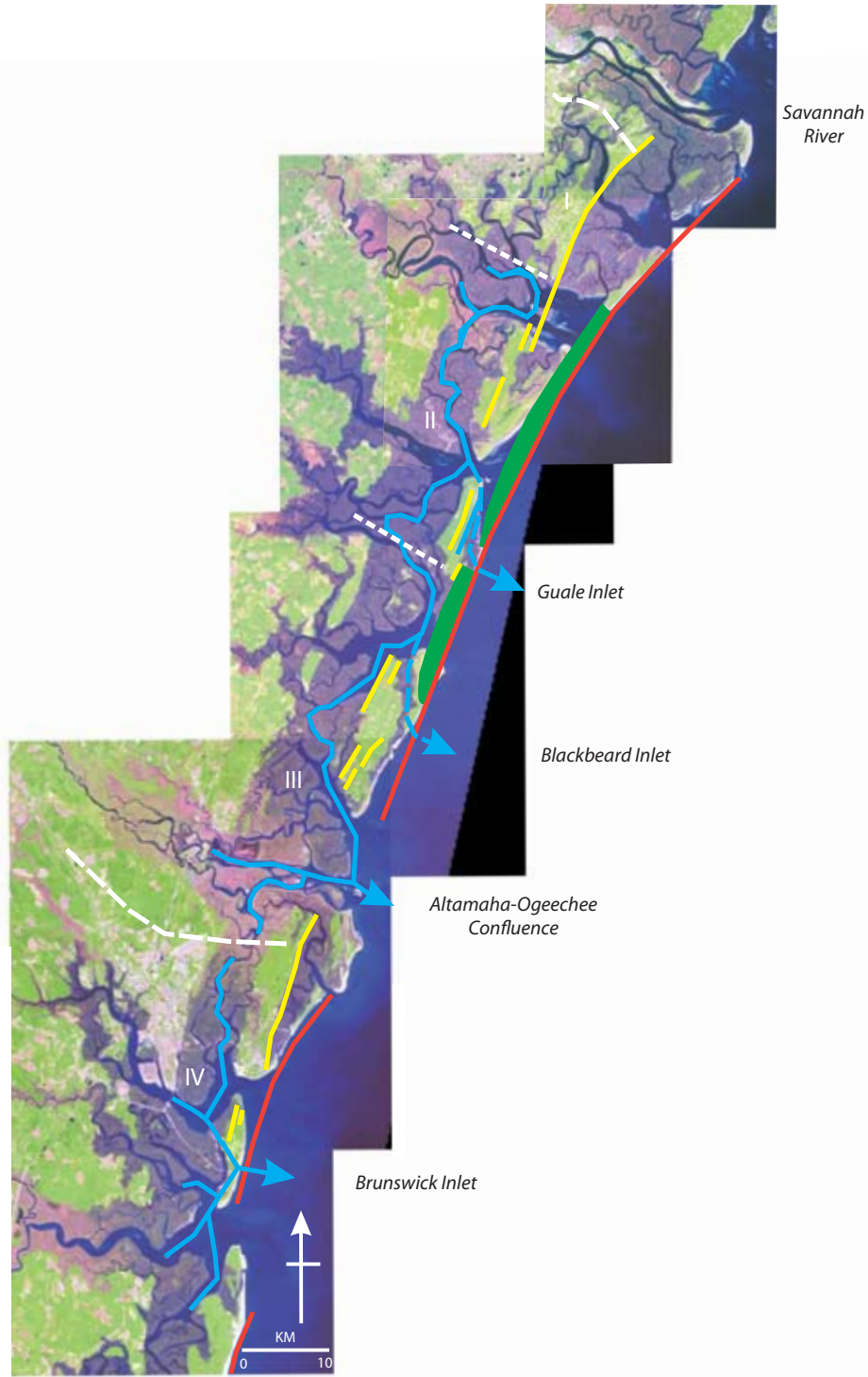
### MECHANISM OF BREACHING

Several mechanisms are possible for the development of the breaches described above. In the case of Ossabaw Sound the Silver Bluff barrier was eroded, allowing a connection between the Ogeechee and the marshes behind the Holocene beach ridge. These marshes may have already drained to the Atlantic via a small inlet that was taken over after the avulsion of the Ogeechee. Wilmington River seems to be an example of a small tidal estuary that has breached the Silver Bluff barrier, possibly by headward erosion. Similar small inlets may have been utilized in other breaches. It is also possible that both Silver Bluff and Holocene beach ridges were eroded by meandering back-barrier tidal distributaries without the necessity of an existing inlet. This certainly seems to be likely where S. Newport River impinges on Holocene beach ridges at the southern end of St. Catherines Island and may also apply at St. Catherines Sound. As a third possibility, some breaches may occur directly as a result of wave erosion. This could have occurred at St. Catherines Sound during the destruction of Guale

Island. Finally, it may be that some sounds are longstanding features with minor changes in size and trajectory taking place in response to local changes in their tidal distributaries (inlet jumping, Chowns, Schultz, and Griffin, 2002). As examples, Sapelo River was probably diverted from Doboy Sound at some time, while North and South Newport rivers might easily switch positions between Sapelo and St. Catherines sounds.

As argued previously for Brunswick River (Chowns et al., 2008), the tendency for inlets to straighten is a predictable consequence of the modern marine transgression. As sea level rises, back-barrier environments are flooded and sediment is trapped upstream in the estuaries. This has the dual effect of increasing the size of the tidal prism and reducing the supply of sand to the longshore transport system. The end result is to favor tidal over wave processes and to break the longshore transport system down into a series of individual inlet sediment cells (Oertel, 1975b), in other words, to favor inlet-straightening over spit-building. It is significant that, with the exception of Blackbeard and Guale inlets, all the breaches described in this chapter have occurred during a period when the Georgia Bight has experienced approximately 3–4 m of sea level rise (DePratter and Howard, 1981; Gayes et al., 1992, Scott, Gayes, and Collins, 1995; Colquhoun, Brooks, and Stone, 1995). Conversely, Blackbeard and Guale islands with their associated marshes are interpreted to be the relics of spits and diverted inlets formed at a time, between about 4300 and 3600 cal B.P. (Thomas, 2008: chap. 4; this volume, chap. 1) when wave processes were favored by a minor regression (fig. 9.10). This was also a period of increased sedimentation rates as judged by the progradation of Cracker Tom Hammock on St. Catherines Island. It was also an interval of major cultural change and perhaps abandonment on the island (Thomas, 2008, chap. 16; this volume, chap. 1).

Any new breach within the barrier islands implies changes in the coastal drainage system. Some of these changes involve only the local switching of inlets, while others may have regional implications. The relocation of Brunswick River from St. Andrews Sound to St. Simons Sound is an example of local inlet jumping (Chowns, Schultz, and Griffin, 2002; Chowns et al., 2008). While the more recent changes at St. Catherines and Sapelo sounds are probably local, the older breaches at Blackbeard and Guale inlets



may be related to more significant changes in the drainage of the Ogeechee.

### THE OGEECHEE

All the estuaries on the Georgia coast make a relatively direct connection with the Atlantic, perpendicular to the coast. This is somewhat surprising given the longshore transport system and led Chowns et al. (2008) to suspect that southeasterly flowing channels had been abandoned in favor of more easterly channels; a consequence of Holocene transgression. The Ogeechee provides one of the best examples, with St. Catherines Sound being the most logical place for a former outlet. If the Ogeechee has been displaced, its former course must have followed the low country southward between the Princess Anne and Silver Bluff barriers, the approximate location of modern Bear River.

The low country between the Silver Bluff and Princess Anne barriers may be divided into four different sectors (fig. 9.11). The northernmost sector (sector I), between the Savannah River and Ossabaw Sound, is mainly Pleistocene with only narrow Holocene marshes. Within this area Pamlico, Princess Anne, and Silver Bluff barriers are preserved and there is no evidence of a major alluvial channel (Henry, Giles, and Woolsey, 1973; Alexander and Henry, 2007). Despite low elevation, this sector forms the drainage divide between the Savannah and Ogeechee rivers. In the middle sectors (II and III), between Ossabaw Sound and the Altamaha, the Holocene marshes expand to a width of around 8 km at the expense of either Princess Anne or Silver Bluff barriers. Between the Medway and S. Newport rivers (sector II) erosion is concentrated on the northwest side, and Princess Anne deposits are entirely absent. Further south, between the S. Newport

and Altamaha (sector III), erosion switches to the southeast and the Silver Bluff is drastically trimmed. In a fourth sector south of the Altamaha, the Holocene marshes narrow and Princess Anne and Pamlico barriers are well preserved. Once again this constriction, landward of St. Simons Island, is a significant (although porous) drainage divide.

Given that the Ogeechee formerly occupied the low country behind Ossabaw Island, it may be argued that the entire middle sector between drainage divides on the south side of the Savannah and south side of the Altamaha is likely the valley of the Ogeechee at a time when it was a major tributary of the Altamaha. The breaching of Blackbeard and Guale inlets, and later Ossabaw Sound, would have segmented this valley and allowed its tributaries (e.g., the Medway, Newport, and Sapelo rivers) direct access to the Atlantic. Depending on the relative ages of Blackbeard and Guale inlets, the mouth of the Ogeechee may have shifted progressively north over time (figs. 9.11 and 9.12). One possible objection to this scenario is the lack of meander scars sculpting the putative valley bluffs. However, much of the valley is now obscured by marsh deposits laid down during transgression, and until about 15 ka the Ogeechee was a braided river (Leigh, Srivastava, and Brook, 2004; Leigh, 2006). The bluffs overlooking the lower reaches of the Savannah and Altamaha are similarly lacking in meander scars.

One unusual characteristic that may be explained by the breaching of inlets through the avulsion of meanders is the bowl-like shape, and pairing of tidal distributaries. Thus at Ossabaw Sound it was the shape of the confluence between the Little Ogeechee and Ogeechee that first suggested avulsion. St. Catherines Sound

Fig. 9.11 (*left*). Reconstruction of the Ogeechee valley behind the Silver Bluff (yellow) and Sea Island (red) strand lines prior to the breaching of Blackbeard and Guale inlets. Note the relic meanders in the pattern of distributaries in the low country behind the Silver Bluff barrier; also the way in which the restoration of the Blackbeard–St. Catherines and Guale–Ossabaw spits helps define an earlier wave-dominated shoreline possibly related to an interval of forced regression between 4300 and 3600 cal B.P. Dashed white lines separate sectors I–IV within the low country behind the Silver Bluff barrier. Sector IV shows drainage to the Brunswick River described by Chowns et al. (2008).

is complicated by the combination of three estuaries (Bear, Medway, and N. Newport) but the Bear and N. Newport show a similar pairing, while Sapelo Sound is formed by the pairing of the S. Newport and Mud rivers (complicated by Sapelo River). Further south, the original confluence of the Ogeechee (Doboy Sound) and Altamaha has been obscured by transgression.

A possible means of testing the original course of the Ogeechee is to check the distribution of micaceous sands within the channel fills encased beneath the marshes. Barring the

Savannah and Altamaha, the Ogeechee is the only southeasterly flowing river likely to carry significant mica from the Piedmont since all other rivers rise on the coastal plain. The Altamaha also carries much mica but it is unlikely to have flowed northeast in a direction opposed to longshore transport. Based on the abundance of mica in Pleistocene valley fill behind Jekyll Island, Chowns et al. (2008) propose that the Altamaha was diverted to the south at one time and also occupied the low country between the Princess Anne and Silver Bluff barriers. However, this was at a period (dated around 32 ka)

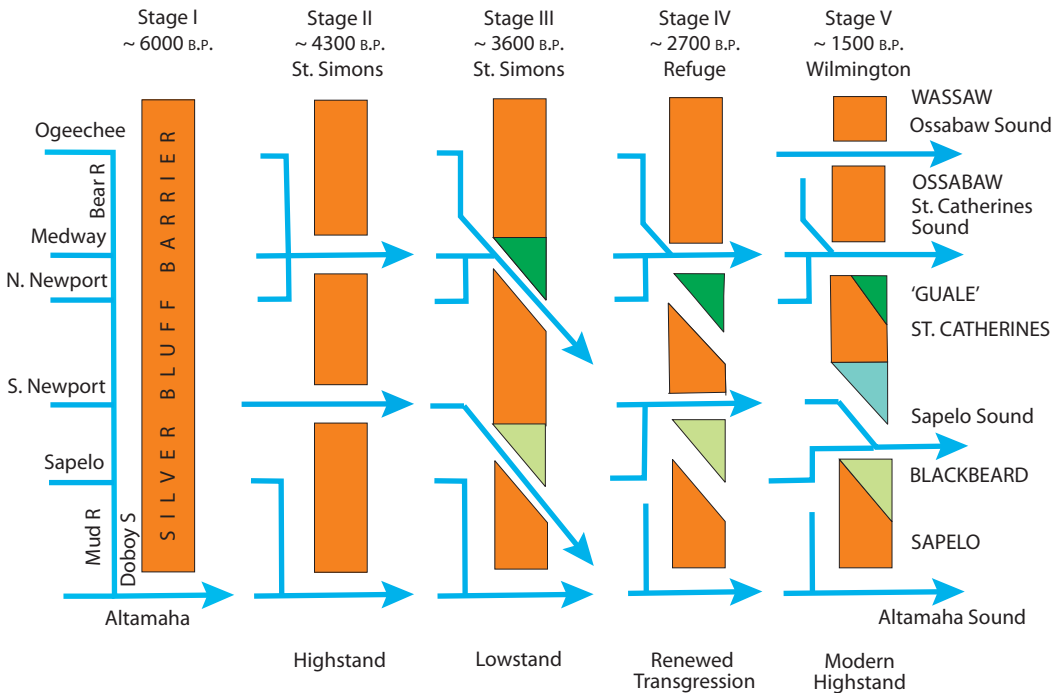


Fig. 9.12. Diagram illustrating the proposed succession of changes during the breaching of the Sea Islands and segmentation of the low-country portion of the Ogeechee valley. Green triangles are spits: Guale (dark green), St. Catherine's (cyan), and Blackbeard (light green). Islands are indicated in capital letters; rivers and inlets in lower case. Stage I illustrates the Silver Bluff barrier and low-country valley of the Ogeechee prior to flooding by the Holocene transgression. Stage II coincides with the breaching of the first inlets during a highstand around 4300 <sup>14</sup>C cal B.P. During stage III a minor regression (~3600 cal B.P.) encouraged spit building and diversion of inlets. When transgression resumed in stage IV (~2700 cal B.P.) inlets were straightened and spits breached. Stage V shows accretion of the dissected spits (Blackbeard and Guale islands) to the next adjacent island down the longshore transport direction. This is essentially the modern condition except that Guale Island has been lost to erosion.

when sea level was much lower and the valley was narrower and more deeply incised—alluvial rather than estuarine. Farrell, Henry, and Cofer-Shabica (1993a) record no trace of mica in estuarine fill behind Cumberland Island (dated between about 3000 and 1000  $^{14}\text{C}$  yr B.P.; cal 3210–930 cal B.P.), suggesting that this connection may also have been severed during the 5300–4300 cal B.P. highstand (Gayes et al., 1992; Scott, Gayes, and Collins, 1995; Thomas, 2008: chap. 4).

If the Ogeechee originally joined the Altamaha or opened into Doboy Sound, this would imply a diversion of around 55 km parallel to the coast. By comparison, the Pee Dee River is displaced by about 35 km behind the Grand Strand of South Carolina (Baldwin et al., 2006). In its most extreme version this scenario would require the welding of the Georgia Sea Islands into a continuous strand, like that in South Carolina—a possibility supported by the apparent continuity of the Silver Bluff strandline between the Savannah and Altamaha rivers (fig. 9.11). Thus, it is possible that the Ogeechee was diverted into the low country seaward of the Princess Anne barrier by the development of the Silver Bluff strandline. Depending on the age assigned to the Silver Bluff barrier, this might coincide with the time the Pee Dee River was diverted by the Myrtle Beach barriers (marine isotope stage Q3b according to Baldwin et al., 2006).

Assuming that the inlets between the Savannah and Altamaha were closed or much reduced in size around 3600  $^{14}\text{C}$  yr. B.P. (3910 cal B.P.), it is possible to approximate an equilibrium shoreline (fig. 9.11). This reconstruction assumes a wave-dominated coast with longshore transport of sand unimpeded by large tidal deltas or other promontories. The resulting arcuate curve forms a tangent with beach ridges on Wassaw, St. Catherines Spit, and Blackbeard Island but is markedly discordant with the southern parts of Tybee, Ossabaw, and Sapelo islands and the northern part of St. Catherines Island. It suggests that Tybee, Ossabaw, and Sapelo islands have all rotated clockwise, perhaps as a result of increased tidal velocities and sediment starvation. It is significant that much of the loss from St. Catherines Sound may be restored by the reconstruction of Guale Island, especially if the island originated as a spit at the southern end of Ossabaw.

## CONCLUSIONS

From a combination of basic stratigraphic principles (crosscutting relations and superposition) combined with absolute dating by  $^{14}\text{C}$  and optically stimulated luminescence, it is hoped to be able to elucidate recent shoreline changes in the vicinity of St. Catherines Island and relate them to the archaeological landscape. From preliminary studies I hypothesize that:

(1) Ossabaw Sound is the youngest of the major inlets on the Georgia coast and was formed when the Ogeechee was diverted from St. Catherines Sound to its present location sometime before 1880  $^{14}\text{C}$  yr. B.P. (1640 cal B.P. Deptford period).

(2) Sapelo and St. Catherines sounds were formed by the modification of earlier inlets, which lie south of the modern channels and are now abandoned and infilled by marsh; Blackbeard Marsh in the case of Sapelo Sound and Guale Marsh in the case of St. Catherines Sound. Guale Inlet was active between 4290 and 3100  $^{14}\text{C}$  yr (4870–3350 cal B.P.) and both inlets may date from the transgression between about 5300 and 4300 cal B.P. (St. Simons period).

(3) Blackbeard and Guale islands originated as spits formed through longshore transport on the north sides of their respective inlets. They probably developed during a minor regression or stillstand between about 4300 and 3600 cal B.P.; St. Simons period). It is argued that wave-driven processes and spit building are favored by the reduction in the volume of the tidal prism during periods of regression.

(4) The breaching of Sapelo Sound and the isolation of Blackbeard Island are recorded as a prominent discontinuity (Zapala Scarp) at the north end of St. Catherines Spit. Radiometric dating shows that this scarp was cut prior to 1720  $^{14}\text{C}$  yr B.P. (1610 cal B.P.), while archaeological sites suggest that it was cut earlier, during the early Refuge period (~2700 cal B.P.) as the Holocene transgression resumed.

(5) A similar island, called Guale Island (Bishop et al., 2007), formerly existed northeast of St. Catherines Island and was likely formed in the same way, by the severing of a spit from Ossabaw Island. Although this island has now been lost to erosion, part of Guale Inlet survives beneath Seaside Marsh. Radiometric dating indicates that this inlet was abandoned sometime between 3100 and 1720  $^{14}\text{C}$  yr (3350–1580 cal

B.P.; Refuge-Deptford periods), presumably as a result of loss of discharge due to the breaching of St. Catherines Sound.

(6) The modern estuaries at Ossabaw, St. Catherines, and Sapelo sounds all seem to date to Refuge-Deptford times. All led to the straightening of inlets, which is interpreted to be the result of increased tidal current velocities as a consequence of the inundation of low-country marshes during renewed transgression. Breaching was most likely triggered by avulsion following storm flooding in the tangle of distributaries clustered around the inlets.

(7) Because the Ogeechee is the proximal source of sand for St. Catherines Island, it is possible that the spit preserves a record of the breaching of St. Catherines and Ossabaw sounds. Two prominent discontinuities, east and west of Jungle Road, record episodes of erosion and rebuilding that may be related to these breaches, but limited radiometric dates fail to support this conclusion at present.

(8) The straightening of these estuaries has diverted drainage from the low country behind the Silver Bluff beach ridge. It is posited that this was once the valley of the Ogeechee, originally a tribu-

tary of the Altamaha, but now segmented as another consequence of the Holocene transgression.

(9) The interpretation presented here emphasizes the importance of fundamentally deltaic processes in the construction of the Georgia coast. The waterways tangled between the Princess Anne and Silver Bluff beach ridges are tide-dominated distributaries. Within this low country, divides are highly "porous" and liable to significant changes due to avulsion.

## NOTES

1. Chowns gratefully acknowledges grant support from St. Catherines Island Research Program and from the University of West Georgia. He is particularly indebted to colleagues and students who assisted in the field and laboratory: the editors, Gale Bishop, Bud Rollins, and Dave Thomas; Royce Hayes and his staff on St. Catherines Island; colleagues Richard Sanders, Andrew Ivester, Randy Kath, and John Congleton; and student assistants Brian Stogner, Jeff Madden, Lee Albright, Eric Polly, and Michael Boatman.

2. The 2700 cal B.P. date cited throughout this chapter is an estimate based on the span of early Refuge (2850–2500 cal B.P.) and particularly the occurrence of early Refuge ceramics at 9Li49. But in truth, this estimate could easily range from about 2500 cal B.P. to even 3000 cal B.P.

3. This estimate is an average of  $1170 \pm 50$  and  $1010 \pm 50$  (Beta-217245 and Beta-217246).



## CHAPTER 10

### VIBRACORES AND VIBRACORE TRANSECTS: CONSTRAINING THE GEOLOGICAL AND CULTURAL HISTORY OF ST. CATHERINES ISLAND

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BRIAN K. MEYER, R. KELLY VANCE, ROBERT K. BOOTH, FREDRICK  
J. RICH, DONALD B. POTTER, AND TIMOTHY KEITH-LUCAS

Vibracoring is a subsurface sediment acquisition (sediment coring) technique (Pierce and Howard, 1969; Howard and Frey, 1975; Dreher et al., 2008) that returns sediment preserved within its stratigraphic and sedimentologic context. This process (see appendix 1) generates a continuous, contiguous sediment sample at a point by vibrating an aluminum core barrel vertically into the sediment (fig. 10.1). One advantage of vibracoring is that core depths (up to ~7.5 m) can be extracted preserving stratigraphic layering, sedimentary structures, fossils, and lithology in their natural context.

#### VIBRACORE PROTOCOLS ON ST. CATHERINES ISLAND

Our vibracore rig (fig. 10.1) consists of a 5.5 horsepower Briggs and Stratton gasoline powered engine, a cement vibrator, a clamping device to attach the vibrator onto 6 m (20 ft) segments of aluminum irrigation pipe 75 cm (3.0 in.) in diameter, with a wall thickness of 1.27 mm (0.050 in.), and an aluminum tripod and draw-works to extract the core barrel from the ground. The engine spins a flexible cable at high speed that causes the unevenly weighted head at its distal end to vibrate. The head, mounted by bolts to a weighted adapter that clamps to the aluminum core barrels, causes the pipe to vibrate into the substrate. Penetration of sediment and roots is enhanced by sharpening and filing serrations into the end of the aluminum pipe, producing a sawtoothed cutting edge. Because the adapter can easily be repositioned up the shaft as the core is vibrated into the substrate, the rig is capable of

handling barrels of any length, although extraction of cores longer than 7.5 m becomes problematic. Six-meter (20 ft) core barrel lengths have been found to be optimal for our operation on St. Catherines Island. Once maximum penetration is accomplished (nearly to the length of core barrel available or until the vibracore no longer penetrates the substrate) drilling ceases. At this point, the depth to the top of the sediment surface inside the pipe is measured, the length of the pipe remaining above the ground is measured, and the former is subtracted from the latter to determine compaction of sediment inside the core barrel. The core's location and compaction and total depth measurements are recorded in a field notebook. The upper end of the pipe is plugged with a sewer plug and sealed with bolt compression or inflation of the air seal prior to pulling to create a partial vacuum inside the pipe to help hold the sediment in place. The core barrel is then extracted using a tripod with two lever hoists (known as come-a-longs) connected to the pipe with hemp rope tied into Prusik Knots. The come-a-longs are first used in tandem to overcome initial friction, then used in parallel, one after another, to more rapidly pull the core as friction decreases as the pipe is extracted. When the lower end of the tube appears, it, too, is plugged with a sewer plug (and if any sediment has fallen out, the tube should be packed with aluminum foil). The pipe is trimmed to approximate the core length (which is less than total depth due to sediment compaction and/or limited penetration) by cutting the pipe off with a hacksaw just above the top surface of sediment. The core is marked with catalog numbers and the core orientation is indicated by placing consistent

arrows labeled “down” (or “up”) directly on the aluminum pipe. The location of the core is identified with global positioning system (GPS) data and the longitude and latitude, and elevation are recorded in the notebook or on a logging form (fig. 10.2B).

The core is transported to a laboratory or shelter and a straight line marked along the length of the core tube. An electric saw with a carbide blade set to slightly greater depth of the wall thickness is then used to saw along the straight line. The core tube is then squeezed into a holding trough (we use a trough constructed of rough lumber  $5.08 \times 10.16$  cm and  $5.08 \times 20.32$  cm [ $2 \times 8$  in. and  $2 \times 4$  in.]) to hold the core and track the saw) and taped with duct tape every half meter (about two feet) after it has been cut (fig. 10.2A), the core is then rotated  $180^\circ$  and cut a second time along its length, and retaped to hold the core tube shut as it is manipulated out of the cutting trough. Then a cut is made through the sediment and tape with a thin knife, coping saw or piano wire to separate the core into two hemicylinders. Holding the core with the cut vertical, the core is then allowed to split open laying each half with the cut surface horizontal. The surface of the exposed sediment core is then gently shaved with a sharp knife or trowel to prepare the core for description (fig. 10.2C). A metric tape or folding metric scale is laid on, or along, the length of the core and the core photographed, then described on a log form. Geologists normally log from the surface downward, starting at the surface as “0” and logging downward to total depth (TD) of the core. Sediment color, type, sorting and variation, layering, and sedimentary structures and “fossils” (if present) are noted. In the case of critically detailed work, the compaction of the sediment is proportioned along the length of the log to compensate for compaction.

Samples from the core are taken from critical zones for sedimentological study (grain size analysis and determination of mineralogy), to acquire organics for radiocarbon dating and palynology or to obtain macro and microfaunal records of the sedimentary environment. Samples to be processed by  $^{14}\text{C}$  methods are collected, cut, and cleaned to insure lack of contamination, and wrapped in aluminum foil to be sent to a laboratory specializing in  $^{14}\text{C}$  dating. Palynological samples are collected, cut, and cleaned to ensure lack of contamination of surface pollen and spores, and wrapped in aluminum foil to be sent

to a laboratory specializing in palynological analysis (usually Rich’s or Booth’s laboratory).

The vibracoring procedure is simple and the equipment is relatively easy to maintain and transport. Penetration success and core recovery in the vibracoring process, however, are largely dependent on lithology and sediment pore water saturation. Pure, dry sand tends to attenuate the vibration of the barrel and slow its descent; mud, if saturated with water, is easy to penetrate, and rock or even semilithified sediment will stop penetration of the barrel. Humate cemented sand has proven to be an impediment to vibracore penetration on the Pleistocene core of the island. Dense clay can also be difficult to penetrate and may be very resistant to core barrel extraction. The vibration of the pipe can be translated to the core sample itself, and may compact the sediments or disrupt laminations or bedding in the sediment, especially along the edges of the pipe surface, causing drag structures.

In the case of geological exploration, sites to be drilled are often selected for their presumed stratigraphic value as single cores (figs. 10.3–10.5), or as a line of cores (a *transect*) that allows one to correlate laterally using Steno’s laws of stratigraphy; superposition, lateral continuity, and original horizontality (Steno, 1669) to generate a cross section (figs. 10.6–10.8). In geology, the linearity of transect lines is often sacrificed for necessity of being able to drill, potential stratigraphic value of slight offsets or convenience. In the case of archaeological exploration, linearity is more important and alignment with survey grids is critical. Sites may be selected to physically test stratigraphy, magnetic resistivity, or Ground Penetrating Radar (GPR) anomalies, providing a rapid and only minimally invasive peek into the buried cultural history of a site.

#### THE VIBRACORE EVIDENCE FROM ST. CATHERINES ISLAND

A series of stratigraphic cores were drilled on St. Catherines Island by several teams from Georgia Southern University, the University of the South, the University of Pittsburgh, and the American Museum of Natural History, forming what we informally call the SCI Geology Research Consortium. The drilling of vibracores has been facilitated by Royce Hayes and the St. Catherines Island Foundation staff since 1989 and a complete catalog of all known vibracores from the island is included as



Fig. 10.1. Components of the St. Catherines vibracore in use in the field. **A**, Georgia Southern University drill team vibracoring near Gator Pond in 2008, showing gasoline engine, vibrator cable clamped to aluminum pipe under tripod as clamp is being raised to continue drilling; **B**, close-up of vibrator head clamped to irrigation pipe at total depth as sewer plug is being inflated to seal core in pipe; **C**, core being extracted by come-a-longs as crew chief Vance records data; **D**, AMNH crew coring at St. Catherines Shell Ring as crew chief Bishop supervises forcing the pipe into dry ground; **E**, Island Ecology Program coring at Flag Lagoon supervised by crew chiefs Potter (on tripod) and Keith-Lucas (kneeling) attempting to pull a core. Photographs A, B, C, and E by Gale Bishop; D by Anna Semon.

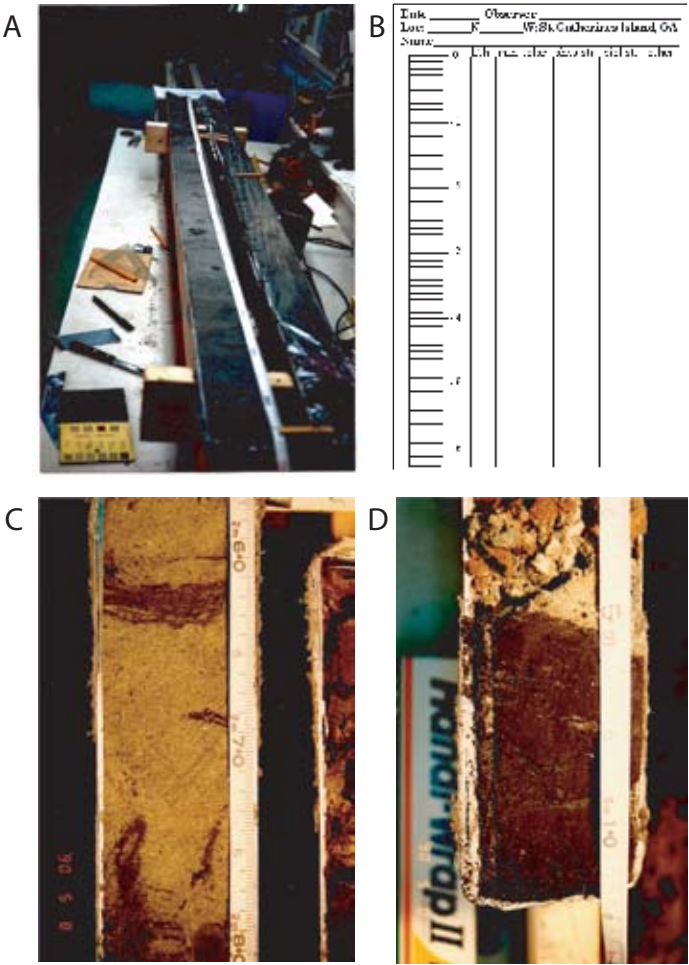


Fig. 10.2. Logging of vibracores is done under the roof of a shed. **A**, The core is placed into a trough constructed of two-by-fours cut lengthwise on two sides with a carbide disk on an electric saw, then cut through the sediment and laid open exposing the core to inspection (note the thin knife, Munsell Color Chart, sediment size chart, straight edge, pencils, hand lens, and tape measure; **B**, one example of a possible computer-generated logging form; **C**, Cracker Tom core, image of split core showing sand with mud flaser above and lined ghost shrimp burrow near bottom, and **D**, bottom of Cracker Tom Bridge (note foil cap) showing compact peat that stopped drilling. Photographs A, C, and D by Gale Bishop.

appendix 2, at the end of this volume. Initial drilling (table 10.1) was done by the SCI Geology Research Consortium to document lithology, stratigraphy, and sedimentary structures at points hypothesized to harbor interesting geological data. Initial coring was done at Mission Santa Catalina de Guale in 1989 (to test the equipment in the Island core). Subsequent efforts have focused on the following sites:

(1) Offshore at Yellow Banks Bluff to test the

continuity of relict marsh mud exposed there (fig. 10.3);

(2) On Cracker Tom Causeway (fig. 10.7) to investigate stratigraphy of McQueen Marsh (Booth and Rich, 1999, Booth, Rich, and Bishop, 1999; Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008);

(3) In State Road Pond in the Pleistocene core to test the Pleistocene stratigraphy (fig. 10.5);

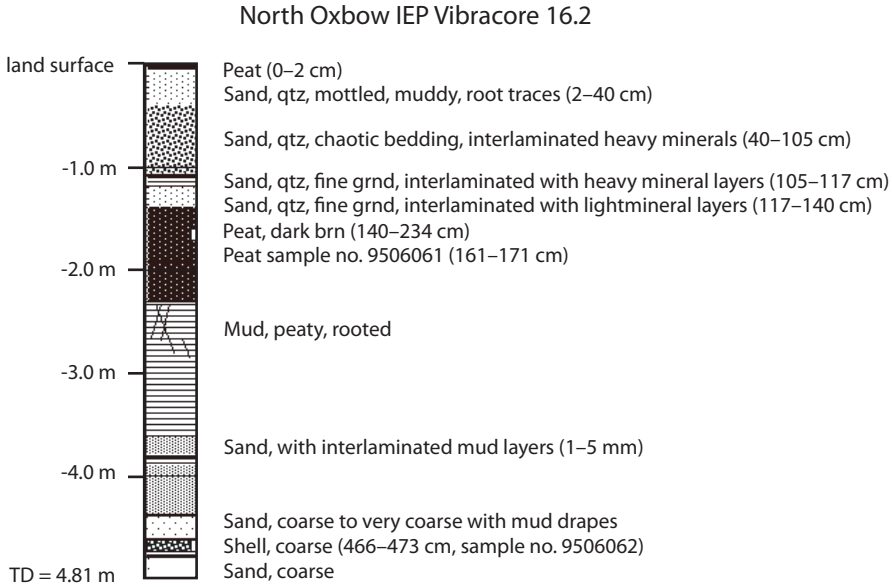


Fig. 10.3. Log of IEP vibracore 16.2 in North Oxbow south of Sand Pit Road showing stratigraphy underlying an ancient meander scar floored by a shell lag and overlying transgressive facies (sand, marsh, and freshwater peat) marking a still-stand at marsh level followed by a second transgression in overlying sequence of sand, backbeach, horizontally laminated heavy mineral sand, and overlying chaotically bedded heavy mineral-rich sand (perhaps a trample bed from cattle during the mid and late 1900s). Total depth = 4.81 m.

(4) On Terrain #6 (an east-west Holocene terrain) to document (fig. 10.4) its stratigraphy;

(5) In Long Marsh west of Hickory Hill to investigate its subsurface;

(6) The sediment underlying Beach Pond (Booth et al., 1999).

All members of the consortium have utilized the St. Catherines Island vibracore equipment to investigate geological conditions pertinent to their specific research program and to create real world, hands-on, field-based educational activities for their students. Cores drilled by the University of the South were often sited with consensus of Potter, Keith-Lucas, and Bishop; one core led to documentation of the North Oxbow (fig. 10.3) near Sand Pit Road (and the site of Bishop's hydrological study of sea turtle nests in 1996). Another consensus led to vibracore sites adjacent to the St. Catherines Shell Ring in Long Field, on the west side of the island; additions to these core sites produced the St. Catherines Shell Ring transect (fig. 10.6) (Bishop et al., 2007).

#### YELLOW BANKS BLUFF AND SEASIDE SPIT

Twelve vibracores recovered from three transects have been described, analyzed, and interpreted by Linsley (1993), Bishop et al. (2007), and Linsley, Bishop, and Rollins (2008). Transects A and B are located on the northeastern portion of St. Catherines Island, and Transect C lies along Cracker Tom Causeway in the east-central portion of the island. The state of knowledge of the geological foundation of St. Catherines Island has been summarized by Bishop et al., 2007 and in chapter 3 of this volume. These summaries subdivide the island into at least three major geomorphic systems: the island core, beach ridge complexes, and salt marsh (Linsley, Bishop, and Rollins, 2008, fig. 3.1; this volume: fig. 3.2). The island core comprises the western portion of the island, has a relatively high elevation of ~4 to a maximum of 8.8 m (29 ft), is relatively level, and its vegetation consists of a mature, mixed deciduous–pine forest and fallow agricultural fields in various stages of succession.

Several series of parallel to subparallel, low-lying ridges (Bishop et al., 2007, fig. 57; average elevation of 1–4 m) comprise the accretionary terrain complexes located at the northern tip of the island (within which the “great dunes” have the maximum elevation on St. Catherines Island of 10.4 m [34 ft]), as well as bordering the south and southeast. Adjacent beach ridges are separated by swales containing intertidal to low supratidal creek and marsh meadows or ephemeral freshwater ponds (especially after heavy rains). The accretionary terrain complexes are vegetated primarily by cabbage palm, saw palmetto, hickory, pine, and live oak. The salt marsh fringes the island core on the east and the southwest and consists of meandering tidal creeks separated by marsh meadows vegetated by cordgrass (*Spartina alterniflora*) at the elevation of mean high tide (Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008). On the eastern side of the island, extensive marsh meadows lie behind the beach

barriers, Seaside Spit, Middle Beach, and in interdune swales behind South Beach.

The island core sediment consists of predominantly tan, fine- to medium-grained sand, intensively bioturbated by plant roots penetrating to a depth of 2–2.5 m. Below this depth some primary sedimentary structures are preserved, and the color changes to light gray. Primary sedimentary structures at this depth consist of horizontally laminated interbeds of quartz and heavy mineral sand, some cross-bedded units (see chap. 11, fig. 11.7), and occasional burrows of the Carolinian ghost shrimp (*Callichirus major*) (Frey, Howard, and Pryor, 1978). Heavy minerals are disseminated throughout the quartz sand body, but also occur concentrated in discrete laminae characteristic of backbeach facies (Bishop et al., 2007).

The accretional beach ridge complexes are Holocene features that formed as transverse dunes associated with a nearly modern mean sea level position (Bishop et al., 2007: figs. 38,

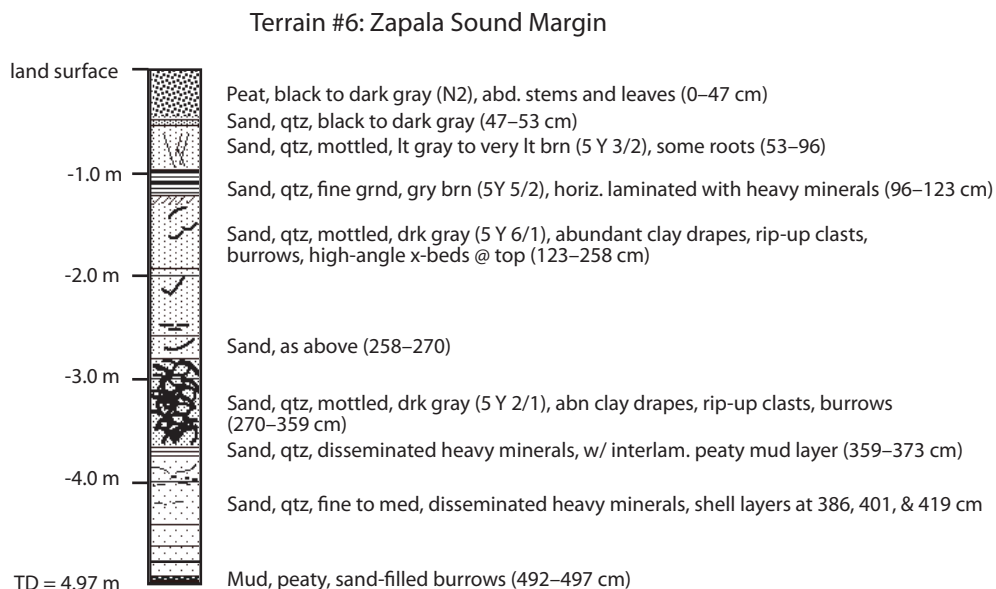


Fig. 10.4. Terrain #6 vibracore taken in swale pond in east-west terrain. This core has a muddy peat at its bottom (total depth = 4.97 m), overlain by a sand with three shell layers up to 4.0 m, then marked by a thin laminated sand overlain by a heavily mottled, burrowed, muddy sand from 3.66 to 2.70 m, in turn overlain by a sand with abundant clay drapes, burrows, and tabular cross-beds at its top from 2.70 to 1.23 m, a thin horizontally laminated sand bed from 1.23 to 0.96 m, a fine-grained rooted sand from 0.96 to 0.47 m, and a very organic peat from 0.47 to 0.00 m.

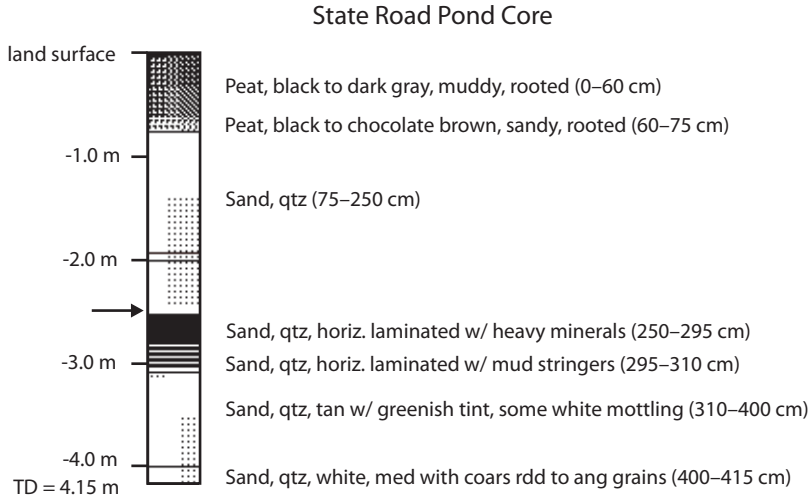


Fig. 10.5. State Road Pond core, located on the younger Pleistocene terrain, has interlaminated heavy mineral and quartz sand (2.50–3.10 m) indicating a sea level elevation of -2.50 m (arrow) when the top of this later Pleistocene layer was deposited.

41, and 59; Linsley, Bishop, and Rollins, 2008). Along the Georgia Bight, beach ridges are generally found on the northern and southern ends of the island cores or along the oceanward sides, where rates of fluvial sediment supply are high. Marked progradation of beach ridge accretionary terrains has occurred on islands fed by the deltas of the Savannah, Ogeechee, and Altamaha rivers (Oertel, 1979; Bishop et al., 2007: fig. 7; see Bishop et al., this volume, chap. 3: fig. 3.1). Because St. Catherines Island lacks nearby fluvial sources, sand for beach ridges must come from longshore transport of reworked continental shelf sand, erosion of the island core, or from islands, tidal deltas, or estuaries to the north (see chap. 8, this volume). The southeastern portion of the island consists of a sequence of discrete beach ridge “packages” that become progressively younger to the southeast and east. These sediment “packages” may represent periods of rapid accretionary activity during the Holocene punctuated with periods of erosion due to inlet mouth migration, major storm events, sea level changes, or pulses of sedimentation. They can be chronologically sequenced using crosscutting relationships (see Oertel, 1975b, 1979). Rollins, Beratan, and Pottinger (chap. 8, this

volume) describes the deposition of three distinct beach ridges over a five-year interval at the north end of St. Catherines Island following Hurricane Hugo in 1989 (Linsley, Bishop, and Rollins, 2008; Pottinger, 1996).

At Yellow Banks Bluff, sand eroded from the base of the bluff by waves during nor’easters on spring high tides steepens and undercuts the slope with consequent slope re-equilibration by mass wasting. Blocks of soil, knit together by grasses, saw palmetto stems and roots, and trees tumble off the scarp face into the ocean below as the scarp migrates westward. Waves disaggregate the slump blocks at the base of the bluff, producing a beach “boneyard” of skeletal trees, and a heavy mineral placer along the base of the bluff (see Bishop et al., 2007: figs. 22–24). The rate of bluff retreat at Yellow Banks Bluff is 1.8 m/yr (5.9 ft) (Potter, Padgett, and Trimble, 2007; Bishop and Meyer, chap. 14: fig. 14.13; Potter, this volume, chap. 7). Approximately 5 m of sand are exposed for 0.8 km (0.5 mi) along this prominent bluff. There is general consensus that at least the lower portion of Yellow Banks Bluff is attributable to the Silver Bluff shoreline of Pleistocene age (Bishop et al., 2007; Martin and Rindsberg, this volume, chap. 5; Vento and Stahlman, this

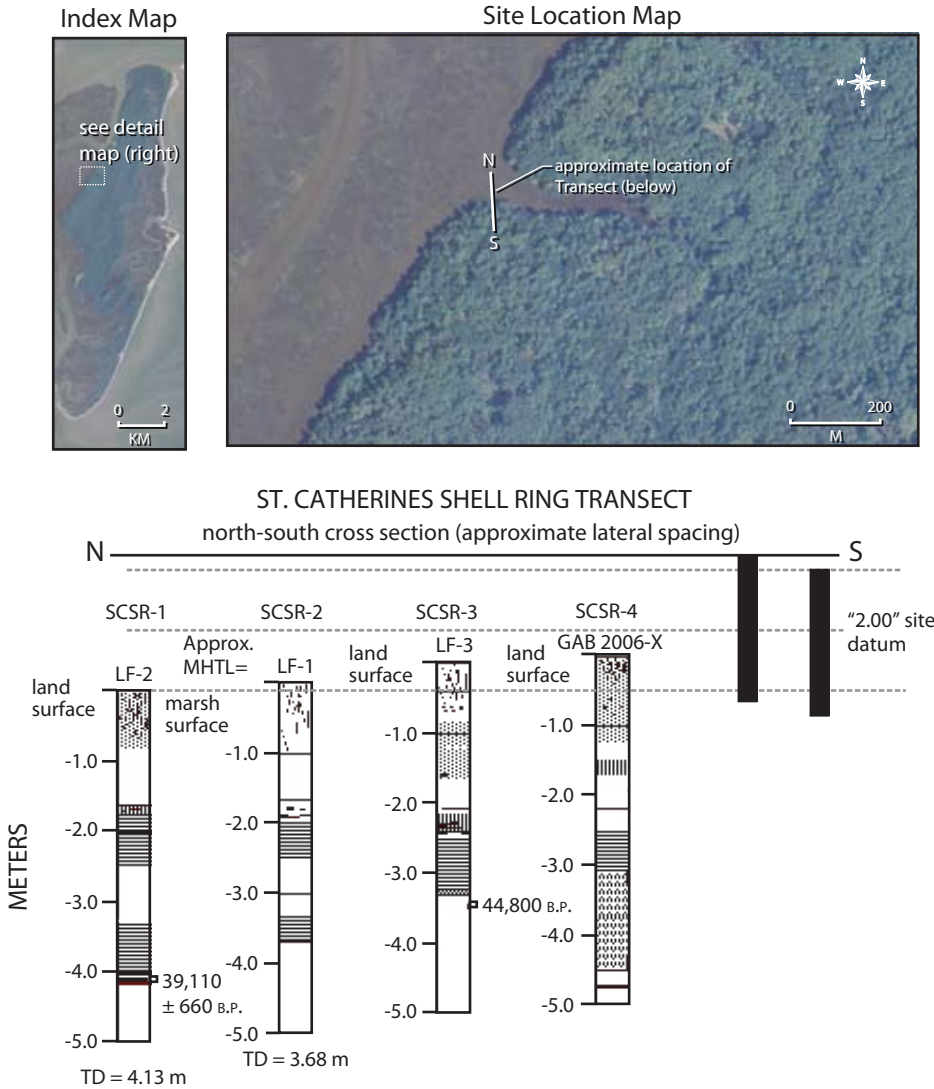


Fig. 10.6. Original St. Catherines Shell Ring Transect showing collaborative drilling effort by scientists to connect geology and archaeology. Three cores on left (SCSR LF #2, SCSR LF #1, and SCSR LF #3) drilled by faculty and students of the University of the South Island Ecology Program, fourth core from left (SCSR #4, GAB 20061102-1) drilled by team from Georgia Southern University, the St. Catherines Island Foundation, and archaeologists from the American Museum of Natural History, and a series of cores into the St. Catherines Shell Ring drilled by a GSU and AMNH team are represented by the two blank cores to the right. Aerial imagery from United States Department of Agriculture (USDA), National Agriculture Imagery Program (NAIP), 2006.

volume, chap. 4). Archaic archaeological sites near the bluff, rapidly being lost to progressive accelerating erosion, attest to the human appreciation and utilization of the scenic and functional

values of this portion of the island for approximately 4000 years. Two nearly continuous, intensively burrowed horizons have been mapped along the face of

Yellow Banks Bluff (see Bishop et al., 2007: fig. 10.23; Martin and Rindsberg, this volume, chap. 5). Burrows are short, unbranched, and are most apparent in darker gray sediment (Stapor and Mathews, 1983). These two burrowed zones are interpreted by Martin and Rindsberg (chap. 5) as washover fans burrowed by fiddler crabs and insects during the Silver Bluff portion of the Pleistocene. They may mark marine erosional terraces during the formation of the Silver Bluff shoreline. A horizontal maze of ghost shrimp burrows (*Callichirus major*) has been mapped beneath the former position of the bluff near its south end (Bishop et al., this volume, chap. 3: fig. 3.4). These two burrowed "erosional surfaces," marking former sea level highstands, occur at ~1.5 m (4.92 ft) above the base of the bluff near its north end (see Martin and Rindsberg, this volume, chap. 5).

Vibracores of a relict marsh mud at the south end of the bluff encountered 9.1 m (30 ft) of marsh sediment there, as previously mentioned. Seaside Spit is a wedge of sand deposited on top of the mud surface of Seaside Marsh. Seaside Spit lies immediately south of Yellow Banks Bluff and consists of a perched prism of beach sand and washover fans "parked" on top of Seaside Marsh (Bishop et al., 2007: figs. 25–27; Bishop et al., this volume, chap. 3: fig. 3.4). The sand, mobilized from Yellow Banks, is carried by the longshore drift that generally moved from north to south on the Georgia coast. During storms, sand is commonly washed over this spit, or berm, forming a series of washover fans (Bishop et al., 2007: figs. 26, 28, 29; see this volume, chap. 3; chap. 13: fig. 13.1) that constitute up to 80% of the 1.69 km (1.05 mi) length of Seaside Spit. This shoreline is currently in full retreat. Retreat of the shoreline at Seaside Spit was about 65 m (213 ft) from 1999 to 2002 (Potter, Padgett, and Trimble, 2007). Brian Meyer computed longer-term retreats as 6.5–9 m/yr (21–30 ft/yr) between 1979 and 2005, and nearly 21 m/yr (70 ft/yr) from 1999 to 2002 as measured from aerial photographs and storm high-tide positions over the interval 1999–2002. This retreat has obliterated Black Hammock, a wooded high area on the exposed beach that was present further east (now offshore), on Seaside Spit prior to 1971, "with enough vegetation to get lost in while hunting coons." (Royce Hayes, personal commun.). Prezant et al. (2002) report that "The southern half (about 1.5 km) of North Beach consists of fine-grained quartz sand and

compacted semiconsolidated relict marsh mud representing the trailing edge of a rapidly migrating facies mosaic that has retreated at an average rate of 3.8–4.0 m per year for about the last 50 years (Oertel and Chamberlain, 1975; West, Rollins, and Busch, 1990; Goodfriend and Rollins, 1998). The relict marsh mud exposed almost continuously along Seaside Spit was extensively documented by Morris and Rollins (1977), who interpreted mud-dwelling organism associations as "holistic" communities of Kauffman and Scott (1976). Pemberton and Frey (1985), Rollins, West, and Busch (1990), and West, Rollins, and Busch (1990), described the palimpsest relict marsh mud surfaces and Glossifungites Ichnofacies exposed along North and Middle beaches.

To the north and south, the western margin of Seaside Marsh Meadow is a series of emarginated reentrants and points (see chap. 3, this volume), a feature named King New Ground Scarp. The view across Seaside Marsh Meadow toward North and Middle beaches emphasizes the great expanses of marsh meadows on the ocean side of St. Catherine's Island that are now but a remnant of their former size.

North, Middle, and South beaches form a slightly concave, curved eastern boundary to this marsh, and abundant washover fans accommodate the westward transport of sand in response to rising sea level and easterly storms along its trace. Berms or beaches (Seaside Spit and Middle Beach) form as the turbulent waters of the ocean remove sand from the eastern beachfront, leaving behind the relict muds of the marsh. We anticipate that when we vibracore one of these meander scars (Bishop et al., chap. 3: fig. 3.6), we will encounter Pleistocene island core facies immediately beneath the Holocene meander plain sediments, as was discovered near Cracker Tom Hammock (Booth and Rich, 1999; Bishop et al., 2007: fig. 10.36).

#### CRACKER TOM HAMMOCK

The Cracker Tom vibracore transect of 1990 is parallel to and north of Cracker Tom Causeway, extending from the island core across the marsh to Cracker Tom Bridge. The intent of this transect was to investigate the stratigraphic foundation of the island (Bishop et al., 2007). Sediment lithology, stratigraphy, sedimentary structures, and trace fossils were logged (Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008) and cores were correlated.

Booth and Rich (1999) extracted three additional cores called Cracker Tom Bridge (CTB), Cracker Tom Hammock (CTH), and Cracker Tom Rosetta (CTR) from the low ridge flanks in the marsh between Cracker Tom Hammock and the island core. After analyzing and evaluating samples collected from the three vibracores comprising the Cracker Tom Hammock Transect, Booth, Rich, and Bishop (1999) published *Palynology and Depositional History of the Late Pleistocene and Holocene Coastal Sediments from St. Catherines Island, Georgia, USA*.

The stratigraphic sequence (from bottom to top) in the Cracker Tom Transect consists of black-brown compact peat (CTB) and moderate yellow-brown consolidated sand (CTH) (unit A) underlying a sharp boundary, representing an erosional surface on top of the darker Pleistocene sediment. The formation of this erosional surface (disconformity) required subaerial exposure of ancient St. Catherines Island. Overlying this disconformity is a layer of very light gray to yellowish gray fine- to coarse-grained sand (unit B) with small clay-filled burrows with a basal shell lag of pale yellowish brown unconsolidated sand with abundant shells (gastropods and disarticulated bivalves) interpreted to be a transgressive sand deposited by a rising sea level. Overlying unit B is a light gray burrowed mud and sandy mud (unit C) with an eroded surface and carrying abundant oyster shells (*Crassostrea virginica*) in one core (CTH: 1.94–2.25 m) inferred to represent marsh facies. The upper surface is erosional and oxidized. Overlying the marsh sediment of unit C is another sandy unit, laminated with heavy mineral layers at its base giving way to mottled, organic sand above. Thus, the sequence is thought to represent a basal lithosome plus three sedimentary packets (fig. 10.7; see also chap. 3: fig. 3.3). A basal terrestrial Pleistocene lithosome is separated by a diastem from overlying Holocene nearshore marine, marsh, and shoreline deposits. The Holocene deposits consist of three sedimentary packets: (1) a basal transgressive nearshore sand body, overlain by (2) a marsh sequence with an erosional upper surface forming a second disconformity or diastem, and in turn overlain by (3) backbeach, shoreface, and marsh deposits.

Peat from 5.02–5.12 m in the Cracker Tom Bridge vibracore was radiocarbon dated and yielded a date of  $47,620 \pm 2500$  yr B.P. (USGS WW1197) and was overlain by marine shells and charcoal, which were also dated. The char-

coal yielded a date of  $6020 \pm 50$  yr B.P. (USGS WW1198) and a shell, *Americardia*, yielded a date of  $4060 \pm 50$  yr B.P. (USGS WW1262). An oyster bed entrained within a dark gray mud in the Cracker Tom Hammock core (CTH: 1.94–2.25 m) yielded an oyster shell (*Crassostrea virginica*) radiocarbon dated at  $3200 \pm 70$  yr B.P. (UGA-6442). These dates firmly bracket the Pleistocene-Holocene disconformity representing approximately 40,000 years at Cracker Tom Hammock. The disconformity documented in the Cracker Tom vibracore transect represents one of the best Georgia barrier island records of a sea level lowstand and subsequent sea level rise. This sea level rise (marine transgression) resulted in the hypothesized destruction of Guale Island (see chap. 3: fig. 3.3), and the accumulation of sediment in the accretionary terrains to the south and east that make up the remainder of St. Catherines Island.

The Pleistocene peat below the disconformity contained a palynoflora consisting of 85% monolete pteridophyte spores of the fern *Woodwardia* and other hydrophyte taxa (Booth and Rich, 1999). Other taxa present in the Pleistocene sample included *Pinus*, *Quercus*, *Carya*, and *Poaceae* with northern temperate flora in smaller abundance (*Picea*, *Tilia*, *Fagus*, and *Tsuga*). The palynoflora association of the peat was used to infer that environmental conditions at the depositional site included a dense stand of ferns growing alongside characteristically southeastern floral elements dominated by the fern *Woodwardia virginica*. Holocene portions of the cores are derived from plants of nearshore marine, salt marsh, and tidal flat environments similar to those now found on St. Catherines Island (Booth et al., 1999; Rich and Booth, this volume, chap. 6).

The depositional environments of the original Cracker Tom Transect were previously interpreted (Bishop et al., 2007: fig. 36), but not correlated. This correlation is presented to link and summarize the depositional and temporal relationships and environments represented in the Cracker Tom Transect (fig. 10.7). Dates obtained from organic constituents in the cores precisely constrain the basal disconformity (Booth and Rich, 1999; Booth et al., 1999; Linsley, Bishop, and Rollins, 2008; Thomas, 2008). The dates also provide an average rate of deposition on the southeastern Holocene accretional terrains. Laminated sand of a transgressive beach and a small fan delta accumulated by erosion of an an-

cient scarp and reworking of sediment (Cracker Tom Scarp core -2.0–0.0 m) forming a continuous backbeach facies. The underlying forebeach sediment (Cracker Tom Scarp core -2.0–4.0 m) marks a rapid transgression between 6020 and ~3200 yr B.P. A period of stasis may have allowed formation of a small marsh protected by a beach ridge on the east, prior to a rise in sea level.

#### BEACH POND

Booth et al. (1999) described a core from Beach Pond, a freshwater pond and marsh, then located 50–100 m behind the active beach scarp in the mid-southern portion of St. Catherines Island. They recovered a 4.5 m sediment core from the pond to reconstruct the paleoecology of the site. Sediment was Holocene in age (<10,000 years), and the palynoflora record suggests cyclic deposition. Until 1999, the modern vegetation of Beach Pond was dominated by freshwater flora, including *Pluchea* and other composites, *Typha*, Cyperaceae, and Poaceae. This flora contrasts with palynology of the core, revealing dynamic changes in depositional environments and plant communities during sediment accumulation. Sediments from the lower portion of the core represented nearshore marine environments and probable accumulation in a shallow lagoon, characterized by the abundant pollen of *Pinus* with a high percentage of broken grains. Wood recovered from the uppermost lagoonal sediments yielded a radiocarbon date (AMS) of  $1210 \pm 40$  B.P. (Beta-115910). The lower layers are overlain by tidal-flat-derived sediments, which are overlain by a thin peat layer derived from an interdunal swale community dominated by *Myrica*. A return to brackish marsh conditions is indicated by the presence of *Limonium*, Cheno-Am type (e.g., *Salicornia*), and abundant Poaceae pollen. The modern freshwater pond plant community was established as the salinity decreased; this is indicated by the abundance of freshwater plant taxa (i.e., *Azolla*, *Typha*, Cyperaceae). At this time (2010), Beach Pond is being invaded by saltwater, and the freshwater flora is dying as the beach shifts westward and the pond cycles back to salt marsh conditions.

#### THE SCARPS OF ST. CATHERINES ISLAND

A comprehensive overview of the origins of the Georgia barrier islands and specifically St. Catherines Island was published by Bishop et al. (2007). They reviewed the ages, characteristics,

and history of the sediments constituting the island, and the characteristics and distributions of island plant, animal, and human communities. Deposits of heavy minerals on St. Catherines Island were also documented, and the source rocks, transport, and concentration of the minerals on the coast as backshore placers, stranded during times of rapid recession were described (Pilkey, 1963; Woolsey, Henry, and Hunt, 1975; Bishop, 1990; W.A. Pirkle and F.L. Pirkle, 2007; Pirkle et al., 2007; Vance and Pirkle, 2007). The dynamic and rapid changes recorded in the sedimentary record of St. Catherines Island still confound and obscure the record and continue to perplex geologists and ecologists today (part of the reason for the Fourth Caldwell Conference and this volume). In 1989, Bishop had postulated that immediately before the last lowstand (i.e., ~18,000 yr B.P.), St. Catherines was an island doublet, similar to the Sapelo Island/Blackbeard Island pair today (Bishop et al., 2007, 2009; Linsley, Bishop, and Rollins, 2008; Thomas, 2008; see this volume, chap. 3: figs. 3.2 and 3.6).

Salient portions of the 2007 GSA field trip guidebook (Bishop et al., 2007) document aspects of the geology of St. Catherines Island that we wish to reemphasize here. The northern end of St. Catherines is most illustrative in terms of the development of the island's geological history, being comprised of the island core, accretional terraces to the north, northwest, and northeast (see Bishop et al., this volume, chap. 3: figs. 3.4–5). The scarps previously documented (Bishop et al., 2007: fig. 10.6) for St. Catherines Island are modified here to include two additional scarps. We now define four scarps bounding the north end of St. Catherines Island—Walburg Scarp, Northwest Scarp, Engineers Scarp, and St. Catherines Scarp. Walburg Scarp forms the northwest boundary of ancient St. Catherines Island, along with a newly recognized Northwest Scarp. The newly renamed Engineers Scarp, formerly included as part of St. Catherines Scarp, forms the boundary between the island core and the accretional terraces deposited by fluctuation of St. Catherines Sound to the north. The newly restricted St. Catherines Scarp forms Yellow Banks Bluff (this volume, chap. 3: fig. 3.2).

The present dynamic Atlantic margin of St. Catherines Island is formed by North Beach, Middle Beach, and South Beach. North Beach is developed on accretional terraces of the northeast shoulder of the island, on the detritus of Yellow

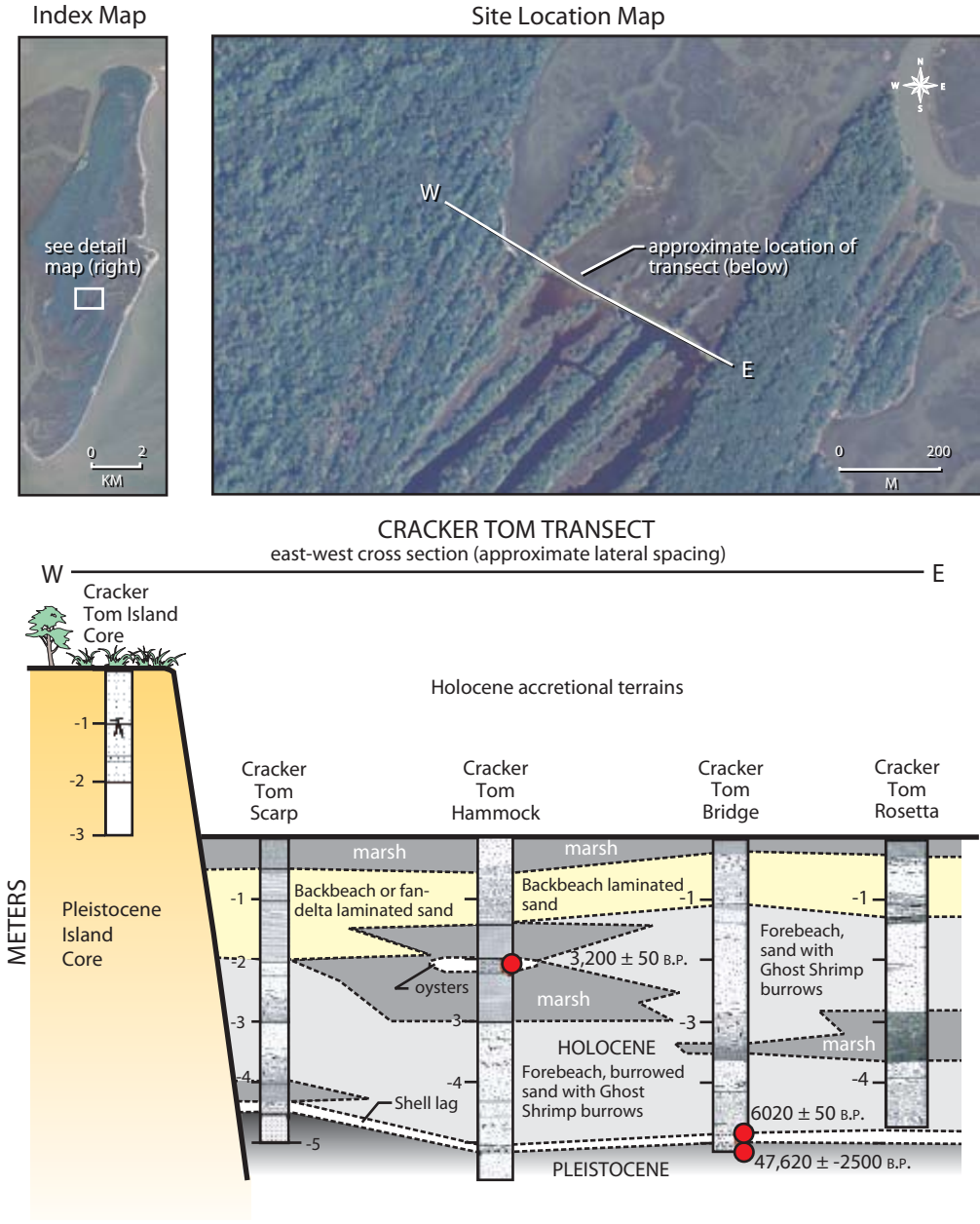


Fig. 10.7. Correlated Cracker Tom Transect showing depositional environments, radiocarbon dates, relative ages, and geomorphology in cross section. Note especially the discontinuity at the bottom of the accretionary terrains with the fern peat at total depth dated at  $47,620 \pm 2500$   $^{14}\text{C}$  yr B.P. and immediately overlain by charcoal dated at  $6020 \pm 50$   $^{14}\text{C}$  yr B.P. bracketing the Pleistocene-Holocene discontinuity. The dated oyster shell at -2.0 m in Cracker Tom Hammock core ( $3200 \pm 50$   $^{14}\text{C}$  yr B.P.) roughly correlates to the elevation of discontinuity #2 in the St. Catherine's Shell Ring Transect (redrafted after Bishop et al., 2007: fig. 36; and Booth et al., 1999: fig. 8). Aerial imagery from United States Department of Agriculture (USDA), National Agriculture Imagery Program (NAIP), 2006.

Banks Bluff, and on the surface of Seaside Marsh as washover fans from the berm of Seaside Spit. Middle Beach is a remnant of older accretional terrains formed and destroyed as sediment from Guale Island was transported southward. These terrains have all eroded away except for a small hammock near McQueen Inlet. Except for this small hammock, surface evidence of past exposure history is largely lacking, but evidence may lurk in the subsurface or within the geomorphology of McQueen and Seaside Marsh meadows. South Beach is developed on the eroding edge of Holocene accretionary terrains that may be composed of sand derived from the destruction of Guale Island (Bishop et al., 2007: fig. 70; see Bishop et al., this volume, chap. 3: fig. 3.3, and Bishop and Meyer, this volume, chap. 14: fig. 14.7).

The history of St. Catherines Island is recorded in the position of the scarps, accretional terrains, and island stratigraphy (Bishop et al., 2007). The features that document a Holocene highstand include backbeach sediment on Sand Pit Road ~2 m above normal high-tide level (see Bishop et al., 2007: fig. 11; this volume, chap. 3: fig. 3.4) and an erosional surface cutting into Yellow Banks Bluff about 1.5 m from its base (Bishop et al., 2007: figs. 23, 24). Evidence for lower than current sea level lies in the lower strata of a series of topographically subdued, accretionary swale and ridge terrains overlain by dunes (see Vance et al., this volume: fig. 11.4). A lowstand is also indicated by geology at Sand Pit Road southward; where the beach is underlain by marsh mud and peat at about -1.17 m, forming an aquitard (fig. 10.3) that perches the water table (see this volume, chap. 3: fig. 3.4). Behind the beach ridges just south of where Sand Pit Road runs onto the island core is an ancient oxbow pond with a second oxbow present immediately north of Yellow Banks Bluff, now all but eroded away by beach retreat. All of the known archaeological sites on the northern end of St. Catherines Island are restricted to the Pleistocene island core. These sites range in age (fig. 10.9) from the Late Archaic period (3000–1000 cal B.C.) to the Irene period (cal A.D. 1300–1580; Thomas, 2008: chap. 15; see also chap. 1, this volume).

Back Creek Scarp forms part of the ancient Atlantic margin of St. Catherines Island along Back Creek Road south of Cracker Tom Causeway. This scarp runs along the edge of the ancient shoreface along Back Creek Road (this volume:

figs. 3.2 and 3.4). The high-standing Pleistocene island core on which the road is constructed stands in marked contrast to the forested beach ridges of the ancient low-lying Holocene ridge and swale terrains to the east. This boundary is prominent and can be traced for 2.0 km (1.2 mi) along Back Creek Road to its junction with South Beach Road, where the road exits the Pleistocene island core onto a high Holocene beach ridge.

#### ST. CATHERINES SHELL RING

The St. Catherines Shell Ring (9Li231) was first recorded in 1979 during the systematic survey of the island (Thomas, 2008, 2010; Sanger and Thomas, 2010). Chester DePratter and two archaeologists from the American Museum of Natural History excavated three test pits at this site, recovering diagnostic Late Archaic ceramics. Radiocarbon dates processed from these test pits were the oldest cultural dates from the island (Thomas, 2008, chaps. 14–16, 20). The American Museum of Natural History team returned to this site in 2006, renaming the locality the “St. Catherines Shell Ring” and initiating multiyear excavations: a large-scale mapping project, an extensive geophysical survey of the site (see figs. 10.10, 10.11, and 10.12), and the vibracore transect described in this chapter.

While the AMNH team was excavating in May 2006, G.A. Bishop noted that several of the archaeological excavations approached the water table (at a depth of ~2 m below ground surface). He suggested the site would provide a perfect place for a vibracore transect to tie the archaeological evidence into the deeper geological record of strata beneath the St. Catherines Shell Ring. This concept was explored on June 7, 2006, with Bran Potter and Tim Keith-Lucas of the Island Ecology Program at the University of the South (Sewanee, Tennessee). The professors and their students obtained and logged three vibracores along a north-south transect in the marsh immediately adjacent to the archaeological investigations in the shell ring. Bishop also logged the three cores and recognized the presence of potentially significant sediments in two of them—a peat in the bottom of one core, perhaps correlative with the Cracker Tom peat (Booth, Rich, and Bishop, 1999; Booth et al., 1999) and a “trampled” shell lens from a core recovered close to the island.

In November 2006, Bishop worked with the American Museum of Natural History archae-

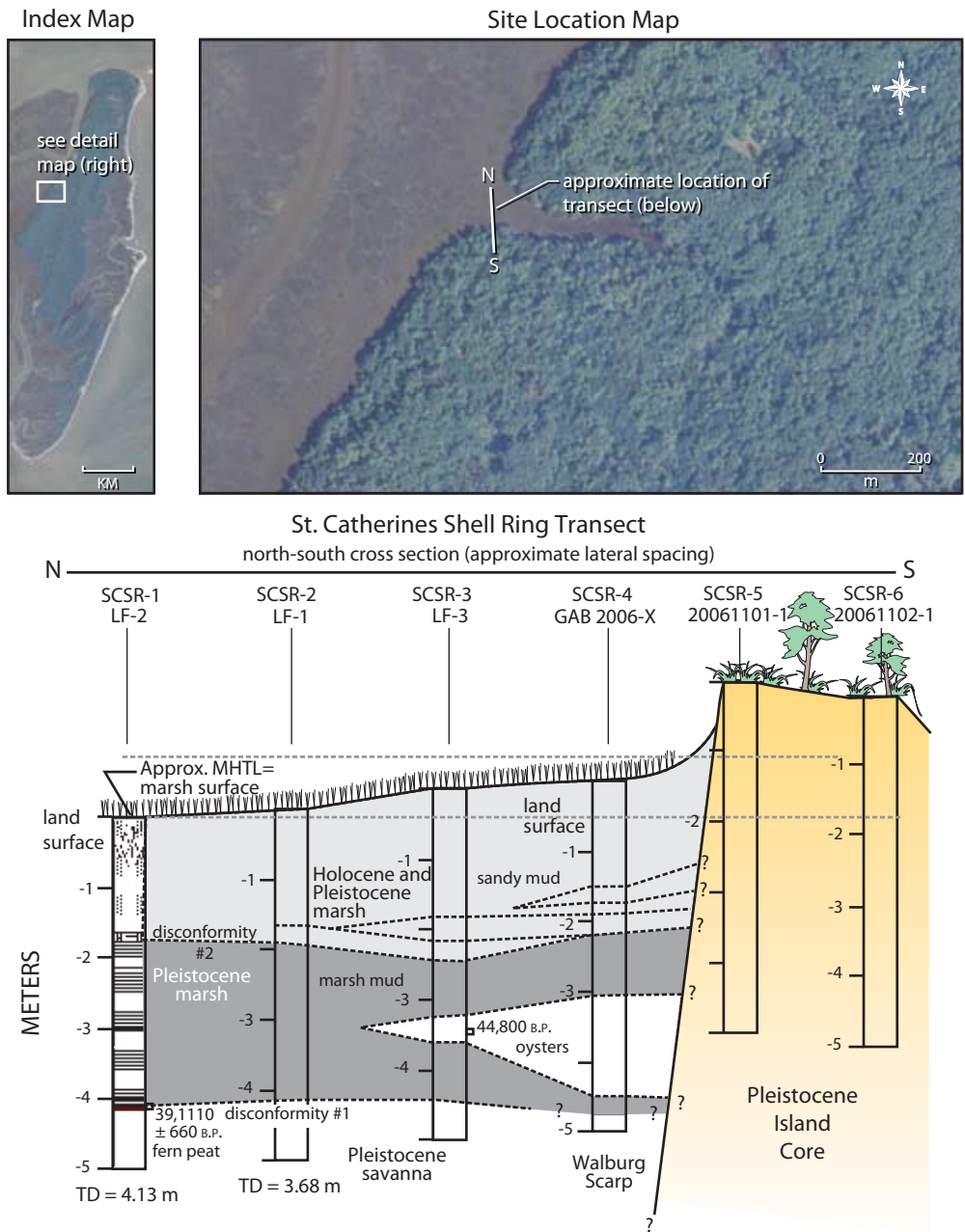
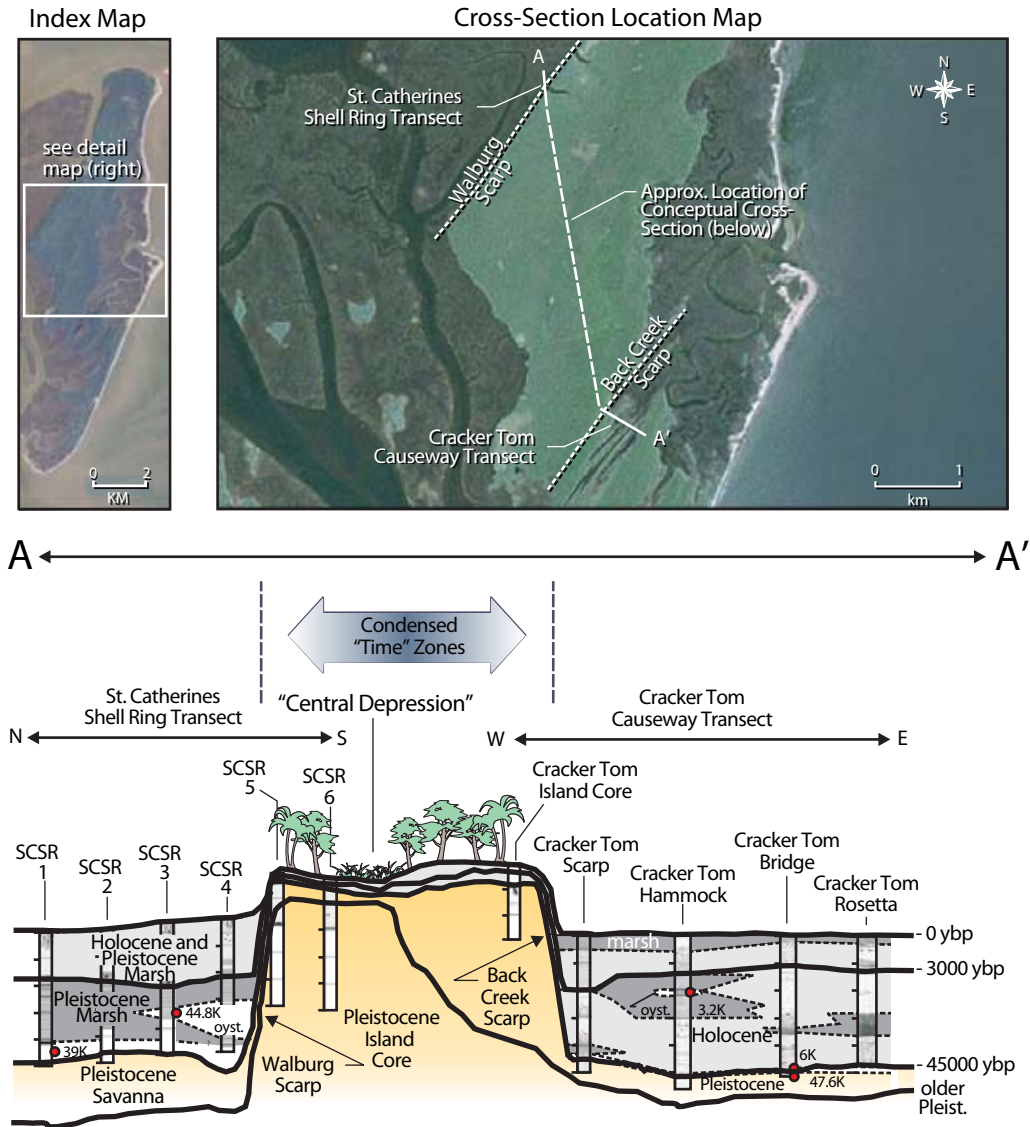


Fig. 10.8. Correlated geology at St. Catherine's Shell Ring Transect showing depositional environments, radiocarbon dates, relative ages, and geomorphology in cross section. The lower disconformity marks an erosional boundary between the older Pleistocene terrestrial and overlying younger Pleistocene marsh facies. The upper disconformity is thought to mark the boundary between the younger Pleistocene and Holocene marsh facies on the west side of the island. The composition of Walburg Scarp and the Pleistocene marsh facies has not yet been determined by vibracoring. Aerial imagery from United States Department of Agriculture (USDA), National Agriculture Imagery Program (NAIP), 2006.



Note: The scale of the island core has been compressed laterally for presentational purposes.

Fig. 10.9. Cross section of St. Catherines Island integrating St. Catherines and Cracker Tom transects into an interpretive model including the geology. Note the “condensed zone” as isochrons cross from the geological realm to the archaeological realm.

ologists to extend the St. Catherines Shell Ring vibracore transect to the south (fig. 10.1D). This research connected the Island Ecology Program cores in the marsh via three new geology cores drilled by Bishop’s team (fig. 10.8) into the ar-

chaeology of the St. Catherines Shell Ring.<sup>1</sup>

The upper component of the cores at the St. Catherines Shell Ring is constrained by the overlying archaeological deposits. The culturally constructed shell ring is a nearly perfect circle, mea-

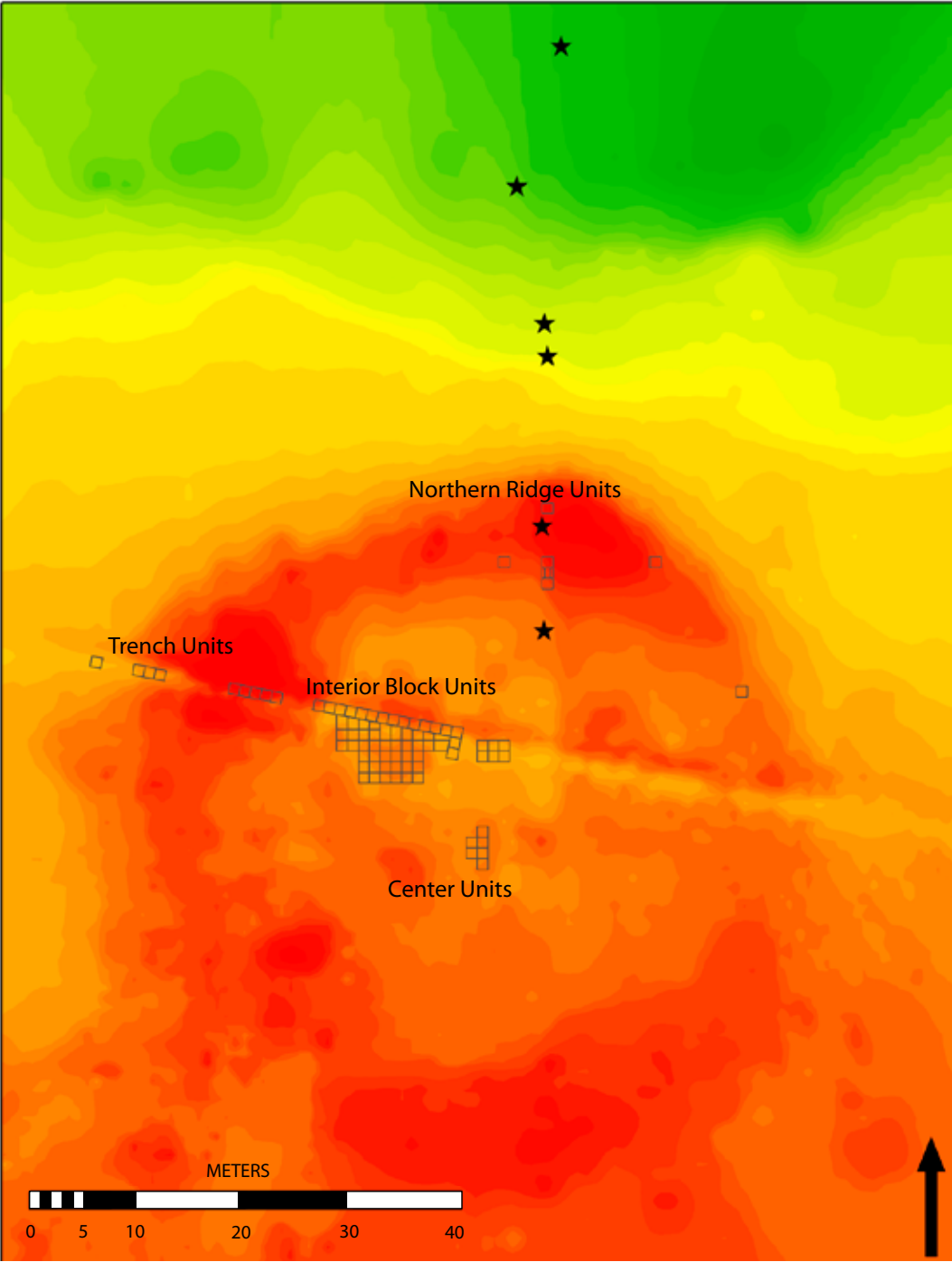


Fig. 10.10. Color-shaded topographic map of archaeological excavations at the St. Catherines Shell Ring; areas of higher elevation are indicated in red.. The diagonal line running approximately east-west is the antebellum boundary ditch defining the northern extent of Long Field. The St. Catherines vibracore transect extends northward under the “R” in words “Northern Ridge Units.” Black stars represent vibracore locations.

suring 70 m between the two exterior edges of the shell ring. The shell that makes up the circle varies in thickness from roughly 1 m to 25 cm in a heavily plowed area. This distinctive shell ring defines an interior, shell-free plaza that is 34 m across. To date, we have processed 41 <sup>14</sup>C dates from the St. Catherines Shell Ring, employing a variety of sampling strategies in selecting samples for radiocarbon dating (Sanger and Thomas, 2010).<sup>2</sup> The earliest known cultural event at the St. Catherines Shell Ring is the construction of several small, shell-filled pits, which date to 2540–2290 cal B.C. A century later, 2230–2030 cal B.C., the vast majority of the shell used in

constructing the circular ring was deliberately deposited across the site, burying the preexisting shell-filled pits. Sometime during this sequence, cal 2410–2210 cal B.C., a large number of circular, straight-walled, flat-bottomed pits were excavated within the interior space created by the shell ring (Sanger and Thomas, 2010).<sup>3</sup>

The marsh cores were integrated into the transect, and that transect has been correlated (fig. 10.8) to show the stratigraphic relationships of the site. In one of the first cores logged (SCSR 1; LF #2), a basal peat was encountered and sampled for dating (SCSR core 1; LF #2: 410–413 cm). Sample splits of the peat and shell samples

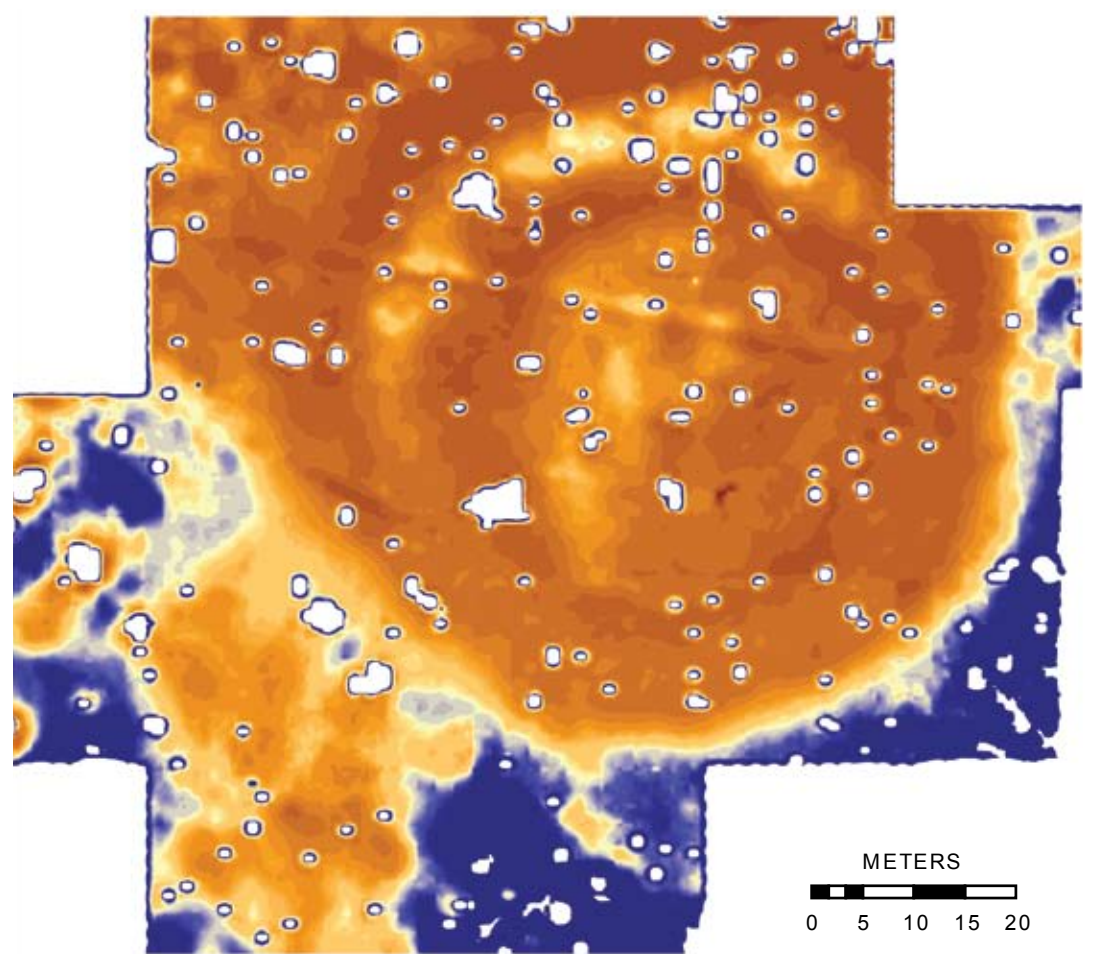


Fig. 10.11. Soil resistance map of the St. Catherines Shell Ring. The color scale ranges from dark orange (low resistance) to yellow (median resistance) to dark blue (high resistance). White areas indicate gaps in data collection due to obstructions such as living trees and vegetation, or excavation areas. The shell ring is clearly defined here as a lower resistance signature than the high resistance signature of the surrounding area.

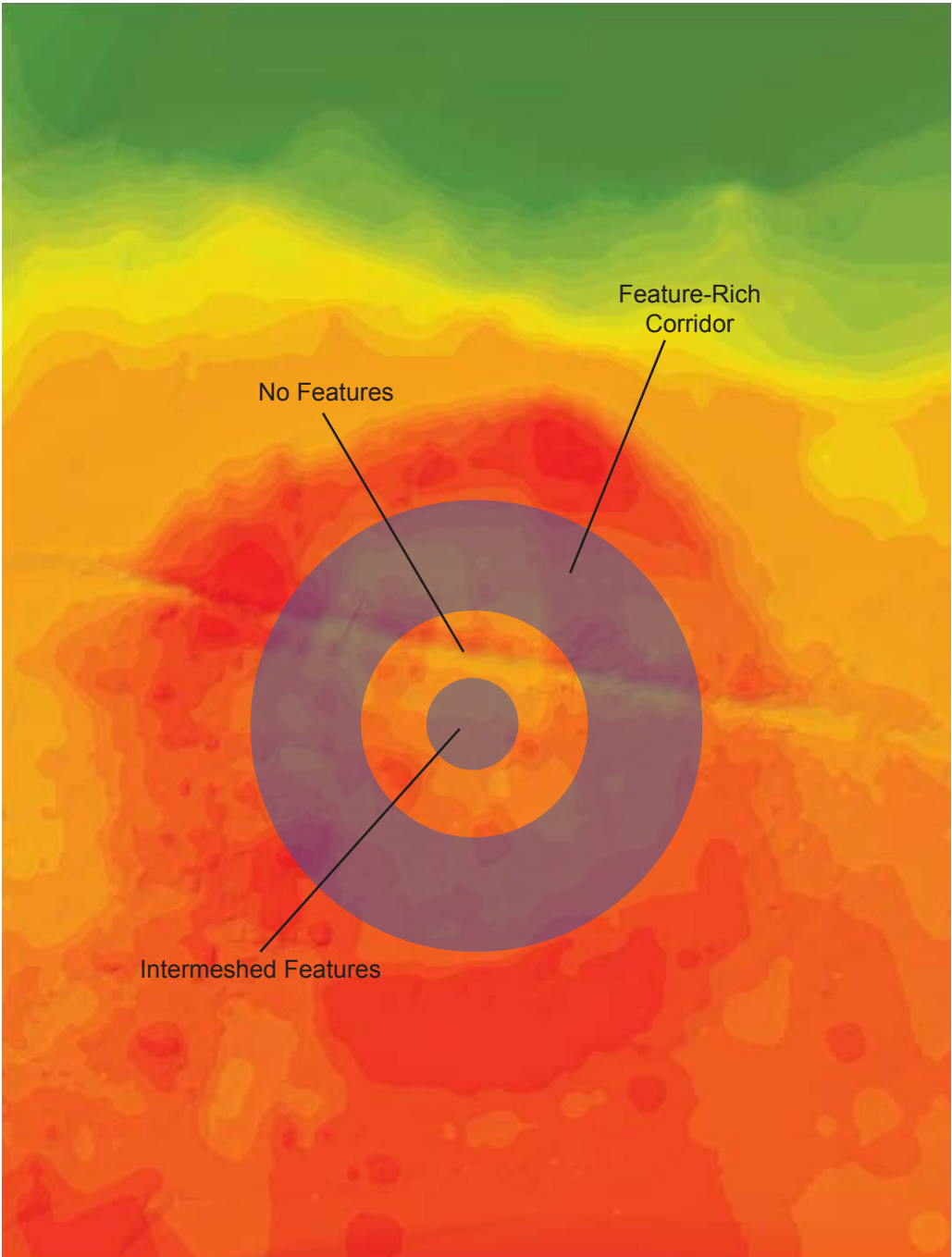


Fig. 10.12. Color-coded topographic interpretive diagram showing the internal structure of the St. Catherine's Shell Ring (after Sanger and Thomas, 2010: fig. 3.12).

were sent to Thomas, who submitted them to Beta Analytic for  $^{14}\text{C}$  dating. The dates from St. Catherines Shell Ring peat ( $>44,800$  [Beta-217823]  $39,110 \pm 660$  B.P. [Beta-217824]), are similar to the peat date from the core at Cracker Tom Bridge ( $47,620 \pm 2500$  B.P. [USGS WW1197]). These are among the oldest dates from St. Catherines Island and appear to mark a time when sea level dropped, exposing the flanks of St. Catherines Island to colonization by a maritime forest with a fern-dominated understory (see chap. 3, fig. 3.3F).

Correlation of the St. Catherines Shell Ring Transect (fig. 10.8) shows that horizontal marsh deposits of the north and western side of St. Catherines Island continue uninterrupted into Vibracore SCSR-4. The St. Catherines Shell Ring is perched on the edge of the Pleistocene island core, constraining the age of the habitation surface at  $\sim 5000$  yr B.P. These sediments bracket Walburg Scarp and indicate that it has been a relatively stable core feature for  $\sim 5000$  years. It would be useful to extend a core deeper into the subsurface beneath the SCSR-5 and SCSR-6 sites to test whether or not the ancient stratigraphy extends underneath the west side of the island, dating the earlier history of Walburg Scarp (fig. 10.8).

Two interruptions in sedimentation are seen in the cross section (fig. 10.8), a lower disconformity marked by transgression of marsh sediments onto a freshwater fern peat at approximately  $-4$  m and a change from deposition of marsh mud to sandy mud of a higher marsh at approximately  $-2$  m. The lower disconformity is bracketed by a date on the peat ( $39,110 \pm 660$  B.P. [Beta-217824]) and a date on the oyster shells in the overlying marsh mud ( $>44,800$  B.P. [Beta-217823]). Both dates approach the limits of the  $^{14}\text{C}$  methods, necessitating a return to relative dating by superposition. The dates indicate that the marsh hosting the oyster bioherm was situated on the bank of a tidal river some  $44,800$  yr B.P. It is not yet clear whether Walburg Scarp is part of the lower disconformity, or whether it is even older than the lower disconformity and antedates deposition of the lower sequence of marsh sediment.

From a geological perspective, the juxtaposition of intervals of time represented by packets of sediment in the marshes surrounding St. Catherines Island and the equivalent, but thinner sediment within the island core would represent a sort of "condensed interval," where time lines

converge and island history is compressed into a thin interval across the island. This concept has been explored by attempting to draw isochrons across the island (fig. 10.9).

Booth (personal commun.) has conducted palynological analysis on two samples taken from the St. Catherines Shell Ring. The two strata beneath the St. Catherines Shell Ring have been dated, as previously discussed. He also pointed out that both dates approach the maximum range of  $^{14}\text{C}$  dating.

Two samples were taken in SCSR #4 and a palynological analysis of the peat sample in [LF #1:  $-4.10$  m] was done by Booth at Lehigh University and he reported (Booth, personal commun.; Rich and Booth, chap. 6):

SAMPLE 20061102-1, 322 cm, SHELL BED:

The pollen assemblage from the shell bed was dominated by *Pinus* (pine) and *Quercus* (oak); these occurred in approximately equal percentages.... Other arboreal types that were likely present in the region include *Carya* (pecan/hickory), *Liquidambar* (sweet gum), *Nyssa* (tupelo/black gum), *Betula* (birch), Cupressaceae/Taxodiaceae (probably cypress), and *Ulmus* (elm). Abundant nonarboreal types included Chenopodiaceae/Amaranthaceae type (likely salt marsh chenopods) and Poaceae (grasses), consistent with deposition in or near a salt marsh environment. The palynology of the sample is quite similar to that of the lowermost sample from the Cracker Tom Hammock core (CTH559), which is presumably also late Pleistocene in age and characterized by codominance of *Pinus* and *Quercus*, and significant amounts of *Carya*, *Liquidambar*, Cupressaceae/Taxodiaceae, Poaceae, and Chenopodiaceae/Amaranthaceae type. Trace amounts of *Fagus* (beech) also occurred in both the shell bed sample and the lowermost Cracker Tom Hammock sample.

SAMPLE SCSR-1, 406 cm, PEAT: The

lowermost peat is dominated by *Pinus*.... Other common arboreal types include *Quercus*, Cupressaceae/Taxodiaceae, *Carya*, *Betula*, *Fagus*, *Liquidambar*, and *Nyssa*. The relatively high *Fagus* percentage (3%) suggests the local presence of

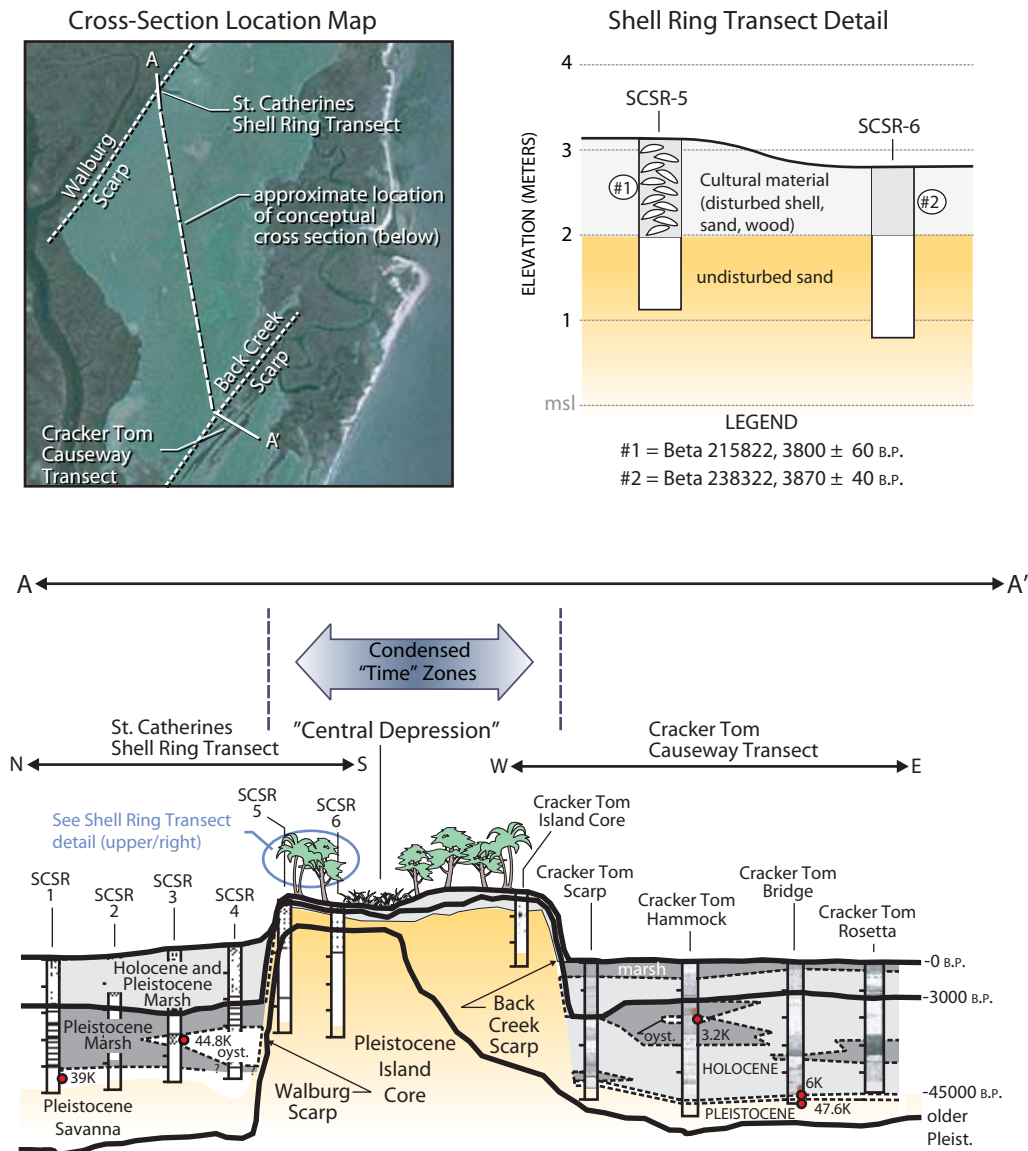


Fig. 10.13. Integrative model of St. Catherine's Island geoarchaeology into which the authors hope to add additional detail in future collaborative studies. Note: The scale of the island core has been compressed laterally for presentational purposes.

beech populations. Beech currently does not occur in coastal Georgia, except for some disjunct populations on north-facing bluffs of the Savannah River. The nonar-boreal pollen of the peat indicates deposi-

tion in a freshwater peatland environment, dominated by ferns (*Osmunda*, *Woodwar-dia*-type), grasses, and sedges. The palyn-ology, and particularly the abundance of *Woodwardia*-type ferns, is relatively simi-

lar to the palynology of the basal peat of the Cracker Tom Bridge core (CTB511), which was also late Pleistocene in age.

Correlation of the geology into and under the St. Catherines Shell Ring (fig. 10.8) shows a massive oyster bioherm thickening toward the island core, a perched water table indicated by limonite concretions, and a layer of "beach rock" underlying St. Catherines Shell Ring. Beach rock (a limonite or humate cemented sandstone) is often found underlying parts of the older Pleistocene parts of St. Catherines Island. Thom (1967) described humate occurrences in Australia, South Carolina, and on Sapelo Island. It is a dark brown or black cemented sand, often exceeding 3 m (20 ft) in thickness derived from Fe and the humic acids of decaying plant material and carried below ground in true solution or colloidal suspension. Thom thought humate deposits marked former water table positions.

The upper disconformity is marked by the top of the aforementioned ancient marsh with its oyster bioherm and the overlying sandy mud of more recent marsh sediments (yet undated) and a pervasive zone of limonitic concretions at its base just above the marsh mud. This concretionary zone is thought to be the result of, and marks the position of, freshwater outflow from the island core, i.e., a perched water table. It remains unclear whether the marsh mud underlying disconformity #2 forms a seal against Walburg Scarp or extends eastward under the St. Catherines Shell Ring beneath Walburg Scarp; either way it holds a perched water table. This relationship will be essential to understanding the evolutionary history of Walburg Scarp and, consequently, the configuration of the ancient St. Catherines geometry on the west side of the island.

The Terrain #6 vibracore (fig. 10.4) was taken in a swale pond in an east-west terrain. This core had a muddy peat at its bottom (TD 4.97 m), which was overlain by a sand with three shell layers up to 4.0 m, then was marked by a thin laminated sand overlain by a heavily mottled, burrowed, muddy sand from 3.66 m to 2.70 m. This was, in turn overlain by a sand with abundant clay drapes, burrows, and tabular cross beds at its top from 2.70 to 1.23 m, with a thin horizontally laminated sand bed from 1.23 to 0.96 m, a fine-grained rooted sand from 0.96

to 0.47 m. Finally, there was a very organic peat from 0.47 to 0.00 m. This sequence of sediment and sedimentary structures is interpreted to represent the channel margin facies of the north edge of ancient Zapala Sound. The mottled muddy sand from 3.66 to 2.70 m is interpreted as a tidal mud flat on the channel margin with its surface at, or near midtide level, putting sea level at half the tidal range, or approximately at -1.70 m. The core is floored at total depth by a peaty mud, perhaps marking the disconformity seen at Cracker Tom and St. Catherines Shell Ring and described by Vance et al. (chap. 11, this volume).

#### GATOR POND

In 2008, Kelly Vance led three Georgia Southern University undergraduate students (Ferguson et al., 2009) in exploration of a sag structure at Road Junction 61 on the southwest side of Gator Pond Marsh (see Vance et al., chap. 11: fig. 11.14A). This subsurface structure was discovered by Vance and Bishop in 2007 during GPR profiling with a 100 MHz antenna. This exploration effort resulted in the recovery of 10 cores ranging in depth from 2.2–5 m in a zigzag traverse from road junctions 10 to 61 to 60 to the active excavation site of the pond at the old Crane Yard. Cores obtained from higher, well-drained areas were characterized by essentially structureless, medium- to fine-grained, subangular to subrounded, quartz sands with <1% disseminated dark, heavy minerals in the uppermost 1.5–2.5 m. Among these were two cores (our cores 8 and 9) from sites on topographically high, dry ground on the east and west sides of the drainage extending from Gator Pond to the Crane Yard site. These short cores (2.3 and 2.1 m) did not penetrate the base of these upper structureless sands. The relatively structureless uppermost sands are probably Holocene eolian sands (see Vento and Stahlman, chap. 4). Underlying sands (of Pleistocene age) are also largely fine- to medium-grained, but are distinct from the upper sands by the presence of inclined laminations defined by 4% to 12% concentrations of dark, heavy minerals. The laminated heavy mineral-rich sands are fine to very fine grained and similar strata have been attributed to a back beach depositional environment. Excavation of a new pond at the Crane Yard site in 2008 allowed construction of a composite section by utilizing strata exposed in the excavation wall plus vibracore samples. The excavation exposed

an indurated humate-cemented sand (a vibracore impediment) at 1 to 1.5 m depth. The vibracore rig was erected in the bottom of the excavation where the indurated sand had been removed. The composite section is sand-dominated but includes some scour structures and lenses of finer sediment in the upper meter. Below the humate-cemented sands (1–1.5 m depth), heavy mineral sand concentrations (3%–5%) defined faint bedding in tan, fine- to medium-grained, subangular to subrounded, mica-bearing, quartz sands at 2.0 to 2.7 m depth. Thin (1 cm) lenses of red-brown, very fine, micaceous quartz sand and heavy minerals with traces of clay were observed at 3.7 m depth. Ghost shrimp burrows were identified (Gale Bishop) in fine- to medium-grained, subangular quartz sand at 3.9 to 4.6 m depth. The burrows were 1–2 cm in diameter with dark, clay-rich walls and a sand-filled interior. The core terminated in an iron oxide-cemented horizon at a depth of 4.9 m below the ground surface.

One of the goals of this vibracore traverse was to explore low areas that may have preserved layers of sediment rich in organic components that could be used in palynological investigations. Organic matter was a minor component in topsoils in the upper 20 to 30 cm of core from the higher, well-drained sites. One core (our Core 2), from the southwest margin of Gator Pond Marsh, contained ~30 cm (compacted thickness) of plant debris and significant amounts of organic material mixed with fine to very fine sand to depths of 1 m. The upper meter of strata exposed in the walls of the Crane Yard pond excavation also contained substantial concentrations of organic components to a depth of 1 m. The organic-rich upper meter in the Gator Pond Marsh core is underlain by relatively structureless fine- to medium-grained, subangular quartz sand to a depth of 3.9 m, where a sharp oxidized contact was observed with underlying sands characterized by heavy mineral laminations. The east wall of the excavation at the Crane Yard site exposed 15 cm of dark gray to black organic topsoil grading downward into white, fine- to medium-grained sand. The white sand was underlain by chocolate-brown, fine- to medium-grained sand that graded downward into a zone of black fine sand, silt and organic components at a depth of 75 to 95 cm. A thin gray-to-brown sand below the second organic sediment layer gave way to an underlying sandy clay layer

characterized by Liesegang banding at ~1.2 to 1.4 m depth. Small springs (perched water table?) were observed at this depth and the water smelled strongly of hydrogen sulfide. The exposure in the west side of the pit revealed small lenses and troughs of finer sediment within the upper meter of sands and a larger trough or scour cross-section bearing dark, laminated sand at 0.9 to 1 m depth. Older topographic maps and current Lidar topographic terrain models (Brian Meyer) indicate that the former, more extensive Gator Pond marsh drained into the area of the new Crane Yard pond.

Fred Rich and Shannon Ferguson conducted a palynological evaluation of core samples from the Gator Pond marsh area and the Crane Yard pond excavation. This research indicates these areas were dominated by freshwater wetlands during the deposition of the upper meter of sediment (Ferguson, Rich, and Vance, 2010). The analyses also indicate an increase in diversity of the floral community with depth and the presence of an open freshwater wetland that was gradually taken over by shrubs and trees. Nine wetland taxa identified in samples taken at 70 cm to 100 cm depth include *Sphangnum*, *Botryococcus*, *Myriophyllum*, *Nuphar*, *Nymphaea*, *Ovoidites*, *Polygonum*, *Taxodium*, and *Utricularia*. The diversity and open nature of the interpreted environment are compatible with the conditions described by Jonathan Bryan in 1753 as “a perfect Meadow...finely watered with Springs...” (Hayes and Thomas, 2008). Additional coring in the interior of Gator Pond marsh and some of the ephemeral wetlands in the low interior of the island should penetrate deeper horizons of organic matter to extend this wetland record. The GPR profiles can provide some guidance in core site selection by indicating the extent of basin development. The present profile inventory suggests the ephemeral wetlands near the present Windmill Pond would be good candidates for additional vibracoring sites (see chap. 11, fig. 11.8A).

#### ST. CATHERINES AND SAPELO SOUNDS

Accretionary beach ridge complexes at both ends of St. Catherines Island, oriented perpendicular to the present-day northeast-southwest trending beaches, represent Holocene changes in the channel margins of St. Catherines Sound and Sapelo Sound (Linsley, Bishop, and Rollins, 2008). This indicates that the sounds and

Pleistocene cores of the Georgia Sea Islands are stable core features, but the unconstrained mouths of the sounds are historically active and act like loose fire hoses, whipping rapidly back and forth along the coastline, generating the erosional boundaries and accretionary packages of the beach ridge complexes. Oertel (1975, 1979), Kana, Hayter, and Work (1999), and Rollins, Beratan, and Pottinger (chap. 8, this vol.) discussed the dynamics associated with beach ridge complexes adjacent to inlets. Most St. Catherines Island beach ridges are parallel linear features hundreds of meters long and 2–4 m high seen forming as longitudinal dunes on the leading edge of accretional terraces on North and South beaches (Bishop et al., 2007: fig. 16).

Marsh system facies tracts are dominated by tidal creeks, rivers, and sounds. Lateral migration of the tidal creeks and rivers incises the sounds (Farrell, Hoffman, and Henry, 1993; Bishop et al., 2007: figs. 31, 32; this volume, chap. 3: figs. 3.4–5) an average of 10–15 m (Henderson and Frey, 1986). The rate of lateral migration is often 1–2 m per year (Letzsch and Frey, 1980b) with erosional depths depending upon channel depth. Large tidal rivers may also cut channels to depths exceeding 10 m (Duc and Tye, 1987), while small tidal creeks cut channels to lesser depths.

## SUMMARY AND CONCLUSIONS

Vibracores and vibracore transects provide stratigraphic control to establish relative dating and access to materials for radiocarbon dating within a stratigraphic context. Vibracoring documents the erosional surfaces (disconformities) bracketing sedimentary packets and defines the lateral and vertical limits of sedimentary packets that record past depositional environments. The sequences of facies deposited through time establish the geological history of St. Catherines Island. Vibracore techniques have been applied to tie three of the archaeological sites into a geologic framework. At all three sites the vibracore data demonstrate the presence of marine conditions in proximity to the sites when they were occupied.

From the geological and geoarchaeological data presented above, we can surmise the following:<sup>4</sup>

(1) St. Catherines Island is comprised of an older Pleistocene island core surrounded by Ho-

locene sediment.

(2) The island core appears to be comprised of at least two ages of Pleistocene sediment, an older one forming the western part of the island and a younger one forming the part of island to the east; these components are separated by a central depression.

(3) The easternmost part of the island core is slightly higher and has a less mature topography, with surficial strata that may consist of dunes built of sand blown from the beaches to the east.

(4) Underlying the Holocene sediment on the east and west sides of the island are one or two disconformities bracketed by basal shell beds above and peat beds beneath. The upper disconformity on the west side is marked by limonite concretions and “beach rock.”

(5) Peat beds penetrated by vibracores in the Cracker Tom and St. Catherines Shell Ring transects are Pleistocene, <sup>14</sup>C dated at 47,620 ± 2500 B.P. (USGS WW1197) and 39,110 ± 660 B.P. (Beta-217824), respectively; microfossils consist predominantly of spores and fragments of the fern *Woodwardia*.

(6) A peat bed penetrated by an Island Ecology Program vibracore 16.2 on North Beach (~27,000 B.P.) is also Pleistocene, but is significantly younger than the peat beds from Cracker Tom and St. Catherines Shell Ring transects.

(7) Charcoal and a marine bivalve, *Americardia*, shell lying immediately above the 44,000 B.P. peat at Cracker Tom were dated at 6020 ± 50 B.P. (USGS WW1198) and 4060 ± 50 B.P. (USGS WW1262) respectively, bracketing the major disconformity between the Pleistocene core and younger strata surrounding St. Catherines Island.

(8) High elevations of ghost shrimp burrows and laminated heavy mineral sand layers in vibracores (SRP 1, 2.50–2.95 m) indicate a sea level approximately 2–5 m above today’s sea level when that part of the island core was deposited.

(9) Backbeach and marsh facies deposited above the basal disconformity in the Cracker Tom Transect and St. Catherines Shell Ring Transect record sea level rising against the island.

(10) The upper disconformity on the west side of the island at St. Catherines Shell Ring is the lower boundary for the overlying sedimentary packet, marking a probable still-stand at –2.0 m.

(11) The uppermost lagoonal sediments in

the Beach Pond vibracore contained a wood clast that yielded a radiocarbon date of  $1210 \pm 40$  B.P. (Beta-115910).

These primary data can, in turn, be synthesized into several conclusions about the geology of St. Catherines Island:

(1) Vibracore transects indicate that St. Catherines Island formed during the Pleistocene in two major cycles of sedimentation at an elevation of some 4.0 m above current sea level.

(2) An island doublet, St. Catherines Island and Guale Island, formed during the latest cycle (see Bishop et al., this volume, chap. 3).

(3) St. Catherines Island was subject to sub-aerial exposure at least twice during formation of the island core, most recently in the Wisconsin period.

(4) While sea level was down during the Wisconsin glaciation, shorelines were situated far to the east (near Gray's Reef) and St. Catherines Island was a forested ridge on the mainland with significant fern communities in (low) spots.

(5) As sea level began to rise after the Wisconsin, preexisting (legacy) tidal creeks and rivers were reflooded as shorelines transgressed onto the ridge, laying down a record of transgressive shoreline and marsh facies above one or more disconformities. Erosion of Guale Island began and sand was transported southward along the east face of St. Catherines Island, forming a series of accretional terrains (see Bishop et al., this volume, chap. 3; fig. 10.7).

(6) As Guale Island eroded, the northern end of St. Catherines Island was exposed to erosion, forming an "erosional marine terrace" at ~1.5 m above current sea level (Martin and Rindsberg, 2008). Tidal creeks cut meander scars into the ocean side of St. Catherines Island, forming the North Oxbows and initial phases of meander scars cut into King New Ground Scarp.

In summary, we can see that the historical evolution of St. Catherines Island that was originally developed largely on the basis of geomorphology (Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008, Thomas, 2008) is now being constrained by stratigraphy. Vibracoring around the island has been instrumental in documenting its geological foundation by providing sedimentological, stratigraphical, and palynological data that must be consistently integrated and interpreted. In addition, organic inclusions extracted from the vibracores provide radiocarbon dates that further constrain the evolutionary history of

St. Catherines Island and build an absolute temporal framework for the geology and archaeology. These methods also provide the data to test new hypotheses (Chowns et al., 2008) of island formation, evolution, and of its contingency (Gould, 1989). New geophysical techniques like ground penetrating radar have become available to investigate the geological underpinning of St. Catherines Island (Vance et al., this volume, chap. 11). It will be interesting to note whether optical thermal luminescence methods will provide additional dates on the quartz sand that comprises so much of St. Catherines Island.

So, which way forward? What pertinent problems can be best investigated by future vibracoring on St. Catherines Island? Several obvious vibracore problems are already apparent due to past coring and GPR surveys (see chap. 11, this volume):

(1) What is the age and history of Northwest Marsh and how does it constrain Walburg, Northwest, Engineers and St. Catherines scarps?

(2) Can the hypothesized modification of King New Ground Scarp by erosional emargination of tidal creeks be documented and, if so, what is its timing?

(3) What is the nature of the GPR-identified sag structures within the island core (see Vance et al., this volume, chap. 11)? What are the implications of these structures for past hydrology and the future?

(4) Does the Central Depression really mark an ancient erosional scarp between older and younger Pleistocene sedimentary packages, and if it does, can the underlying disconformity be documented by vibracoring or GPR methods?

(5) Can Back Creek Scarp be documented by vibracore methods and will there be heavy mineral sand placer deposits at its base?

(6) What do Gardeners Peninsula, the arcuate meander scarp on the south side of McQueen Marsh meadow, and lineations within McQueen Marsh meadow tell us about island evolution?

(7) What is the relationship of the island's fringing marsh to the history of sea level fluctuation?

(8) What is the circular structure south and east of South End Settlement: a Carolina Bay, an old meander scar, or a sinkhole?

(9) What is the nature of the inclined strata beneath South End Field?

These and many other questions await resolution through the use of geophysical methods

(GPR, shallow seismic, resistivity), and Lidar terrain modeling used with vibracoring for ground truth and access to samples for geochronological, palynological, and sedimentological study.

## NOTES

1. The AMNH archaeology crew then expanded the vibracore testing to investigate Back Creek Village and McQueen Shell Ring sites on the front of the island core in 2008.

2. We have calibrated these results according to the established protocols already established for St. Catherines Island (Thomas, 2008), namely using the CALIB 5.0.1 Radiocarbon Calibration Program (as initially presented by Stuiver and Reimer, 1993, and updated by Stuiver et al., 2005). For terrestrial samples, we used the IntCal04 curve (Reimer et al., 2004) and for marine samples, we employed

the Marine04 curve, which takes into account the “global” ocean effects (Hughen et al., 2004). We also used the reservoir correction of  $\Delta R = -134 \pm 26$  specific to St. Catherines Island (as derived in Thomas, 2008: chap. 13).

3. A prominent muddy oyster/mussel bed was observed to thicken southward and disappear under the edge of the island core. In subsequent excavations, archaeologists now routinely use vibracore sampling to complement conventional archaeological excavation.

4. Thomas et al. (2008) combined the available stratigraphic and geomorphologic evidence from St. Catherines Island with the known distribution of archaeological ceramics recovered from the more than 200 sites to develop a scenario of island evolution. A reconstruction of the shape of St. Catherines Island at various points through time was made and is inherent in the observations and conclusions of this chapter and volume. In (Thomas, 2008: table 29.1) the 41 “noncultural”  $^{14}\text{C}$  dates are presented that have been processed to interpret the geomorphic evolution of St. Catherines Island and combine it with historical documents (see also appendix 1, this volume).





## CHAPTER 11

### APPLICATION OF GROUND PENETRATING RADAR TO INVESTIGATIONS OF THE STRATIGRAPHY, STRUCTURE, AND HYDROLOGY OF ST. CATHERINES ISLAND

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MEYER, AND ELEANOR J. CAMANN

Ground penetrating radar (GPR) is a high-resolution geophysical tool for relatively shallow imaging of soil, sediment, rock, or ice using electromagnetic waves of 10 to 1000 MHz frequency. For detailed descriptions and discussion of operational theory and technique, the works of Daniels (2004) and Baker, Jordan, and Pardy (2007) and web resources of Olhoeft (2006) and Conyers (2009) are recommended. The equipment and technique have a prolonged history of development beginning with the application of electromagnetic signals to the detection of subsurface features in 1904, followed by the use of pulsed techniques by 1926, that were soon applied to investigation of ice, sand, rock, coal, salt, and water in the 1930s (Daniels, 2004). Lunar exploration in the 1970s promoted improvement and compaction of equipment toward the GPR systems used today in a broad range of noninvasive applications to archaeology, cultural resource management, forensic investigation, mine detection, determination of road, bridge, and building integrity, crevasse detection on glaciers, detection of buried wastes, detection of underground storage tanks and conduits, and the subsurface geological investigation of stratigraphy, structures, and hydrology (Sharma, 2002; Daniels, 2004; Baker, Jordan, and Pardy, 2007).

Geophysical surveys using GPR, magnetometer, and resistivity have been applied to archaeological investigations on St. Catherines Island for more than two decades (Garrison and Baker, 1985; May, 1985; Thomas, 1987; Sanger and Thomas, 2010). The St. Catherines Island investigations have become an operational model for archaeological site conservation by maximizing the

use of noninvasive geophysical surveys and other techniques to focus and limit excavation (David Hurst Thomas and Royce Hayes, personal commun., 2007; Bishop, Vance, and Meyer, 2007). GPR remains an important noninvasive tool for archaeologists in reconnaissance of large buried structures or for high-precision, closely spaced profile grid lines in surveys that allow processing of the data into horizontal planes (“time slices”) or three-dimensional images. The second method accommodates the need for documenting spatial relationships at sites and lateral variation within horizons. Application of geophysics to the geological investigation of St. Catherines Island has been relatively limited and the geological framework for understanding the island evolution has been built on the application of fundamental geological principles and traditional field and laboratory techniques to the sediments and sedimentary rock via limited surface exposure, trenching, augering, and vibracoring (Bishop et al., chap. 3 and chap. 10, this volume; Thomas, 2009; this volume, chaps. 1, 3, and 10).

In 2005, the Department of Geology and Geography at Georgia Southern University acquired a MALA GPR system with a Ramac X3M controller that can be paired with 100 MHz, 250 MHz, 500 MHz, or 800 MHz antennae. These are shielded antennae that incorporate both transmitter and receiver in one unit at fixed spacing. The controller-antenna system can be used for GPR profiling in either cart or sled mode for the 500 MHz and 250 MHz antennae, but requires sledding for the 100 MHz antenna. A laptop computer, or the MALA Ramac monitor can be used to calibrate and configure the system and record

data and profile markers. The compact, durable, heat- and dust-resistant construction and simple operation make the Ramac monitor preferable to the laptop for prolonged field use. The system is powered by a lithium-ion battery that provides approximately five hours of use. A second, fully charged backup battery ensures a full day of use. GPR profile distance is recorded internally using a wheel odometer attached to the antenna or cart or by using a hip chain system. A time triggering mode is also an option if conditions do not allow direct measurement by odometer or hip chain. Survey data recorded in the monitor can be downloaded to a flash drive or through USB cable to a laptop or desktop computer for processing with MALA software.

Access to GPR equipment allows nondestructive geological exploration of the shallow subsurface of St. Catherines Island. Geological exploration, interpretation, and representation of stratigraphy and structure rely heavily on a cross-sectional perspective; consequently, most of the GPR surveys described here were conducted by reflection profiling to develop subsurface cross sections of the geology. The depth of penetration and resolution of subsurface features depends largely on the antenna, the sediment or rock type and density, and the amount and salinity of groundwater. Under identical conditions, lower frequency antennae achieve the greatest penetration, but with lower resolution. Higher frequency antennae provide the best resolution, but least penetration. Under optimum conditions the 100 MHz antenna has the capability to resolve features of 50–60 cm thickness, the 250 MHz antenna can resolve features of 2 cm thickness, the 500 MHz antenna can resolve features of 1 cm thickness, and the 800 MHz antenna can resolve features between 1 cm and 0.6 cm thickness. On St. Catherines Island, the maximum penetration with return of ground radar energy occurs in dry sand. Groundwater increases the dielectric constant and decreases velocity of radar waves. Saltwater saturation results in complete loss of return signal and the presence of clay rapidly attenuates radar energy (Daniels, 2004). Although these characteristics limit effective depth of the radar profile, they also provide indirect information or at least constrain interpretations of subsurface geology.

Vance and Bishop began experimenting with the MALA system and GPR applications on St. Catherines Island in 2005, gradually exploring the potential of the system with the assistance

of coworkers, students, and family using various combinations of antennae, settings, and adjustments for different applications. Results presented here represent some of the applications of the system and implications for geology of the island. The profiles shown or discussed provide a framework that may be used to focus future exploration or to constrain the current interpretations of subsurface geology.

## GPR APPLICATIONS ON ST. CATHERINES ISLAND

### SEA TURTLE NESTS AND GPR

Sea turtle conservation work requires an annual monitoring presence on St. Catherines Island and includes a teacher education program (see <http://scistp.org/>) on the island; consequently, it was natural to run an early GPR experiment on sea turtle nests. Gale Bishop noted the difficulty in locating egg chambers produced by the rare leatherbacks nesting on the St. Catherines beach and wondered if the egg chamber could be detected with GPR (Bishop et al., this volume, chap. 13: fig. 13.4). To test this possibility we used a loggerhead nest in which the egg chamber had been located and ran profiles with 0.5 ft spacing over a 12 ft by 17 ft area that enclosed the body pit of the turtle nest. An 800 MHz antenna was selected for this project to achieve the maximum resolution possible for this shallow feature. We smoothed the sand surface of the body pit to avoid changes in energy coupling produced by surface irregularities. The upper portion of the profiles exhibit what appears to be the broadly concave cross section of the body pit. The profile (fig. 11.1) is one of two profiles that exhibited a broad hyperbolic reflection above a zone with a minimal or weak reflection. This feature coincides with the actual position of the egg chamber. The hyperbolic reflection probably results from radar wave interaction with the compacted sand filling above the eggs and/or the margins of the egg chamber. The weak signal under the hyperbolic reflector may be due to energy loss in the soft mass of turtle eggs (see Bishop et al., this volume, chap. 13: fig. 13.7A, B). The experiment suggests that a leatherback egg chamber could be detected with the 800 MHz antenna. The subtle nature of the nest signature would probably require leveling of the body pit surface to avoid the change in radar energy coupling effects or better yet, laying a smooth, firm, radar

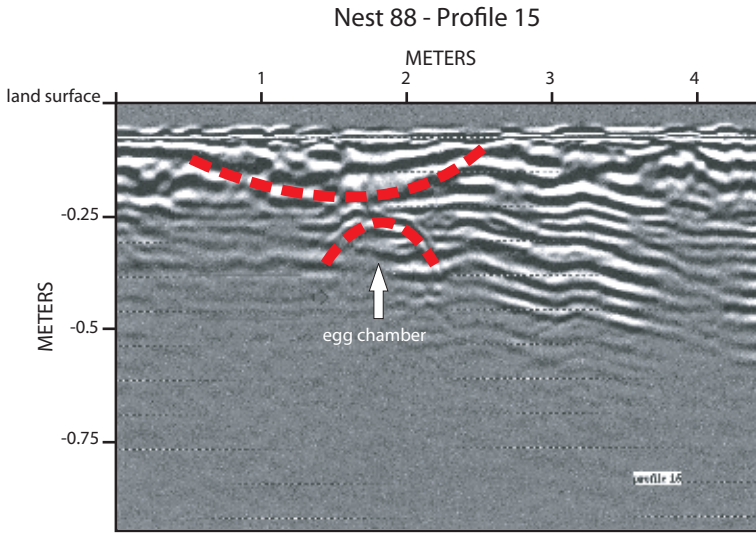


Fig. 11.1. GPR profile (800 MHz) across a loggerhead sea turtle nest. The upper highlights outline the margin of the concave reflections attributed to the body pit. The lower highlights mark the broad hyperbolic reflections that are probably produced by packing of sand into and over the egg chamber and/or the egg chamber walls. Note truncation of reflectors at the margins of the body pit and egg chamber.

transparent sheet over the surface. The 800 MHz antenna is generally limited to penetration depths <1 m but is capable of centimeter-scale resolution. It is designed largely for mapping hidden structural features in walls and floor (rebar, conduits, fractures, voids) but has the potential for exploring fine beach stratigraphy, heavy mineral sand distribution, burrow networks, and localized high-resolution archaeological work. This experiment also indicated that the small odometer wheel would need to be modified for any extended beach work to keep loose sand out of the wheel axles and to increase the frictional contact between the smooth plastic wheel and sand. Using a hip chain anchored at profile stakes would be another very slow option.

#### EXPLORING THE SUBSURFACE STRUCTURE AND STRATIGRAPHY

The road network on St. Catherines Island provides an opportunity for both northwest-southeast profiles across the short axis of the island and northeast-southwest longitudinal profiles. The marked road junctions on the island map prepared by Timothy Keith-Lucas and others provide useful references for profile

endpoints and internal markers. Over 20 km of GPR profiles (see table 11.1) were acquired from 2005 to 2009.

Most of our work has been conducted by two-person teams towing a 100 MHz antenna with attached odometer wheel behind a John Deere Gator ATV with the GPR operator sitting in the back of the ATV using a shoulder-mounted harness for the monitor and battery (fig. 11.2). Initial profiles conducted with a time window of ~290 ns indicated a very strong signal return in the higher, dryer parts of the island, so the time window was opened to ~490 ns to take advantage of conditions that allowed profiling to depths of 7–10 m. Processing of the GPR profiles shown here is limited to minor band pass filtering and time gain adjustment. Most of the profile surfaces had little relief, negating the necessity for topographic corrections.

Velocity of the radar waves may be calculated from diffraction hyperbolae using the MALA Radar Explorer software program. A velocity range from 4 cm/ns to 13 cm/ns was determined by this method. A velocity of 5 cm/ns was used as an average as it gave reasonable agreement with the thickness of sand exposed at Yellow Banks

Bluff and limited data from vibracoring (Bishop et al., this volume, chap. 10). It is emphasized that the depth profile scale will shift markedly if the velocity is changed; consequently, GPR

profiles are often displayed with two-way travel time in nanoseconds on the vertical scale. Profile depth accuracy can be improved by subdividing the profile into layers of differing velocity and

TABLE 11.1  
Ground Penetrating Radar Profile Inventory

File-year	Road junctions → direction	Antenna/ time window
OMPF-06	Jct. 12 → Picnic Bluff	100MHz/shallow
OMPG-06	Jct. 13 → Magnolia Bluff	100 MHz/shallow
OMPH-06	Jct. 13 → Jct. 64	100 MHz/shallow
OMPI-06	Jct. 64 → end Engineers Road	100 MHz/shallow
OMPJ-06	Jct. 26 → Jct. 52	100 MHz/shallow
OMPK-06	Jct. 52 → Jct. 50	100 MHz/shallow
OMPO-07	North end Flag Pond on Jungle Road →Jct. 35	100 MHz/medium
OMPP-07	Jct. 35 → Jct. 32	100 MHz/medium
OMPQ-07	Jct. 32 → Jct. 31 → Jct. 57	100 MHz/medium
OMPR-07	Jct. 57 → Jct. 52 → end near State Pond	100 MHz/medium
OMPT-07	Jct. 13 → Jct. 12 → Jct. 10	100 MHz/medium
OMPU-07	Jct. 10 → Jct. 61 → Jct. 60	100 MHz/medium
OMPV-07	Jct. 60 → last Jct. on Engineers Road	100 MHz/medium
OMP2-07	Jct. 26 → Jct. 71 → Jct. 80	100 MHz/medium
OMP3-07	Jct. 80 → Jct. 68 → 78	100 MHz/medium
OMP4-07	Jct. 68 → Jct. 66 → Jct. 65	100 MHz/medium
OMP5-07	Seaside Dock → Jct. 18 → Jct 45 → Jct. 65 → Jct. dock on Walburg Creek	100 MHz/medium
OMP6-07	Magnolia Bluff → Jct. 13 → Jct. 64 → pasture on north side of barn	100 MHz/medium
OMP7-07	Jct. 57 → Jct. 72 → Jct. 87 → Jct. 83	100 MHz/medium
OMP1-08	Northeast end of Cracker Tom Hammock → Jct. 29 → Jct. 28 → Jct. 53 → Jct. 54 → Jct. 59 → Jct. 58 → Jct. 54 → Jct. 31 → Jct. 29	250 MHz/deep
OMP1-09	Jct. 62 → Jct. 60 → north loop → Jct. 10	100 MHz/medium
OMP3-09	Jct. 60 → Jct. 61 → Jct. 10	250 MHz/deep
OMP4-09	Windmill Jct. → Jct. 13 → Jct. 12 → Sand Pit Road Jct.	250 MHz/deep
OMP5-09	Jct.59 → Jct. 58	250 MHz/deep
OMP6-09	South Pasture 90° to Jct. 59-58	250 MHz/deep
OMP7-09	South Pasture 90° to Jct.59-58	250 MHz/deep
OMP9-09	Jct. 60 → Jct. 61 → Jct. 10	100 MHz/deep



Fig. 11.2. GPR reflection profiling system used on St. Catherines Island to obtain over 20 km of profiles along the island road network. This MALA GPR system includes a 100 MHz antenna with attached control box and odometer wheel towed by a John Deere Gator ATV. Operator (R.K. Vance) sits with monitor and battery pack in a shoulder-mounted harness linked to control box by serial cable and power line (photograph by Lisa Vance).

reprocessing it; however, this treatment is best suited to short profile segments.

Profiles may be treated by identification of radar surfaces and by grouping radar reflection elements into packages or associations and radar facies (Jol and Smith, 1991; Hugenholtz, Moorman, and Wolfe, 2007). The ground radar waves react to changes in subsurface physical properties that may or may not coincide with bedding surfaces or structures. Obtaining ground truth or hard geological data via surface exposures, trenching, augering, and coring is essential for accurate interpretation of the radar surfaces, facies, and elements. This chapter includes interpretation of radar elements and facies in terms of sedimentary bedforms and associations. These interpretations are constrained by geological setting, comparison with bedforms characteristic of similar geological settings, available ground truth, and comparison with published GPR profiles; however, it should be emphasized that these are *interpretations* of radar reflections and alternative interpretations may be viable.

#### HOLOCENE-PLEISTOCENE TERRAIN BOUNDARIES

The younger Holocene accretionary terrains, with characteristic ridge and swale topography

(see this volume, chap. 3: figs. 3.2 and 3.5) provide a frame of reference for recognition of subsurface beach ridge bedforms in older deposits (fig. 11.3). The GPR profiles provide a subsurface geophysical view of the contact between the younger Holocene accretionary terrains and the Pleistocene core of the island. Figure 11.4A is a spliced excerpt from the west end of profile OMPP-06 and the east end of profile OMPQ-06. This segment begins on the west side of a salt marsh 87 m east of Jct. 32 and extends west of Jct. 31. Notable features on the profile include the signal attenuation on the east end of the profile due to the saltwater wedge extending from the marsh. Saltwater saturation limits the GPR to depths of less than 3 m under most of the younger Holocene ridges. The initial profile segment trends southeast to northwest across the strike of the Holocene beach ridges. Heavy dashed lines on the profile are major radar surfaces. At the east end of the profile the uppermost radar surface separates an upper facies of eastward dipping subparallel planar radar reflections or elements from an older, steeper (Pleistocene?) facies characterized by more steeply dipping sigmoidal reflections. The upper facies (Holocene?) changes westward into subhorizontal flattened concave to

convex reflection elements that overlie southward dipping sigmoidal forms. The approximate dip direction of the reflections is obtained at Jct. 32 where the profile turns sharply northeast—note change in apparent dip of the upper and lower facies elements.

The upper facies elements appear discordant to those of the underlying facies. The upper facies also dips southeastward (see east side of Jct. 32 on fig. 11.4A) and thickens toward the marsh, features compatible with sediment filling the marsh or swale. The upper facies thins westward to <1 m near Jct. 31. The upper facies elements overlie and locally truncate middle facies elements. The sigmoidal radar elements of the underlying facies suggest a prograding (regressive) beach system with some periods of transgression marked by lower angle elements truncating and overlying older elements (Johnston, Thompson, and Baedke, 2007). The upper facies may represent overwash deposits and dune ridges and swales that have been flattened over time. The 100 MHz profiles have a 5× exaggeration that compresses features; consequently, reflections or interpreted bedforms with an apparent 30° dip are actually ~6°. The reflections of the middle beach facies exhibit tangential contacts with reflections of an underlying facies composed of horizontal, parallel to subparallel elements including one or two strong reflectors capping weak reflections or bedforms. The weak reflections are interpreted as mud and sandy mud with possible saltwater saturation at depth. These parallel bedforms or reflections constitute an additional lower radar facies. Two strong reflecting surfaces (referred to as the basal reflectors) appear to be a fairly persistent radar surface that may serve as a stratigraphic marker. Road Jct. 32 is probably very close to the boundary between the island core and the younger Holocene accretionary terrains. The base of the



Fig. 11.3 (right). True-color image (2005) of St. Catherines Island showing Pleistocene core and Holocene accretional terrains (aerial image source USDA, NAIP 2005). Locations A–Z are profile segment sites illustrated in figs. 11.4–11.16.

upper facies appears to truncate the middle facies between Jct. 32 and the marsh. The profiles also suggest that some of the younger (eolian portion) sediments overlap and cover at least part of the island core; however, there is no way to verify age equivalence with GPR alone.

The reflector marked with dots in the upper 1.5 m of the profile may be humate concentrations or another pedogenic feature such as B horizon development with iron oxide concentrations. The contact between the white eolian "sugar sand," which is the C horizon of the uppermost soil profile of Vento and Stahlman (chap. 4, this volume) and the hard humic A horizon of an underlying paleosol is a another possibility; Vento and Stahlman note a lack of lateral continuity in specific soil horizons. This shallow reflector is best developed in higher standing portions of the island and may be related to former water tables or soil horizon development. This upper reflector will be referred to here as the humate reflector or pedogenic reflector. Similar looking reflections are identified as water tables in some GPR studies; however, the St. Catherines reflectors are too shallow in areas where the water table was determined and vibracore and auger work display humate or changes in iron oxide concentrations that appear to more closely match this feature. In a few profiles this reflector appears to be superimposed on possible bedforms, favoring an origin related to shallow water table redox gradients or some pedogenic process. This GPR reflector is observed in both the Pleistocene core of the island and some of the adjacent late to middle Holocene beach ridges that are accreted against the Pleistocene core. This observation is in agreement with Vento and Stahlman's observations on more oxidation and humate development in C horizons of the late-middle Holocene terrain. In one GPR profile in the island core, the humate or pedogenic reflector is actually offset by a minor fault indicating brittle behavior consistent with iron oxide or humate cemented sands. The apparent overlap (fig. 11.4B) of the younger upper facies succession onto the older island core beach facies is compatible with investigations and interpretations (Vento and Stahlman, chap. 4, this volume) of the northern end of the island where Holocene paleosols and/or eolian deposits occupy the upper 2–3 m of Yellow Banks Bluff.

A transect across Cracker Tom Causeway onto the island core provides another look at the boundary between younger accretionary terrain

and the island core. This profile (fig. 11.4B) was conducted with a 250 MHz antenna and the scale exaggeration of  $\sim 5\times$  compresses the cross section and steepens apparent dips. The 250 MHz antenna can resolve thinner bedforms, but also produces more noise and clutter from near-surface diffraction hyperbolae generated by roots and shells. The transect segment shown begins on the causeway over the last major salt marsh east of Jct. 29. The saltwater attenuates the radar signal wedge from 1230 to 1265 m on the profile. Marsh is also present on the south side of the road at 1322–1335 m, but the water appears to be brackish to fresh and the signal is not completely attenuated. The 1235–1320 m section runs north to south subparallel to the ridge, then bends sharply northwest across ridge strike from 1325 to 1351 m (Jct. 29). The steeper portion of the bedforms near Jct. 29 dip  $\sim 6^\circ$  (corrected) east to southeast. The change to subhorizontal bed orientation at Jct. 29 coincides with a profile turn to the north subparallel to ridge strike. An approximate base of the Holocene is suggested (red on fig. 11.4B) on the marsh side of the profile using the Cracker Tom vibracore data (Bishop et al., 2009b; this volume, chap. 10) and apparent truncation of strata as a guide. The boundary between the younger Holocene-dominated terrain and the older island core is probably at 1347 m on the profile. At this location near Jct. 29, there are marked changes in reflection intensity and attitude, and the pedogenic reflector (dotted on fig. 11.4B) is well developed on the island core side (contrast with Cracker Tom Hammock in fig. 11.5B, lower). Part of the dramatic change in reflection angle and appearance near Jct. 29 is due to the change in profile strike from ridge-perpendicular to ridge-parallel; however, the collective change in radar reflection and intensity favors this location as the boundary and agrees well with surface topographic features. If Holocene dune ridges override the Pleistocene core here, as suggested in the southeastern profiles and the Yellow Banks soil chronology of Vento and Stahlman (chap. 4, this volume), the Pleistocene and Holocene beach and ridges were nearly parallel as the strike parallel profile section (fig. 11.4B, lower: 1350–1405 m) has consistent subhorizontal, subparallel reflections. Figure 11.5A (upper) shows a northeast-southwest profile segment C–C' between jcts. 53 and 54. This profile shows a change in radar facies at approximately 2.5 m depth between an upper facies characterized by wavy subparallel reflections or

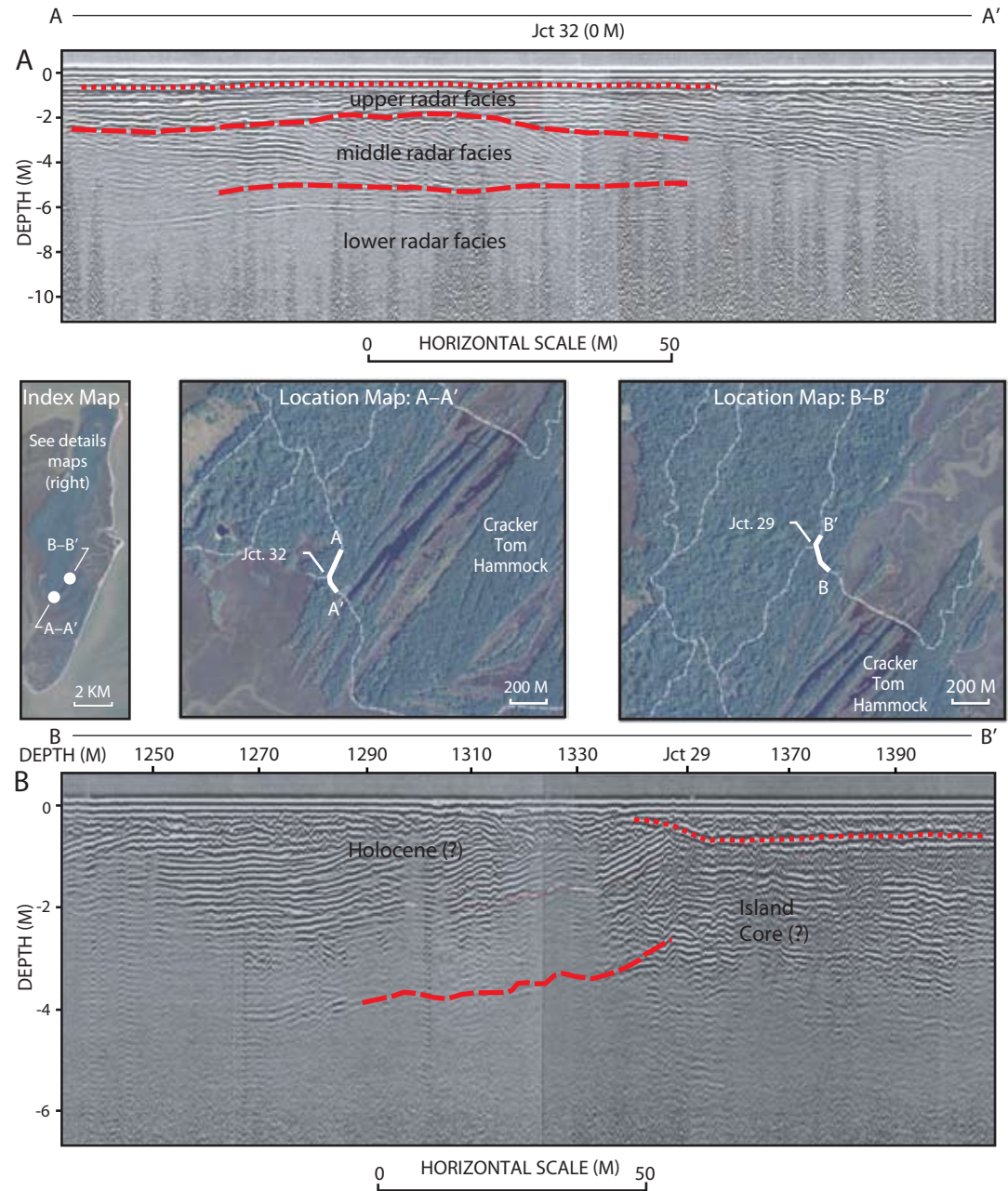


Fig. 11.4. **A**, Profile A–A': composite (end of OMPP-06, beginning of OMPQ-06) NE-E 100 MHz GPR profile. Road Jct. 32 is at 0 m. Location map above shows profile location and orientation. The upper highlight (dotted line) marks a pedogenic or humate cement reflector. The dashed highlights mark radar surfaces separating upper, middle, and lower radar facies. Reflectors on east side dip toward a salt marsh. **B**, Profile B–B': segment from OMP1-08, 250 MHz profile from west side of causeway (~90° to ridges) over Cracker Tom Marsh to Jct. 29 (1350 m) turning subparallel to beach ridge strike on the island core. Highlight is suggested contact between Holocene accretionary terrain and island core (aerial image source USDA, NAIP 2005).

bedforms and a complex underlying facies bearing multiple reflection elements. The lower facies includes some of the sigmoidal clinoform radar elements that characterize prograding (regressive) beach systems (Johnston, Thompson, and Baedke, 2007). The upper wavy facies is overlain by horizontal reflectors in the upper 2 m, perhaps representing pedogenic structure superimposed on eolian deposits.

Cracker Tom Hammock contains a relatively thick (>3 m) sequence of sand (fig. 11.5B, lower: 572–695 m) and satellite images reveal a high-standing landscape more mature in appearance than most of the Holocene accretionary terrains. Chowns et al. (2008) noted the apparent maturity of Cracker Tom Hammock in the context of surrounding accretionary terrains. Vibracoring on the shoulders of the subdued ridges in the marsh on the north side of Cracker Tom Causeway, between Cracker Tom Hammock and the island core, penetrated a disconformity (Booth, Rich, and Bishop, 1999; Linsley, Bishop, and Rollins, 2008). Dating of organic components above and below the disconformity (Rich and Booth, this volume, chap. 6; Bishop et al., this volume, chap. 10) confirms a Pleistocene substrate for the Holocene ridges in the marsh. The ridge pattern on Cracker Tom seems nearly parallel to that visible along the core margin across the salt marsh, while the lower standing ridges in the intervening marsh are discordant to the ridges of both Cracker Tom and the island core margin. These features encourage speculation in the search for a viable explanation. If there is a significant Holocene eolian cover on the eastern island core (chap. 4, this volume), could the highest ridges on Cracker Tom and the ridges on the margins of the island core be correlative younger Holocene dune deposits? Are these deposits age equivalent to the succession that appears to override the core (see fig. 11.4A) along the southeastern end of the island?

What accounts for the lower elevation of the ridges between Cracker Tom and the island core? The interior margin of Cracker Tom Hammock is particularly sharp. Did the former course of the Ogeechee (Chowns et al., 2008) or another stream carve a channel between Cracker Tom and the island core, removing the upper layer of Holocene dune and beach deposits to expose the top of the underlying ridges? Could the high standing Cracker Tom Hammock and the next high standing accretionary ridge package to the

east be the southern tail of Guale Island (chap. 3, figs. 3.2 and 3.5) isolated by shifting channels or tidal creeks? Another possible explanation for the low elevation of the ridges in the marsh between Cracker Tom Hammock and the core is deposition of the beach ridge system during a period of lower sea level and/or diminished sediment supply (see Bishop et al., this volume, chap. 10). This explanation requires that the similarities in orientation and elevation of the ridges of Cracker Tom Hammock and the core are either a coincidence or represent the return to nearly identical conditions of sea level, longshore current, and sediment supply. The adequate resolution of these questions will require more ground truth (vibracore, trenching) and sedimentological evaluation coupled with dating and elevation control. The thick sequence of strata underlying Cracker Tom Hammock and the relative maturity and stability suggest a rich area of future island exploration for both archaeologists and geologists.

An additional means of producing a topographically subdued beach ridge terrain between a younger, higher terrain (like Cracker Tom) and the island core is offered indirectly by Thomas (chap. 1, this volume) in his discussion of hurricanes and paleotempestology. Just as the barrier islands provide a “mega-breakwater” between the sea and mainland, the young island-fringing accretionary terrains are the first barrier between the island core and sea. If the island was subjected to major hurricane strikes after accretion of the low ridges observed today in Cracker Tom marsh, but prior to accretion of ridges in Cracker Tom Hammock, the wave battering and storm surge from the hurricanes should have flattened the younger, least stabilized beach ridges as well as dunes on the margin of the island core (Bishop and Meyer, this volume, chap. 14; fig. 14.3). A Category 5 hurricane may generate storm surges exceeding 5 m, flooding lower elevations of the island core and beveling and breaching the fringing beach ridges. Perhaps the low-standing ridge systems situated between higher ones represent periods of excessive hurricane activity between quiescent periods. Another low ridge system is located between Cracker Tom Hammock and a higher ridge to the east. Does this package also reflect a period of intense hurricane activity?

Differences in accretionary terrain development should be influenced in large part by a combination of sea level change and inlet shifting as well as changes in sand transport and supply

(Linsley, Bishop, and Rollins, 2008; Bishop et al., 2009a; Bishop et al., chap. 3; Bishop et al., chap. 13; Bishop and Meyer, chap. 14: fig. 14.13; and Rollins and Thomas, this volume, chap. 16). These forces can certainly be combined with some of the possibilities described above to achieve the complex pattern of accretionary terrains observed today along the southeastern flank of St. Catherines Island. Barrier islands are extremely dynamic environments and the rapid rate of recent erosion and accretion on St. Catherines Island is well documented (Bishop and Meyer, this volume, chap. 14: figs. 14.10 and 14.13; Potter, this volume, chap. 7). The interpretation of island features relative to a changing sea level is also complicated by evidence for faults and tectonic activity affecting the strata of the southeastern coastal plain (Bartholomew et al., 2007; Vento and Stahlman, this volume, chap. 4), producing an apparent sea level change (local tectonic uplift or subsidence). The presence of minor faults and joints on St. Catherines Island indicates that tectonic influence should be considered.

#### SOUTH PASTURE DISCONFORMITY

The 250 MHz profile (OMP1-08) revealed a striking feature along the southwest to northeast road bordering the east side of South Pasture between Jct. 59 and 58. The profile exhibits an apparent discontinuity 2–5 m below the present surface, extending from Jct. 59 northward, climbing over a 2 m buried scarp onto sandy strata providing good radar reflections, ~570 m north of Jct. 59. The surface is very irregular and displays over 3 m of relief in some areas. Reflection intensity between the soil and discontinuity is very poor. Additional exploration includes another GPR profile (fig. 11.4A, upper profile) between Jct. 59 and 58 to verify results plus two short right-angle profiles that intersect the main profile line in the sand-dominated section (fig. 11.6B, lower profile) and over the discontinuity. The additional GPR profiles indicate that the discontinuity does extend to the east and climbs northward to ~1–1.5 m depth. The 1–1.5 m depth is approximately the same as the base of the upper facies shown in figure 11.4. Two vibracores were obtained in February 2009 with the assistance of an undergraduate research team (Shannon Ferguson, Jesse DeLaMater, Nick Wieclaw) from Georgia Southern University. One vibracore sited over the discontinuity at the 522 m mark on profile OMP5-09 refused penetration at ~3 m depth

(~0.4 m added for compaction) and bottomed out in sticky blue-gray mud. Core logging revealed ~2.6 m of sand-dominated upper section underlain by ~10 cm of very dense, blue-gray clay with iron oxide mottling. The lowest 2–3 cm of clay from the base of the core were mixed with fine sand. The other core site over the sand-dominated section at 624 m on profile OMP5-09 penetrated ~2.4 m and logging revealed nothing but sand. A soil auger hole determined the water table at ~2.7 m on the day the profile was conducted. This water table depth indicates that the dense, sticky clay is perching the water table over the discontinuity at South Pasture. Water saturation of sand as a perched aquifer above the clay explains the very poor signal return above the discontinuity.

What are the origin and significance of this erosional feature? Was the erosional surface a localized product of shifting tidal creek channels along the island's southern margin or a major change in inlet configuration? Is the South Pasture discontinuity correlative with the upper discontinuity (#2 in Bishop et al., this volume, chap. 10: figs. 10.6 and 10.8) identified in the marsh cores from the St. Catherines Shell Ring vibracore transect? Is the buried scarp (see fig. 11.6A, upper: 545–590 m) an older Holocene equivalent to Wamasseo Scarp or Zapala Sound margin (see fig. 3.2; Bishop et al., this volume, chap. 3)? At this time the discovery raises more questions than answers; however, the clay may provide a source of organic material to resolve some of these questions through palynological study and possibly  $^{14}\text{C}$  dating.

#### GPR TRANSECTS ACROSS THE ISLAND CORE

The GPR profiles conducted across the northeast-southwest longitudinal axis of the island reveal one or two persistent basal reflectors (fig. 11.7A, B) that can be traced within the core of the island and beneath at least part of the adjacent Holocene accretionary terrains. These reflectors have sharp upper surfaces with underlying horizontal parallel radar reflections or bedforms. The signal strength fades quickly below these markers, suggesting that the reflecting surfaces represent the interface between sand-dominated and clay-dominated strata. These surfaces may be correlative with the Pleistocene mud and marsh sediments identified in vibracore transects at Cracker Tom Causeway and the St. Catherines Shell Ring (Bishop et al., this volume, chap. 10: figs. 10.6 and 10.8). They may

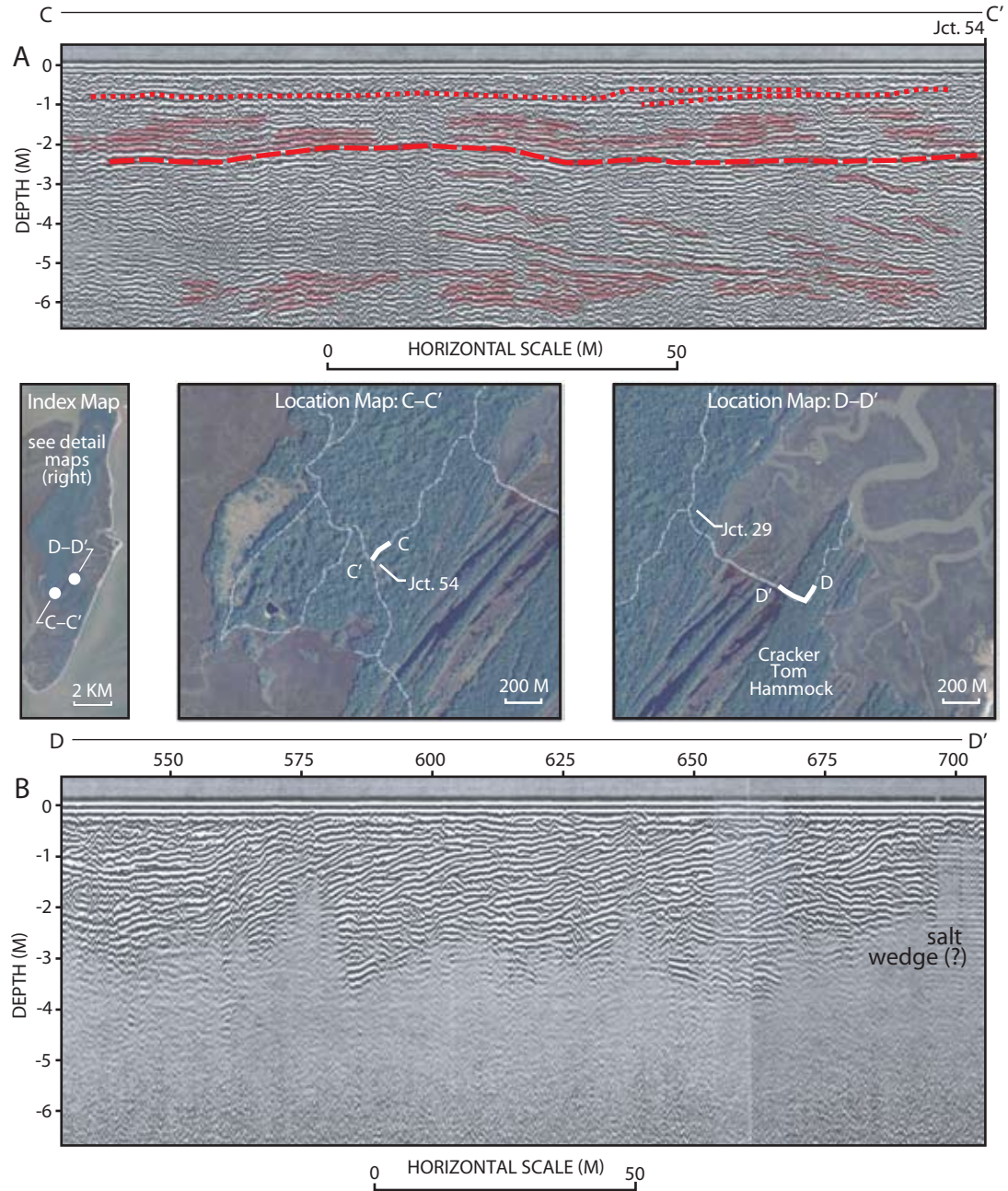


Fig. 11.5. **A**, Profile C-C': NE to SW 250 MHz profile segment from OMP1-08 between jcts. 53 and 54. Upper pedogenic or humate reflector is marked with dotted highlights; the heavy dashed highlight marks radar surface separating middle horizon facies bearing sigmoidal radar elements from upper facies of wavy radar elements or bedforms. **B**, Profile D-D': segment of 250 MHz profile OMP1-08 on Cracker Tom Hammock showing reflection change at 565 m, from a ridge parallel profile to ridge perpendicular profile. Note well-developed sigmoidal clinoform radar elements (565–700 m). A saltwater wedge attenuates radar signal sharply on the west end of the profile (aerial image source USDA, NAIP 2005).

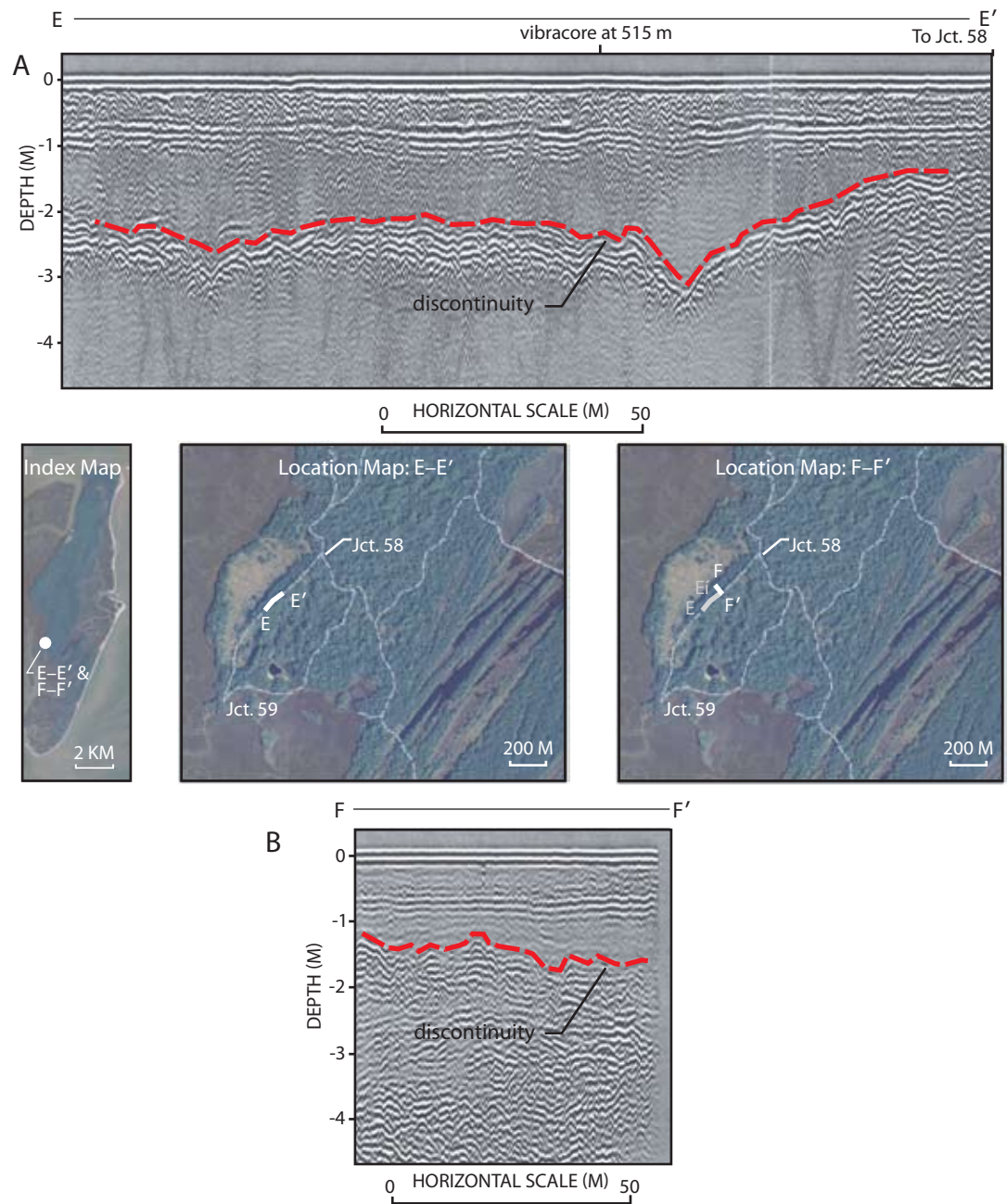


Fig. 11.6. **A**, Profile E-E': SW-NE 250 MHz profile (OMP5-09 segment between jcts. 59 and 58 at South Pasture. Apparent disconformity with 1–1.5 m of relief “climbs” over a buried scarp onto a sand-dominated succession at the NE end of profile. A 3 m vibracore sited at ~515 m along the profile terminated in dense blue-gray clay. Poor signal in sand above clay is probably due to water saturation. **B**, Profile F-F': a short W-E 250 MHz profile (OMP7-09) at right angle to that shown in fig. 11.6A confirms irregular surface of disconformity on sand-dominated succession at north end of profile OMP5-09 (aerial image source USDA, NAIP 2005).

also represent hydrologic boundaries between freshwater-saturated strata and saltwater-saturated strata. Locally these reflectors are incised by scours or small channels indicating local disconformity and a higher energy environment. The bedforms or radar elements (probably sand dominated) above the basal mud or muddy sand exhibit tangential bedding relationships with the lower facies reflectors. If the elevation of the basal reflectors is relatively uniform, they provide a good reference marker to gauge the thickness of the overlying sand-dominated strata. The eastern side of the island has ~6–8 m of sandy strata above the basal reflectors that thin westward to a thickness of 2–5 m along the western margin of the island. GPR penetration and data are more limited along the Central Depression or longitudinal axis of the island. This may be due to higher water tables, more clay-rich sediments near the surface, and/or a combination of these features. There are also intermittent zones of poor GPR signal return in the sand-dominated strata east of the Central Depression. Some of these zones may represent buried interdune marshes, swale ponds, or even freshwater ponds rich in clay and organic components.

Figure 11.7A (upper profile) is a northeast-southwest profile segment G–G' (646–732 m) between Jct. 52 and 71 showing lower planar parallel layers (probable muddy sediments) with strong reflecting horizons at ~5.5 m and 8.5 m depth. The lower planar parallel facies is overlain by a middle facies of radar elements characterized by lower beds dipping gently eastward, forming tangential contacts with the 5.6 m reflector. Radar elements suggesting trough cross-bedded forms are also observed. The eastward-dipping bedforms of the middle facies are overlain by westward-dipping beds suggestive of dune and washover deposits and a 1.5–2 m thick sequence of horizontal subparallel layers. The horizontal layers may represent Holocene eolian deposits and various pedogenic horizons. The State Road Pond core (Bishop et al., this volume, chap. 10; fig. 10.5) provides the nearest ground truth and includes a laminated sand at 2.5 m depth containing heavy minerals. This laminated heavy mineral-bearing sand overlies 15 cm of muddy sand. This could be an overwash fan deposit over a muddy swale or marsh. The depth is compatible with that of the proposed overwash horizon described in the GPR profile above.

Part of an east to west GPR profile (fig.

11.7B, lower profile) from Seaside Dock to the dock at Walburg Creek also shows three radar facies that may be interpreted as lower marsh to offshore clay-rich facies, middle shore or beach facies, upper washover and eolian facies with superimposed pedogenic features, similar to those described above. An additional interesting feature is shown between 650 and 655 m, just west of Jct. 17. An apparent normal fault with ~0.2 m displacement is observed cutting the upper pedogenic reflector, dropping strata on the west side of the fault. The sharp break in the upper pedogenic reflector favors a relatively hard, brittle character (humate cement?) for this feature. The presence of high-angle diffractions shown in fig. 11.7B are common and may be products of constructive interference related to diffraction hyperbolae; however, the spatial relationship with a fault and specific occurrences that cannot be traced to hyperbolic reflections favor mineralized joints in this profile segment. An iron oxide filled joint was observed in core 1 collected by Vance and students as part of a research project (Ferguson et al., 2009) near Gator Pond. Joints have also been recognized at Yellow Banks Bluff (Bishop and Rich, personal commun.).

The middle and upper radar facies thin dramatically to less than 3 m toward the west side of the island. Figure 11.8A (upper profile) shows well-developed cross beds produced by westward flowing currents. The underlying sediments are either clay rich and/or water saturated.

On portions of the King New Ground Road profile west of Jct. 45, the GPR signal was limited to less than 5 m depth. This is probably a result of high water table (estimated at ~2.4 m depth from a drainage ditch observation during GPR survey) and/or a greater proportion of clay-rich sediment near the surface. This region of limited signal return and relatively shallow water table approximately coincides with the distribution of Mandarin-Rutledge soils and former freshwater wetlands (Hayes and Thomas, 2008). Similar poor signal return is observed on GPR profile OMP2-07 on Savannah Road between jcts. 71 and 80, again approximately coincident with the central swale (Thomas, 2008) or Central Depression (Bishop et al., 2007; this volume, chap. 3; fig. 3.2) and Mandarin-Rutledge soil distribution.

An east to west GPR profile (fig. 11.8B, lower profile) from Magnolia Bluff to Jct. 13 to the west side of the island via North Beach Road also

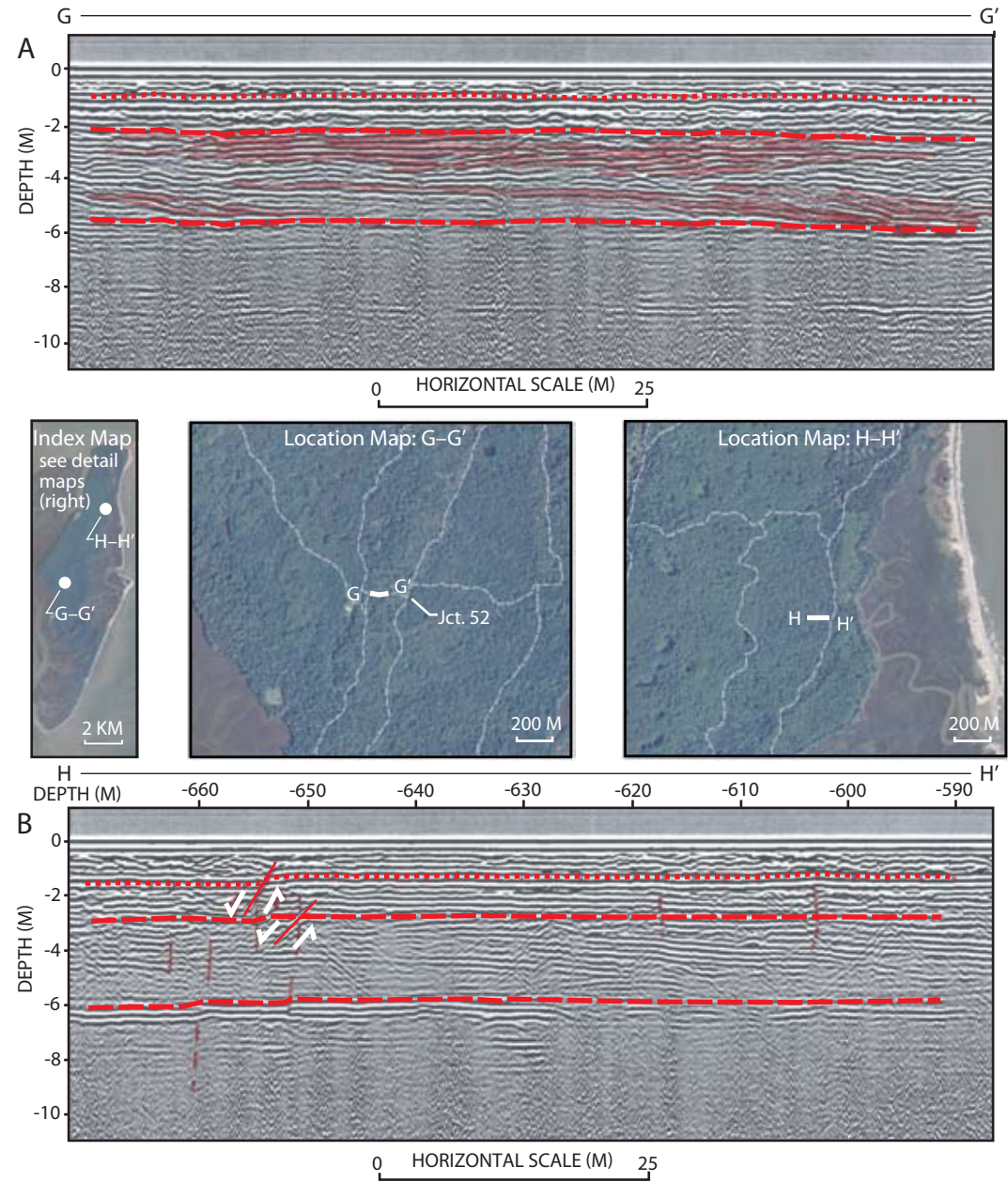


Fig. 11.7. **A**, Profile G-G': SW-NE segment of 100 MHz profile OMP2-07 between jcts. 52 and 71, with heavy dashed highlights separating upper, middle, and lower radar facies. Profile illustrates the sharp, persistent basal reflectors of lower facies observed under much of the island and tangential contact between middle facies reflectors and lower facies reflectors. Dotted highlight marks the pedogenic/humate reflector within an upper facies dominated by horizontal to subhorizontal reflections. **B**, Profile H-H': W-E segment of 100 MHz profile OMP5-07. Note normal faults with ~0.2 m collective displacement cutting the humate reflector (dotted highlights). Arrows indicate relative motion. Dashed highlights separate lower, middle, and upper radar facies (aerial image source USDA, NAIP 2005).

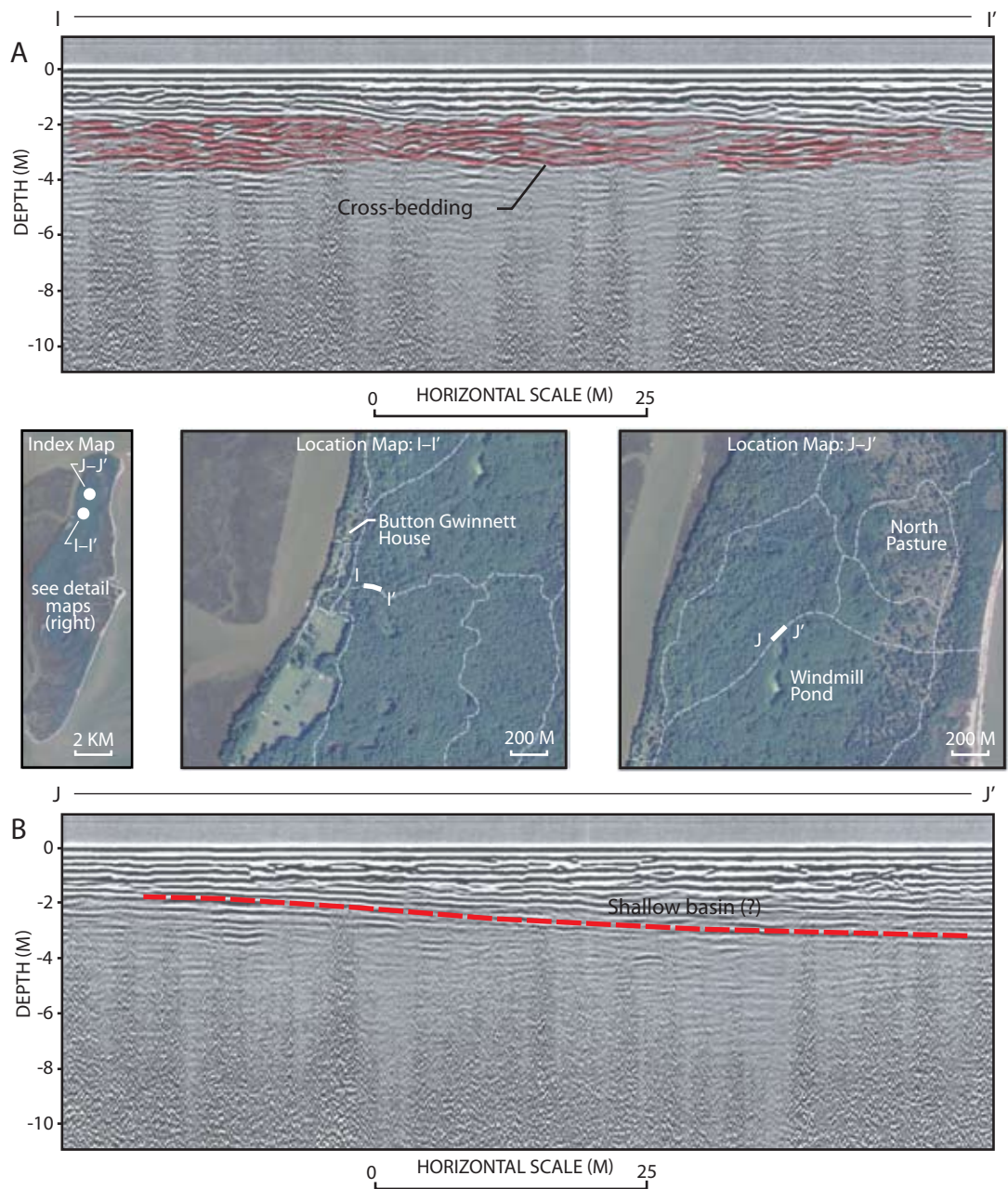


Fig. 11.8. **A**, Profile I-I': NW-SE segment of 100 MHz profile OMP5-07 from west flank of Central Depression. Note well-developed cross beds (highlighted) limited radar penetration. **B**, Profile J-J': SW-NE segment of 100 MHz profile OMP6-07 along North Beach Road, in the Central Depression, suggests western margin of a shallow basin. Poor signal return suggests wet sediments and/or composition rich in clay and organic components (aerial image source USDA, NAIP 2005).

exhibits weak signal return in areas that coincide with the former wetlands of the Central Depression. The region is marked today by ponds, marshes (natural and modified—Royce Hayes, 2009, personal commun.), and hydric soils and vegetation such as river cane (*Arundinaria gigantea*) that favor a shallow water table. A substantial marsh or lake probably existed in the vicinity of Windmill Pond as 100 MHz radar profiles show strata dipping gently inward to form a shallow basin cross section over a 425 m profile segment. The thickness between the lower part of the radar-visible basin and overlying horizontal reflectors suggests up to 2.5 m of sediment accumulated locally in these freshwater wetlands. The sediment accumulations and wet nature of the ground make these excellent sites for future vibracore exploration. The 250 MHz profile (fig. 11.9A, upper) shows a higher resolution view of the western margin of the basin with numerous offset reflections that suggest either fault control of basin formation or fault development in response to the subsidence that formed the basin.

The higher, drier ground east of the Central Depression yields excellent radar signal return for depths of ~7–8 m with the 100 MHz antenna revealing the persistent basal reflectors associated with the lower horizontal planar facies (fig. 11.9B, lower). The major radar surfaces bracket a middle facies of strata inclined toward the east, with the lowest beds tangential to the basal facies beds. The upper facies is dominated by subhorizontal planar reflectors. Identification of true dip direction requires a right-angle view, and figure 11.10A, upper, from a south to north profile between Jct. 13 and Jct. 10, provides this perspective. Note that nearly all beds appear parallel in this view, indicating a north-south strike for the beds of the middle facies.

Figure 11.10B (lower) illustrates the sharp contrast between the lower and middle facies and the vertical and lateral changes in the character of bedforms in the middle facies. Note the eastward dip of the lower strata within the middle horizon or facies versus the westward inclination of overlying cross beds or foresets. Figure 11.11A (upper) is the adjacent profile segment to the west. The GPR signal is limited to ~5 m depth suggesting mud, organic sediments, and/or high water table. Are the west-dipping reflector sands overriding marsh deposits or is the water table simply higher in this location?

The basal reflectors of the lower facies cannot

be traced continuously across the Central Depression; however, the collective profile segments that do show this marker indicate thinning of the overlying sand toward the west. Figure 11.11B, lower, is a segment of profile OMP6-07 located approximately 80 m east of Jct. 64. The profile exhibits an undulating basal reflector with a middle facies that appears to thin westward. This profile terminated in the pasture on the north side of the barn west of Jct. 64. At that point a strong basal reflector was observed at ~3 m below the surface and overlying strata appear horizontal, requiring either erosional thinning or markedly reduced deposition of overlying sands. Determining whether the westward thinning is a product of erosion or reduced deposition of sand is important to both archaeological and geological exploration of the island. Interpretation of missing strata also assumes that the basal reflector on the east and west side of the island is essentially the same unit. The validity of this assumption requires further testing and the proposed (Bishop et al., chap. 3, fig. 3.3) evolution of the island demands it. The surface of the basal reflector undulates to the west and east of Jct. 64, and features that can be interpreted as faults (fig. 11.12A, upper) are present at 1980 m on the profile.

Profile OMPU-06 strikes east to west in a transect from Jct. 10 to Jct. 61, then southeast to northwest from Jct. 61 to Jct. 60. Profile segments (fig. 11.12B, lower: 31–295 m) near Jct. 10 are complex with a thick sequence of sandy sediment that contains three to four distinct radar surfaces. The basal reflector that appears to continue westward is the radar surface at ~8 m depth. It appears to have sand beneath it here because the signal penetrates farther below the surface. The 31–119 m segment shows the upper pedogenic reflector at 0.8–1 m overlying largely subhorizontal strata with local cross-bedding and trough features. The surface between 3.2 and 4 m and appears to be disconformable (at least locally; see scour at 62 m) and overlies a rippled or undulating surface that is best developed along profile segment from 65 to 100 m. The poor radar signal below the rippled surface suggests high clay and/or organic sediments or high water content. This surface may be the top of the Pleistocene if the interpretations and dates of Vento and Stahlman (chap. 4, this volume) are correct. This intensively burrowed surface exposed in the lower 1.5 m of Yellow Banks Bluff has been studied in detail by Martin and

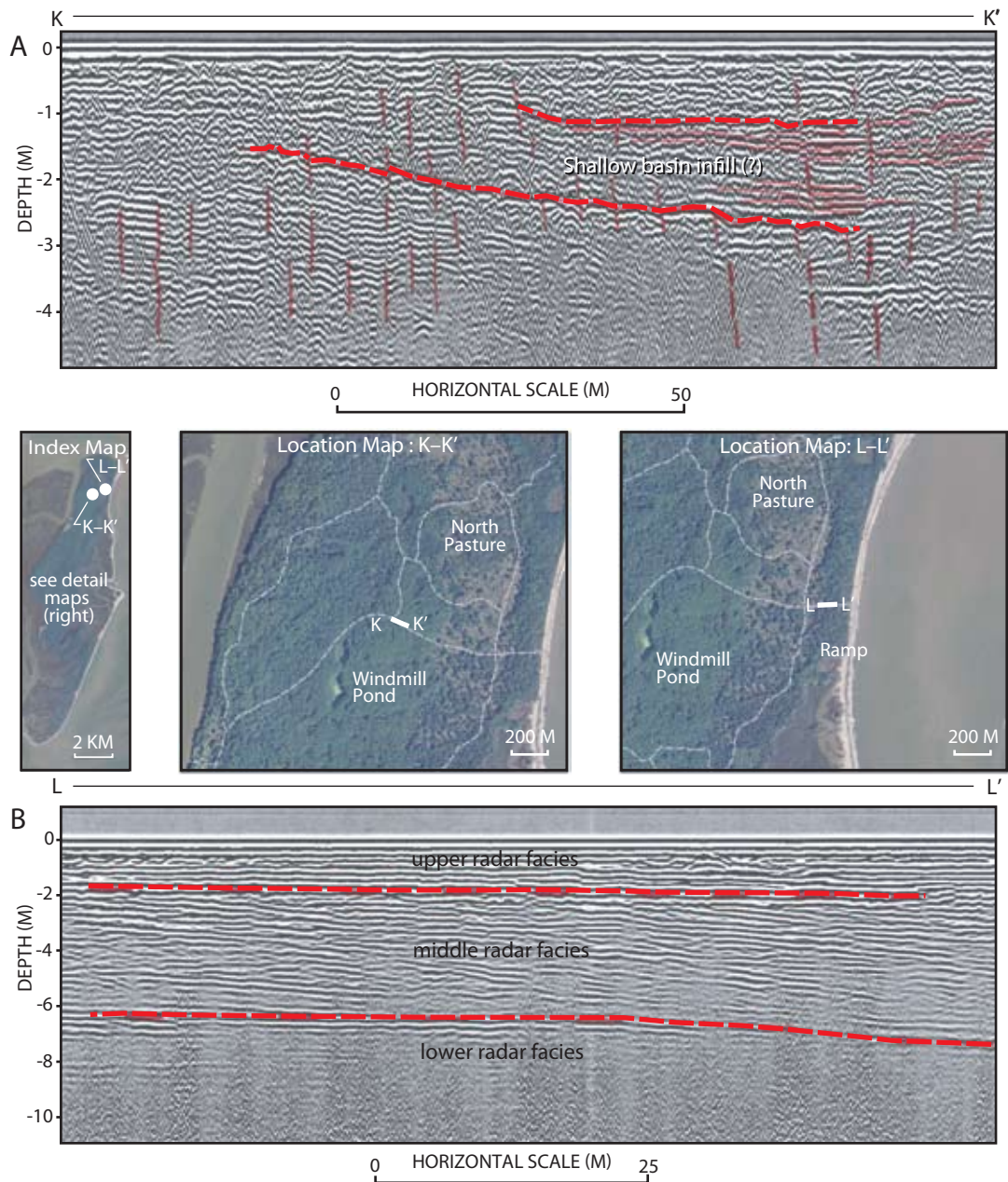


Fig. 11.9. **A**, Profile K-K': W-E segment from 250 MHz profile OMP4-09 east of the profile J-J' (fig. 11.8) in the Central Depression. Highlights on basin bottom and numerous offsets suggesting small faults. Horizontal reflections suggest infilling of the basin and a good site for vibracoring. **B**, Profile L-L': W-E segment from 100 MHz profile OMP6-07, east of the Central Depression near Jct. 13, revealing horizontal planar bedforms of lower radar facies, a middle horizon radar facies of bedforms (radar elements) inclined and tangential to the lower horizon, and an upper radar facies of horizontal to subhorizontal elements (aerial image source USDA, NAIP 2005).

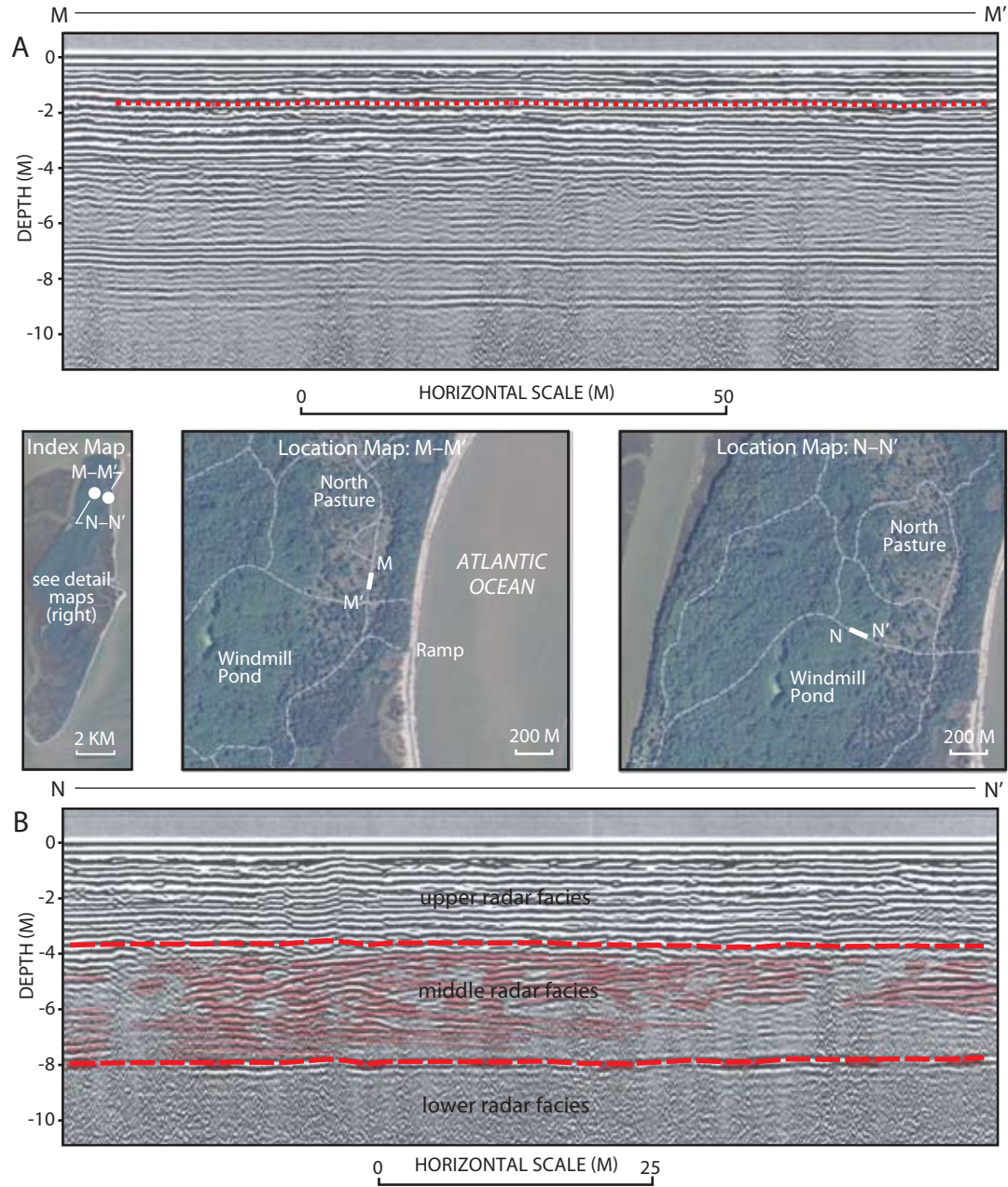


Fig. 11.10. **A**, Profile M–M': N–S segment of 100 MHz profile OMPT-07 between Jct. 13 and Jct. 10 indicates north-south strike for strata of middle horizon or facies. Compare to E–W transect in profile L–L' (fig. 11.9). **B**, Profile N–N': W–E segment from 100 MHz profile OMP6-07 showing lateral changes in attitude of middle facies radar elements or bedforms (highlighted). Basal reflector marking top of lower facies is at lower dashed line. This segment joins Profile O–O' (fig. 11.11) along the eastern flank of the Central Depression (aerial image source USDA, NAIP 2005).

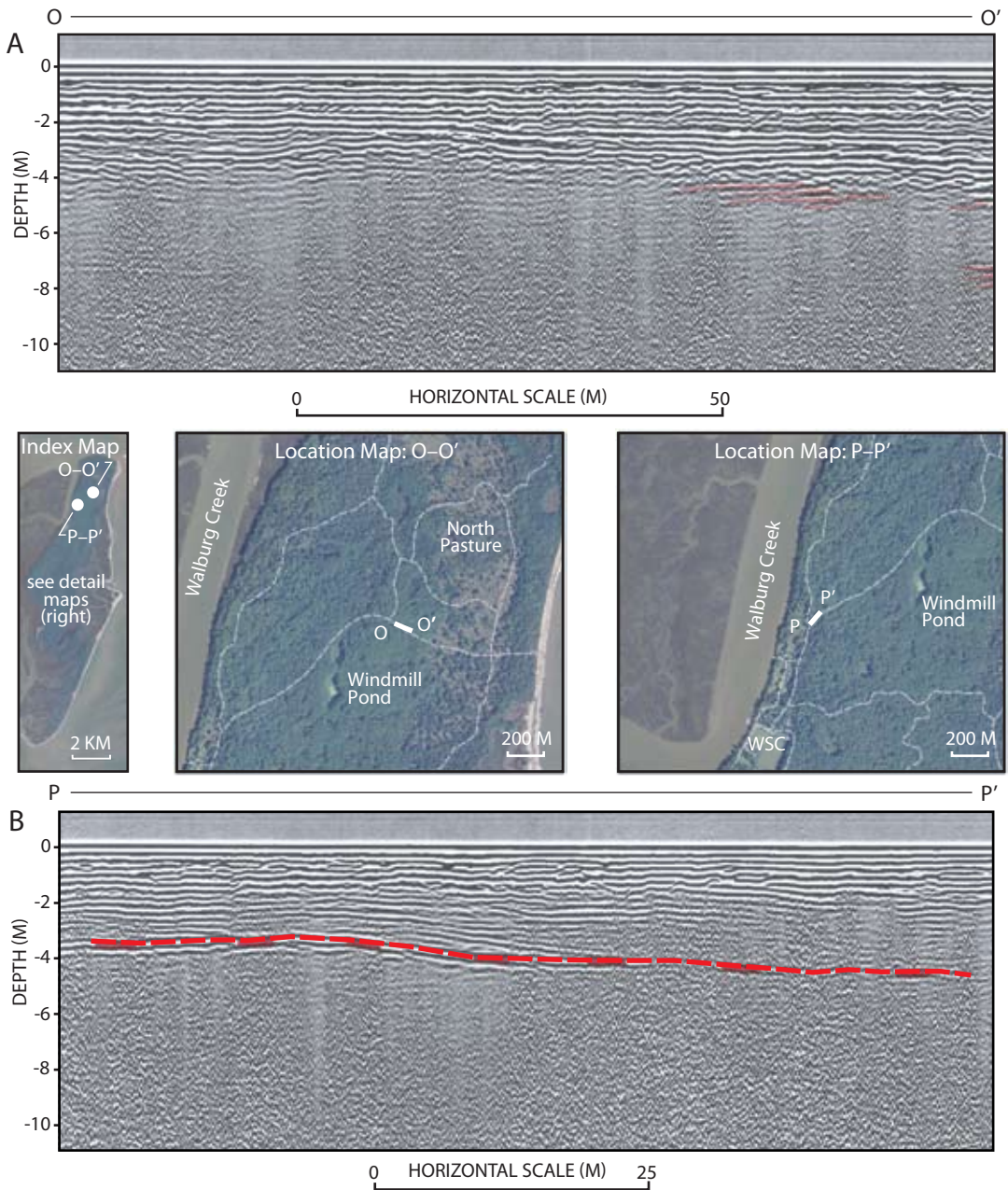


Fig. 11.11. **A**, Profile O-O': Adjacent segment from same W-E profile as Profile N-N' (fig. 11.10) along the eastern flank of the Central Depression. Note the limited depth of GPR signal penetration and return. These zones may be sites of former marshes or ponds with poor signal return due to more clay, organic components, and/or water. **B**, Profile P-P': SW-NE segment from 100 MHz profile OMP6-07 showing undulating surface of basal reflector (highlights) with much thinner overlying sands in contrast with the eastern side of island (aerial image source USDA, NAIP 2005).

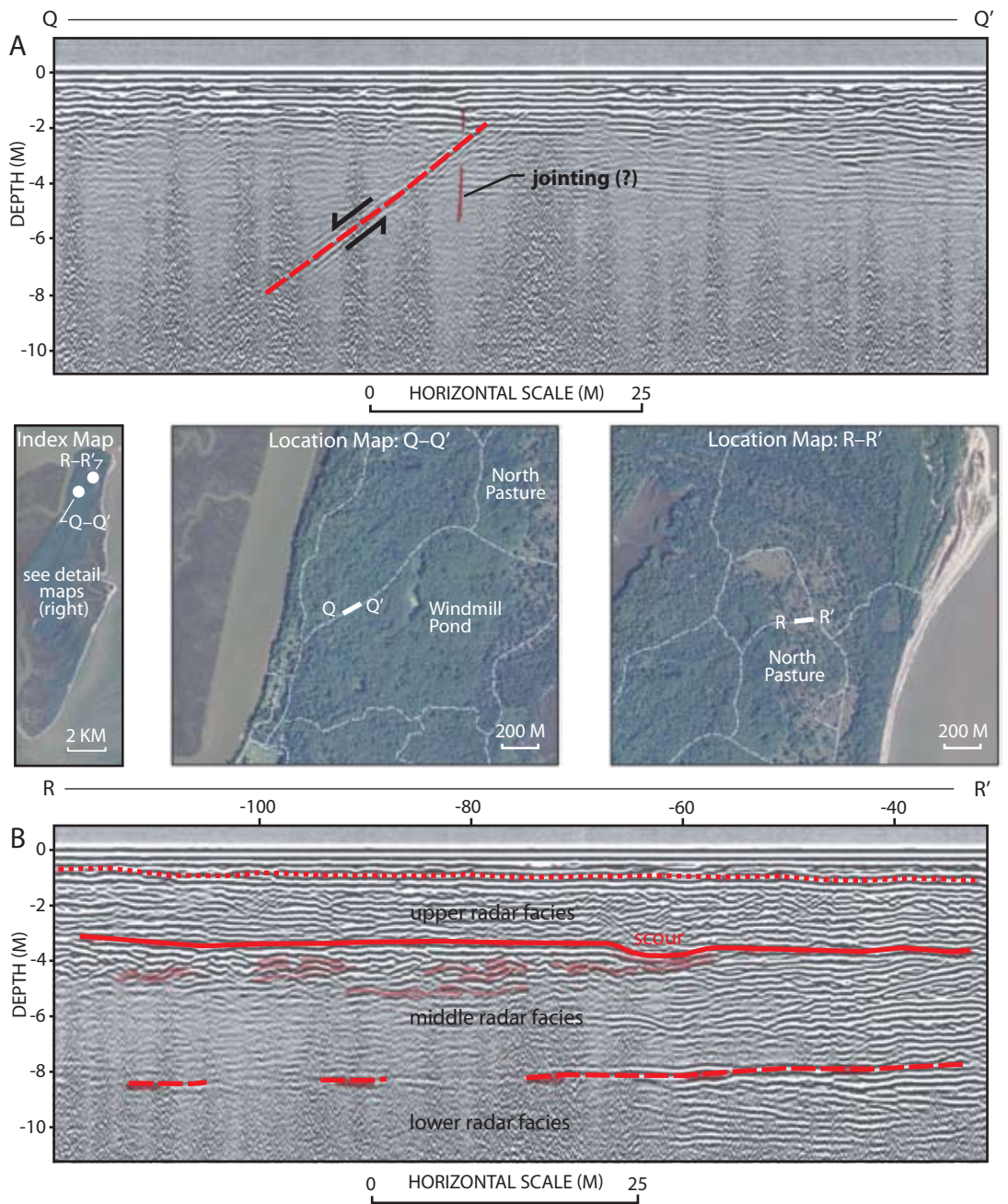


Fig. 11.12. **A**, Profile Q-Q': SW-NE segment from 100 MHz profile OMP6-07 showing thin sands and steeply dipping reflections or diffractions suggesting a small fault and/or joints. Poor signal return suggests a higher water table or more clay and organic components. **B**, Profile R-R': W-E segment from 100 MHz profile OMPU-07 showing pedogenic/humate reflector (dotted highlight) and intense reflectors (dashed highlight) at ~3 m depth overlying a possible marsh (zone of poor signal). Scour (62 m) and rippled surfaces (65–100 m) are highlighted (aerial image source USDA, NAIP 2005).

Rindsberg (chap. 5, this volume) and interpreted as washover fans and associated sediments that were host to a number of organisms. Vento and Stahlman (chap. 4, this volume) describe subaerial exposure and date soil horizons developed on this surface and overlying surfaces but caution that soil horizons developed in overlying Holocene eolian deposits are not laterally continuous. The features on the inland radar profiles could certainly be interpreted as overwash into a marsh or large swale pond if the zones of poor signal return represent clay or organic-rich sediments. If this can be verified with a core, the GPR would be a valuable tool for guiding selection of additional core sites to areas that would yield organic sediments suitable for  $^{14}\text{C}$  dating and palynology studies. The north-south leg of profile OMP1-09 (fig. 11.13A, upper) intersects profile OMPU-07 at Jct. 10, providing a right angle view. Strata appear parallel to subparallel in this area, indicating a general north-south strike of the beds. The intense reflector between 3 and 4 m depth is apparent over a zone of poor signal return. The southwest-northeast leg of the profile (fig. 11.13B, lower) illustrates a strong reflector between 4 and 5 m depth (~top of Pleistocene?) overlain by cross-bedded strata (eolian?) with a sharp local boundary between cross-bedded layers. At ~5.5–7.5 m depth a large wedge of sediment terminates in foreset beds that dip into the “soft” signal zone (marsh?). Is this a cross section of a thick Pleistocene storm washover filling in the marsh behind a breached dune ridge? The cross-sectional geometry of the radar elements/bedforms is certainly compatible with such an interpretation. The beds truncate the underlying strata and dip into the proposed marsh area, leveling out at the top of the sediment wedge as it overrides the marsh. Following this interpretation, the lower dipping strata along segment 1190–1370 m of profile OMP1-09 (fig. 11.14A, upper) may represent ridge and swale systems truncated by overwash and eolian deposits.

The individual horizons described above are very difficult to trace westward since the strata become parallel as the profile turns northwest. Distinctive radar surfaces are limited to the upper pedogenic reflector and basal reflector(s). The basal reflector is about 5 m below the surface in the more “compressed” section near Jct. 60, suggesting that the proposed Holocene base is less than 2 m deep in this area. Vibracores obtained in a transect (Ferguson et al., 2009) be-

tween Jct. 60 and Jct. 10 exhibit multiple humate or iron oxide horizons and lack obvious bedding features or notable structure above 2 m. Heavy minerals concentrated in laminations define bedding below 2 m depth and concentrations may reach 5%–10% in zones a few centimeters thick. Hand auger exploration at Jct. 10 extracted white “sugar sand” at depths of 3 m. The collective auger and vibracore data suggest that the Holocene eolian deposits of the upper facies thin westward from 3 m near Yellow Banks Bluff to 2 m or less on the central and western side of the island. This interpretation is supported by recent profiling (OMP4-09) with the 250 MHz antenna.

An additional feature of interest occurs between 645 and 560 m on the northwest portion of profile OMPU-06 (fig. 11.14B, lower). It shows the faint but well-developed outline of a wedge of sediment thinning to the east or southeast above a basal reflector. The sediment wedge displays foresets dipping in the same direction. Could this be the margin of a Pleistocene tidal delta or bar building toward the south or southeast over muddy sediments (see this volume, chap. 3: fig. 3.3)? The deep water table and relatively high elevations at the northeast end of the island favor strong radar penetration and signal return. There also seems to be better radar penetration of the lower facies in the northern part of the island, suggesting less clay and more sand. This may reflect closer proximity to the major sand supply (Bishop et al., this volume, chap. 3).

#### STRUCTURAL FEATURES AND ISLAND HYDROLOGY

Radar profiling on St. Catherines Island reveals several subsurface features with a synformal appearance in the cross-sectional profile view. The first example was discovered on the north end of the island on profile OMPU-06 (fig. 11.15A, upper) on the northwest-southeast profile leg along the road southwest of Gator Pond. The synformal features lack associated antiforms and the general passive margin tectonic setting does not favor major horizontal compressive stresses of the type that generate such features, so it should be safe to eliminate compressional folding as a realistic possibility. The more realistic possibilities for generating such structures include a filled fluvial or tidal channel, differential compaction over some local high porosity sediment—possibly over a deeply buried chan-

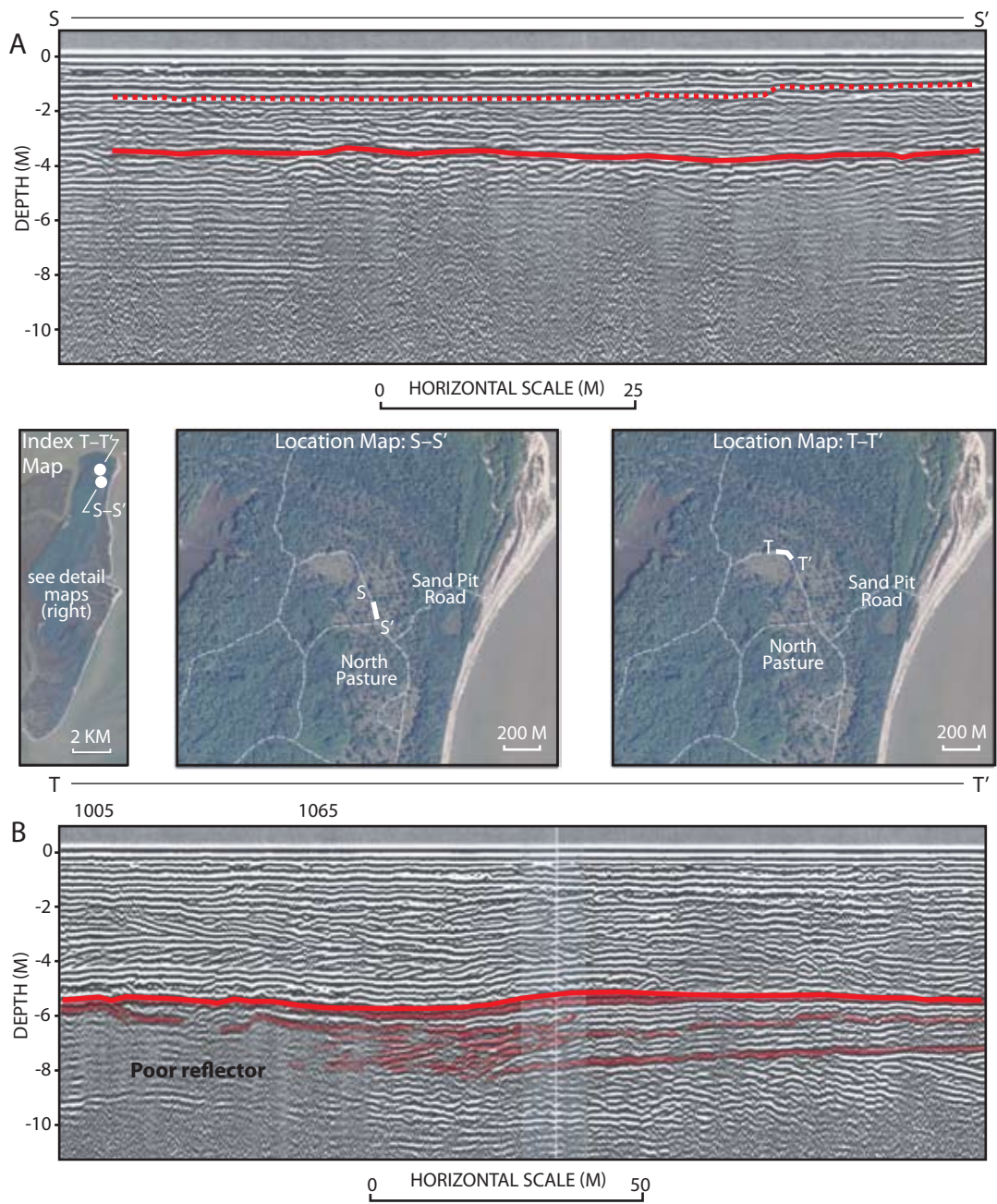


Fig. 11.13. **A**, Profile S-S': N-S profile segment from 100 MHz profile OMP1-09 providing a right-angle view of sequence shown in profile R-R' (fig. 11.12). Note pedogenic/humate reflector (dotted highlight) and the intense reflector (solid highlight) above marsh (?) deposits. Horizontal bedforms indicate N-S strike of strata by comparison with profile R-R' (fig. 11.12). **B**, Profile T-T': W-E-SE segment of 100 MHz profile OMP1-09 showing highlighted reflections/strata interpreted as large washover fan building into and over a marsh or swale pond (area of weak reflections between 1005 and 1065 m). Note well-developed cross-stratification in sequence above marsh and washover (aerial image source USDA, NAIP 2005).

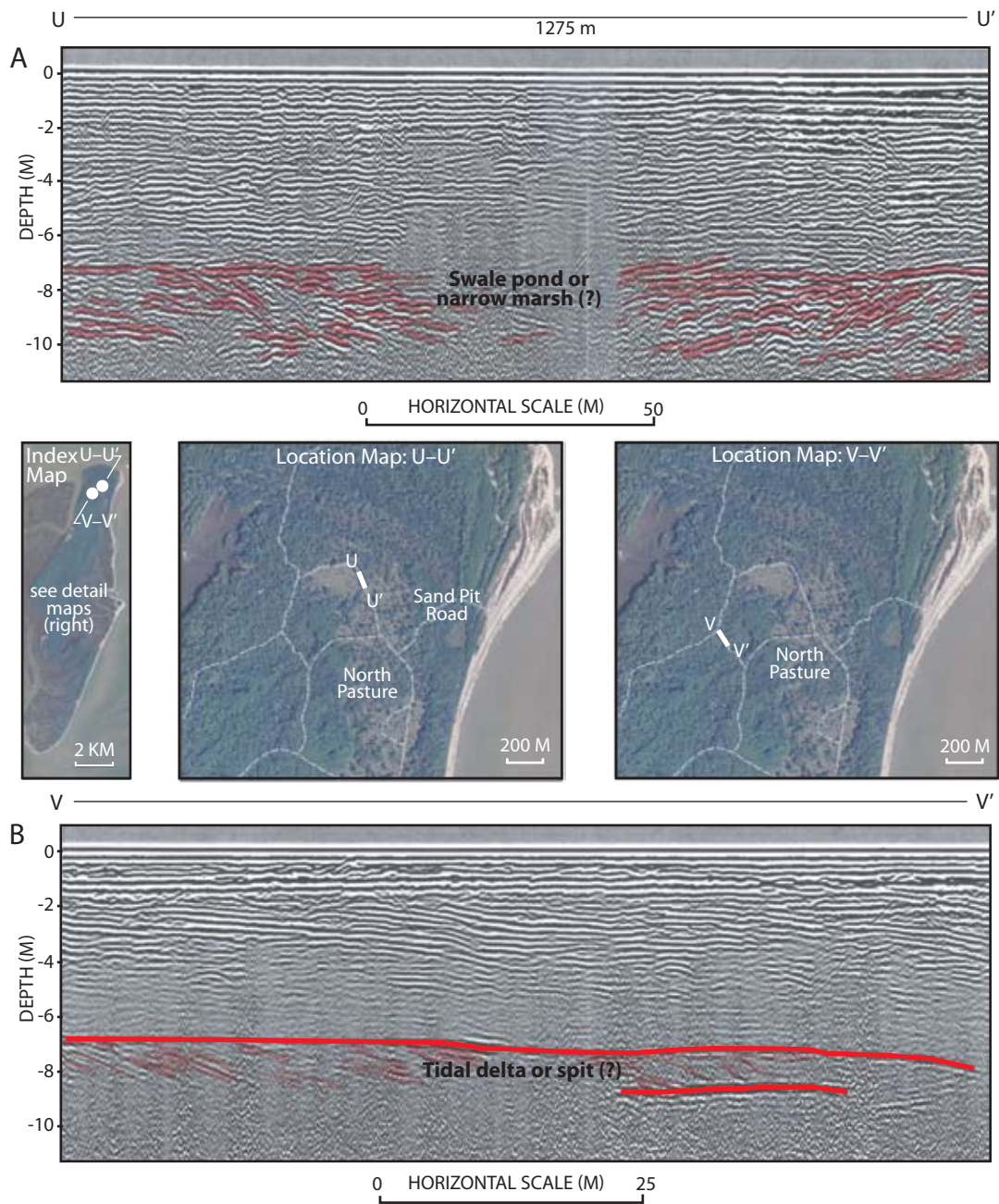


Fig. 11.14. **A**, Profile U-U': NW-SE segment from profile OMP1-09 showing possible swale pond or narrow marsh (~1275) with adjacent sandy strata dipping into and filling (?) swale. Another possibility might be a deep runnel in a beach system. **B**, Profile V-V': NW-SE segment from 100 MHz profile OMPU-07 illustrating foreset bedforms in a layer thinning toward the east or southeast. Could this be the toe of a tidal delta or spit (aerial image source USDA, NAIP 2005)?

nel, or the local collapse of strata into an underlying sinkhole or solution cavity. A narrow graben generated by tensional tectonics is another possibility. If the feature is a channel, there should be truncation of strata along the margin produced when the current eroded the underlying strata. There could also be some high-energy bedforms within the channel. Some possible truncation may have occurred in the upper 2 m along the southeastern margin of the Gator Pond structure. The general appearance of the feature and the thickness of bedforms suggest that underlying strata sagged ~2 m. This appears to have occurred after the development of the sharp reflecting horizon (humate reflector?) marked on the profile. The feature acted as a basin or channel collecting sediments that eventually filled in the depression. The sag feature approximately coincides with a surface topographic low that drains from Gator Pond toward the new pond at the old Crane Yard. The upper 1.2 m of sediment in the profile trough is mostly road fill across the depression.

Dissolution of carbonate rock at depth is another means of generating these sag structures. Carbonate rocks exist at relatively shallow levels beneath some of the barrier islands. Drilling on Cumberland Island encountered carbonate rock and some solution cavities at ~17–24 m below the surface (McLemore et al., 1981) in Pliocene strata. The Upper Brunswick Aquifer (Miocene) is another dissolution candidate with local carbonate units at depths between 30 and 60 m along parts of the coast. The Floridan Aquifer is a deep candidate at ~130 m. Solution cavities and collapse structures or sags localized by joints or faults are a realistic possibility and small displacement faults appear on some of the profiles. The Gator Pond sag feature is being investigated by Vance, Rich, and Bishop working with an undergraduate research team (Ferguson et al., 2009) using a transect of 10 vibracores to obtain shallow stratigraphic control and samples for palynology and sedimentology.

Profile OMP1-09 encountered another sag structure north of Gator Pond (fig. 11.15B, lower) with ~5 m of apparent subsidence along the sag center and numerous potential faults. This profile was conducted along the road that loops around the north end of the island from Jct. 60 to Jct. 10. Potential fault or joint control on development of these sag structures will be tested with additional east-west profiles between the Gator Pond sag and this sag to see if the structures are isolated or

part of a continuous trough or graben. A profile conducted in July 2010 indicates the sag shown in fig. 11.15B extends to the southeast.

Profiles OMPR-07 and OMPK-06 encountered another sag structure below State Road in the vicinity of State Road Pond. Figure 11.16A (upper) from profile OMPK-06 is a shallow-window 100 MHz profile crossing this sag structure. The scale of the shallow time window reveals multiple reflection offsets suggesting small faults associated with the structure. This feature appears to result from 1.5–2.5 m of subsidence in the deeper portions. The sag feature deflects strata to depths of 8 m and is similar to the others in the lack of obvious truncating features indicative of channels. An additional sag feature was discovered on profile OMP2-07 (fig. 11.16B, lower) on Savannah Road between Jct. 80 and the creek to the east. The sand is about 5 m thick and the basal reflector is depressed at this locality.

The sag features appear to have formed by a combination of soft sediment deformation and local brittle failure (of cemented zones) in the form of numerous small-displacement faults. Additional profiles around known sags will document the extent of individual structures and determine if these features are isolated basins or linear troughs. Elongate, troughlike structures would suggest strong control by deeper faults or joints. The occurrence of these features along the Central Depression and present wetlands favors a strong link to island hydrology. The Late Archaic sites along freshwater marsh or lacustrine habitat and the historical accounts of the spring-fed streams and meadows (Hayes and Thomas, 2008) certainly indicate artesian flow. The Floridan artesian aquifer is well below the surface in this area; consequently, the overlying strata must be penetrated by natural conduits such as faults or joints or by man-made conduits (wells) to allow this water to reach the surface. The sag structures may mark areas in which faults or joints have localized dissolution in carbonates at depth or there may have been deep structural subsidence expressed as minor faults and sags at the surface. Either mechanism would provide surface access to the artesian aquifer and the preindustrial potentiometric surface would have produced impressive artesian flow (Krause and Gregg, 1972; Hayes and Thomas, 2008).

Although the artesian springs no longer flow on St. Catherines Island, the importance of these potential hydrologic conduits along the Central

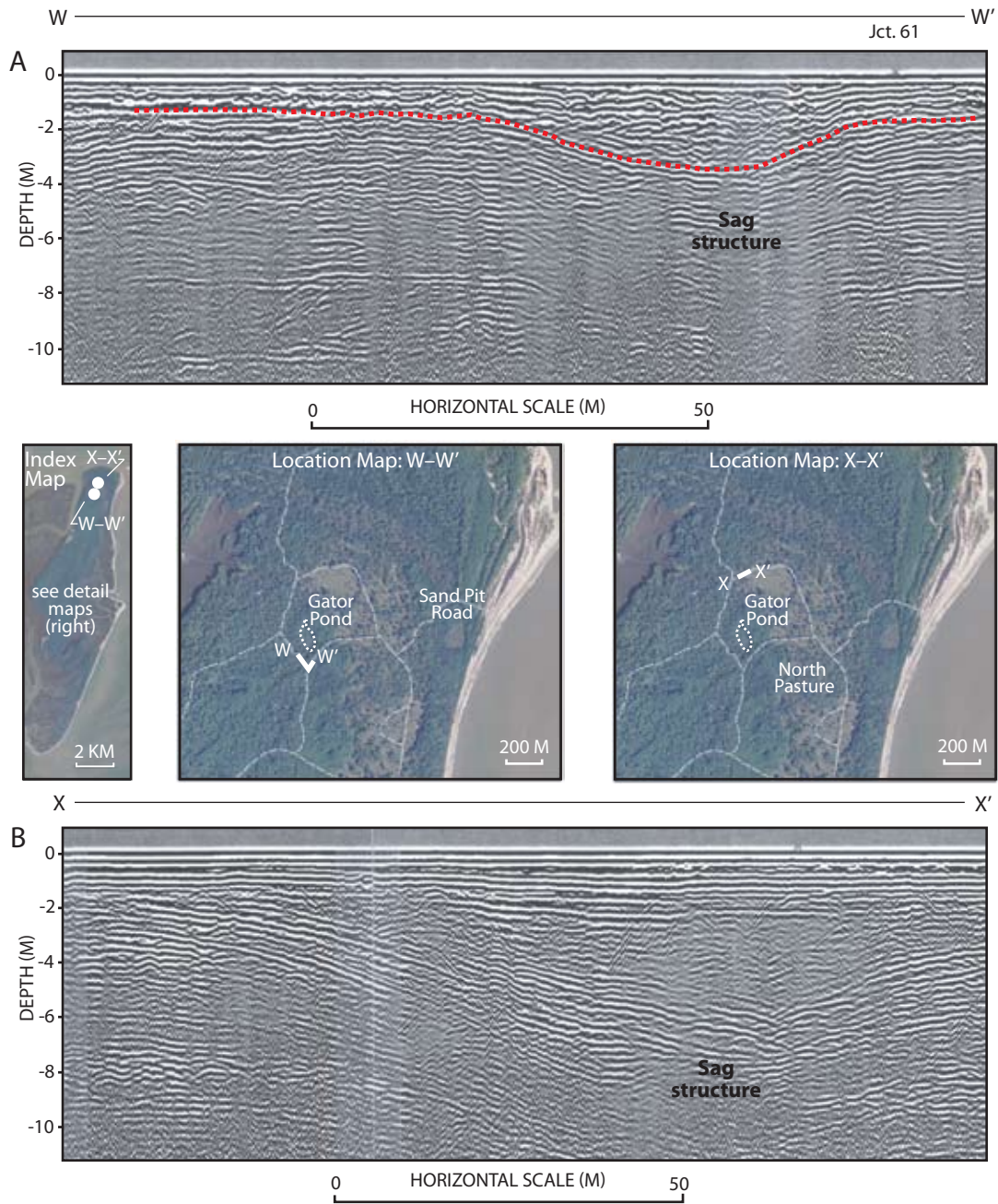


Fig. 11.15. **A**, Profile W-W': Segment (NW-SE-NE) from 100 MHz profile OMPU-07 showing sag structure on southeast side of Gator Pond. Jct. 61 is at 454 m on the profile. Dotted highlight marks pedogenic/humate reflector. **B**, Profile X-X': Broad sag structure north of Gator Pond structure, on SW-NE segment of 100 MHz profile OMP1-09 (aerial image source USDA, NAIP 2005).

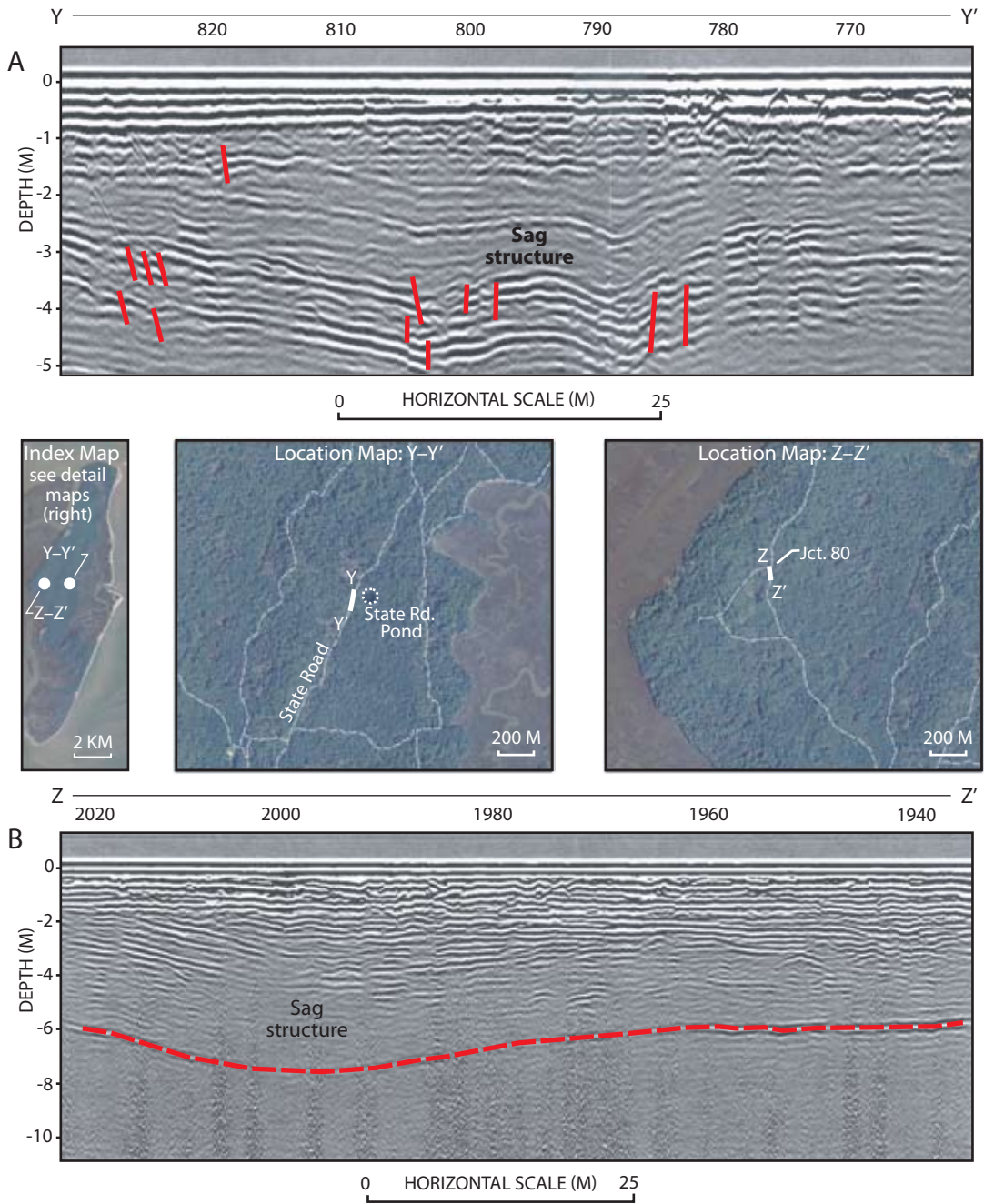


Fig. 11.16. **A**, Profile Y-Y': view of upper portion of sag structure west of State Road Pond. From N-S segment of 100 MHz profile (shallow window) OMPK-06 along State Road. Highlights on small faults suggested by displacement and deformation of reflecting horizons at 806 m, 789 m, and 826 m. **B**, Profile Z-Z': sag feature on NW-SE segment of 100 MHz profile OMP2-07 between Jct. 80 and the creek to the east. Note the deflection of the basal reflector (highlighted) (aerial image source USDA, NAIP 2005).

Depression should not be minimized. Sea level is rising and there is potential for hydrologic communication between the shallow and deep aquifer system via fractures and solution cavities. The saltwater intrusion that affects aquifers of the postindustrial coastal plain of the southeastern United States could contaminate the primary freshwater resource of the island if saltwater enters the same fractures that once produced artesian springs. The continued exploration of the strata and structure of the Central Depression is important for better understanding of critical island hydrology and to better understand the general geological evolution and the role of geology as a major influence on the anthropological trends or patterns of habitation and foraging (Thomas, this volume, chap. 1).

### SUMMARY

GPR provides an excellent tool for noninvasive exploration of relatively shallow (<20 m) stratigraphy, geological structures, and some biogenic structures in rock and sediment. Although the electromagnetic waves of GPR are limited by the presence of clay and saltwater, the relatively thin sand-dominated sediment package that composes much of barrier islands makes GPR an extremely useful geophysical tool for both geologists and archaeologists. Varied combinations of antennae, instrument settings, survey systems, and software programs can be adapted for geological reconnaissance of stratigraphy and structure or high-resolution exploration of heavy mineral laminations in beach sediment, biogenic features (e.g., sea turtle nests), and anthropogenic features such as the island shell ring sites or Mission Santa Catalina de Guale (Thomas, 2008).

It is emphasized that depths shown on the radar profiles are not "absolute truth" and can be shifted significantly by adjusting average velocity used in the GPR software programs. The relative stratigraphic position of the features and interpretation of radar elements as specific bedforms or an association of bedforms is important in the effort to correlate the geophysical signature with available ground truth and apply these interpretations to understanding the structure and evolution of the island. Interpretation of observed radar elements bounded by major radar surfaces and or marked changes in the form of elements allowed organization of much of the island into three major facies or horizons. The lower facies

is characterized by horizontal parallel-to-subparallel elements or bedforms that probably represent clay-rich, relatively low-energy sedimentary environments. The lower facies is overlain by a sand-dominated middle facies exhibiting sigmoidal clinoform radar elements or bedforms typical of beach ridge successions produced by prograding (regressive) systems (Johnston, Thompson, and Baedke, 2007). The middle facies thickens toward the northern end of the island and thins to the west. Poor radar penetration and signal return along the Central Depression and thinning of sand to the west prevent confident correlation of the middle facies to the west side of the island. The middle facies is overlain by an upper facies that includes radar elements or bedforms interpreted as overwash and eolian deposits. Both planar and trough cross beds are suggested and these forms yield to dominantly horizontal to subhorizontal planar elements toward the surface. A common, persistent reflector observed between 0.8 and 1.5 m seems to coincide most closely with humate or iron oxide concentrations.

There are definite local features in the northeastern subsurface that may be correlative with the washover fan horizon described by Martin and Rindsberg (chap. 5, this volume) and the soil horizons described by Vento and Stahlman (chap. 4, this volume). Much of the island core exhibits about 1.5–2 m of surficial sand that shows up on the radar profiles as largely subhorizontal reflections with a superimposed humate/iron oxide reflector. This surficial portion of the upper facies may represent in part an extensive Holocene eolian cover. Much of the underlying middle facies strata can be interpreted as Pleistocene beach facies truncated by overwash fans and dunes with local swale ponds or marshes. These swales or marsh trends could be delineated in the subsurface with additional across-axis 100 MHz profiles coupled with coring or auger work for ground truth and some additional higher resolution 250 MHz profiling.

The discovery of the South Pasture disconformity offers another area of focus for future research with a potential source of organic material for both palynological and radiocarbon dating. If the Yellow Banks Bluff soil profile dates of Vento and Stahlman (chap. 4, this volume) are accurate and the upper horizon recognized on most of the GPR profiles is Holocene eolian cover, the potential of older sites for archaeological exploration is enormous.

Much of the work described here is reconnaissance level, but led to focused research on parts of the Central Depression to explore its origin and the underlying structural and stratigraphic controls on island hydrology. The present level of research suggests that joints and faults along the Central Depression may have localized solution in underlying carbonate rocks producing surface sinks or structural sags. It is also possible that these depressions were localized by minor fault-controlled subsidence. These structural conduits probably tapped the artesian aquifer to produce the springs and freshwater wetlands known in

early colonial times. These conduits could also provide saltwater access into the island core due to pervasive saltwater intrusion associated with the falling potentiometric surface of the Floridan Aquifer. Obtaining additional deep vibracores from the Central Depression, coupled with palynological analyses of organic sediment from the cores, can be teamed with additional radar profiling and continued cataloging of archaeological sites along the former wetlands margin to explore the temporal and spatial extent of the wetlands that were so important to both the geological and human history of the island.



## CHAPTER 12

### POSTSETTLEMENT DISPERSAL AND DYNAMIC REPOPULATION OF ESTUARINE HABITATS BY ADULT *MERCENARIA MERCENARIA*, ST. CATHERINES ISLAND

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Jennings and Hunt (2009: 76) note that “post-larval or juvenile dispersal is important because for many species this is a last chance to migrate to their adult location (Hiddink and Wolff, 2002) as mobility often decreases with increasing size.”<sup>2</sup> Postsettlement passive transport and recruitment of nonsessile bivalves under rigorous hydrodynamic conditions is not a new observation, although it was little explored back in 1991 when Emerson and Grant described it for populations of *Mya arenaria* and when we initiated study of selected *Mercenaria mercenaria* populations on St. Catherines Island. Since the early 1990s, postsettlement dispersal has been documented in several other bivalve species, including *Macoma balthica*, *Gemma gemma*, *Corbicula japonica*, *Austrovenus stutchburyi*, and *Macomona liliana* (Gunther, 1991; Norkko et al., 2001; Hunt and Mullineaux, 2002; Petuha, Lundquist, and Pilditch, 2006; Bowen and Hunt, 2009, among others). These studies have documented postsettlement transport of juvenile bivalves (see discussion by Jennings and Hunt, 2009), either the result of resuspension in the water column or bedload transport (e.g., the dispersal of small juveniles of the New Zealand tellinid *Macomona liliana* over distances of several kilometers on a single spring tide and the bedload transport of larger juveniles over tens of meters on a single tide; Petuha, Lundquist, and Pilditch, 2006). Hunt, Fugate, and Chant (2009) noted that even bedload transport of juvenile bivalves could achieve, over time, cumulative net displacements of kilometers. Many studies have also noted that postsettlement dispersal of some bivalve species can also be influenced by morphology and

behavior, such as the depth of burrowing, the employment of byssal threads (Beukema and de Vlas, 1989), and the use of mucoid drogue lines (Prezant and Chalermat, 1984). Significant postsettlement dispersal of sedentary adult bivalves has seldom been reported, although as early as 1955 Dow and Wallace described storm-induced large-scale passive redistribution of intertidal populations of *M. mercenaria* in coastal Maine.

#### DYNAMIC REPOPULATION OF ESTUARINE HABITATS OF ST. CATHERINES ISLAND BY ADULT *MERCENARIA MERCENARIA*

Two decades ago we documented patterns of postsettlement transport and repopulation on St. Catherines Island by large adult clams inhabiting the Engineers Point West *Mercenaria mercenaria* populations in the fringing marsh adjacent to Walburg Creek and nearby Northwest Marsh, and within point bars along Long Creek (Prezant, Rollins, and Toll, 1990a, 1990b, 1992, 1997; Prezant et al., 1994a, 1994b; Rollins, West, and Busch, 1990; Rollins, Yu, and Busch, 1990; H.B. Rollins, Sandweiss, and J.C. Rollins, 1990; Rollins, Prezant, and Toll, 1990a, 1990b; 1992; 2008; this volume, fig. 12.1).

In 1989, we established along Engineers Point West three 3.5 × 6.0 m quadrats (A, B, C) that encompassed 60 m of an overwash area adjacent to a high-energy levee of Walburg Creek at the northwest margin of St. Catherines Island (figs. 12.2–12.4). All quadrats were at a midintertidal position and arranged sequentially, A–C, downstream from a small tributary channel draining



Fig. 12.1. Aerial photograph of Engineers Point West, St. Catherine's Island. Map from Google Earth™, 2010.

Northwest Marsh. Elongated oyster patch reefs lined a significant portion of the Walburg Creek side but were never included within the quadrats. Specimens of *Mercenaria mercenaria* were abundant in the sand substratum aproning a dense stand of medium to tall fringing *Spartina alterniflora*. Clams were often several centimeters below the sand surface, sometimes nestled against dense *S. alterniflora* roots. During a single low tide interval in August 1989, each quadrat was mapped via laser level and elevations were recorded, at 0.5 m intervals, to the nearest centimeter below a U.S. Coast and Geodetic Survey benchmark. Twelve hours later each quadrat was totally defaunated of clams, also during a single low tide period. Following a complete tidal cycle, the quadrats appeared to have recovered from the collection efforts. Approximately 100 of the collected clams were marked, measured, and weighed, and then replaced randomly within each quadrat. The quadrats were revisited in January 1990, October 1990, and February 1991. During

the subsequent visits each quadrat was remapped, and all clams within the quadrats were harvested, measured, weighed, and aged (via annual growth ring counts). Recruits were sequentially numbered and replaced in each quadrat, along with those of the original and subsequent collections. To assess reproductive maturity, 20 clams were randomly collected during the August 1989 and January 1990 visits from areas adjacent to each quadrat. Gonads were examined by standard histological procedures, following fixation in Helly's fluid. Although all clams were removed from the quadrats during each visit and only marked individuals were replaced, all three quadrats contained unmarked adult clams at each harvest. We did not attempt to assess intraquadrat spacing and density of individuals. Numbered individuals were randomly replaced in the quadrats. Very few juvenile clams were collected at any of the quadrats during the harvests. Laser leveling data were used to construct contour maps of the substrata (contour interval = 2 cm). Isopleth maps



Fig. 12.2. Photographs, at low (left) and high (right) tides, of the fringing marsh along Walburg Creek and the Engineers Point West quahog-monitoring quadrats described in this study.

showing net changes in terms of erosion and aggradation were prepared for each quadrat (figs. 12.5–12.7). The isopleth maps display only the net gain or loss of substratum at the termination of the experiment and do not accurately describe the short-term dynamic changes of each quadrat. Table 12.1 presents the net change in population structure of each quadrat for the entire two-year study period. The cumulative mean length of clams from all quadrats increased over time. The mean size of harvested clams from all quadrats, as measured by total length, provided evidence of selective movement of smaller-sized adult hard clams. For all quadrats the mean length of immigrants was 49.36 mm and the mean length of emigrants was 56.17 mm. Individuals that remained within the boundaries of the quadrats for the duration of the study (statics) averaged 61.27 mm in length. Table 12.1 also records the demographic flux per quadrat. The greatest population loss, as assessed by a percent of the original population, occurred at quadrat C (emigration loss = 62%). Quadrat C also sustained dramatic substratum change during the course of the study due to erosional ravinement and loss of sand over about one-half of the surface. At this site an exposed oyster shell lag was impenetrable by infaunal clams. The lowest emigration loss (40%) was recorded for quadrat B. Although there was significant repositioning of the sand veneer at quadrat B, the substratum remained suitable for burrowing clams. Similar emigration loss (43%) occurred at quadrat A. Immigration gain, measured as a percent of recruits to the original

population, was 29%, 57%, and 74% at quadrats C, B, and A, respectively. Quadrat A represents the most southerly station and the closest to the tidal channel draining Northwest Marsh.

Analysis of variance (ANOVA) comparisons of total lengths of immigrants, emigrants, static individuals, and the original population, for all three quadrats, resulted in differences significant at or above the 95% confidence level between immigrants and emigrants, between immigrants and static individuals, between immigrants and the original population, between emigrants and static individuals, and between static individuals and the original population (table 12.2). Statistically significant differences were not demonstrated between the emigrants and the original population. The average number of individuals per quadrat at the end of the monitored interval (101.33) approximately equaled the original number of individuals (96.67) per quadrat. Note, however, that the final number of individuals at quadrat C was 64 compared to 129 at quadrat A (table 12.1).

Adult clams recovered adjacent to the quadrats were sexually mature and about equally divided between males and females at different stages of pre- and postspawning activity. Subsamples of recruits within the quadrats were also sexually mature.

Overall, quadrat A experienced aggradation of up to 20 cm of sand in spite of localized erosion and shoreward regression of *Spartina* cover concomitant with the development of increased ebb tidal drainage. Erosional scour of up to 20 cm of sand substratum in the southwestern por-



Fig. 12.3. Photograph of portion of Long Creek point bar at low tide, near quahog mark and recapture study site discussed in text.

tion of quadrat B was balanced by about 20 cm of aggradation in the northeastern portion. *Spartina* distribution was only slightly affected by these substratum changes. Quadrat C underwent major net change over the interval studied. Erosional scour was pronounced over the entire quadrat, denuding the western portion of sand and exposing an underlying oyster shell lag. Concurrently, the *Spartina* cover retreated shoreward.

Realizing that their observations at Engineers Point might be considered a localized anomaly associated with a rare confluence of hydrodynamic factors, Prezant, Rollins, Toll, and Skoog performed a comparable mark and recapture experiment over the same time period in Long Creek, on the eastern side of the island (Prezant et al., 1994a, 1994b). They used one of a sequence of point bars located in the ebb-flow dominated tidal creek (fig. 12.3). A runnel occurs on the marsh side of the point bar. Twenty-eight hard clams were collected from the runnel, marked, and replaced. An additional 51 clams were collected from the point bar surface, also marked and replaced. After five months, 65 of 79 clams were recovered; all losses were from the surface of the point bar and none was lost from the low-energy runnel. The latter represents a re-

gion of turbulent flow along the point bar and a likely "catchment" area. Tidal creek point bar sites typically have larger clams than the wash-over fringing marsh zones represented by Engineers Point, and are also subjected to strong channel-side tidal flows with ebb current velocities as high as 1.1 m per second (Howard and Frey, 1985). The average length of clams recovered from Long Creek point bar was 92.1 mm; those lost from the system averaged 86.6 mm in length; those adults recruited into the mouth of the runnel averaged 90.0 mm in length.

## DISCUSSION

As noted by Kraeuter et al. (2009: 273), "It is generally believed that hard clam recruitment ... is controlled by interactions between larval supply, post settlement predation, and substrate composition." In fact, most traditional views of recruitment of benthic marine organisms involve the addition of larval or small juvenile cohorts to established populations with a focus on larval competence, metamorphosis, and ultimate settlement (Sale, 1990). This conventional model of recruitment does not satisfactorily account for the observations of hard clams at Engineers Point.

The rapid population replacement by adult clams following within-quadrat loss of adults demanded an explanatory model that involved wholesale movement of otherwise sedentary adult bivalves. Moreover, the agent(s) of dispersal had to be employed frequently. The relatively rare event of stochastic rafting via slumping along oversteepened tidal creek banks or by tidal current “plucking” of mud clasts did not adequately explain the rapid recolonization by only adult clams. Movement of blocks of rooted *Spartina alterniflora* substratum does occur sporadically on St. Catherines Island, in association with the larger ebb tidal deltas. Such so-called “peat reefs” could be involved with abortive recolonization of *Mercenaria mercenaria* on patches of relict marsh mud along high-energy beaches (West, Rollins, and Busch, 1990). In the experimental sites, the highest emigration and lowest immigration clearly occurred at quadrat C, which correspondingly experienced the greatest substratum change. It is more likely that the clams were transported in a saltational manner associated with specific hydrodynamic events such as episodic storms, probably in combination with the effects of dominant ebb tidal flow velocities. Rarely, marked clams were found entrapped within adjacent surface oyster bars, demonstrating the likely saltational redistribution of these adult bivalves. A number of recent studies have established that, for a given energy sys-

tem, there is a threshold size above which clams escape the combined effects of erosion, entrainment, and transport (Norkko et al., 2001; Hunt et al., 2007; Jennings and Hunt, 2009). For Engineers Point, that size is approximately 61 mm shell length. In higher energy regimes threshold sizes could be even larger.

Postsettlement transport and dispersal of bivalves (either juvenile or adult) invites discussion of potential adaptive strategies. Is postsettlement transport of clams obligatory or facultative? Or both? Consideration of potential adaptive strategies that might aid in postsettlement survival of infaunal bivalves has understandably focused upon depth of burrowing and shell size. Other factors (e.g., siphonal length and access to surface waters) notwithstanding, larger bivalves are generally presumed to burrow deeper than smaller bivalves, and thus are better able to escape predation, and, for many species, the degree of postsettlement mortality is assumed to be a major aspect of recruitment success or failure (Gosselin and Qian, 1997; Hunt and Scheibling, 1997; Jennings and Hunt, 2009; Kraeuter et al., 2009). Jennings and Hunt (2009) point out that juvenile invertebrates are often vulnerable during early postsettlement and suggest that both vertical (burrowing) movement and horizontal (transport) movement at this time may afford critical opportunities for successful migration to adult

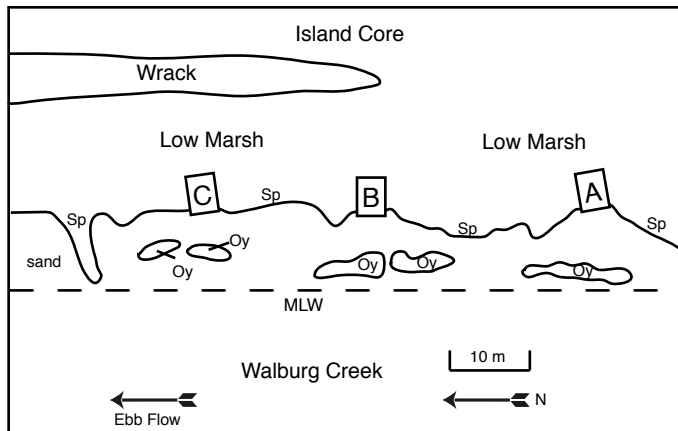
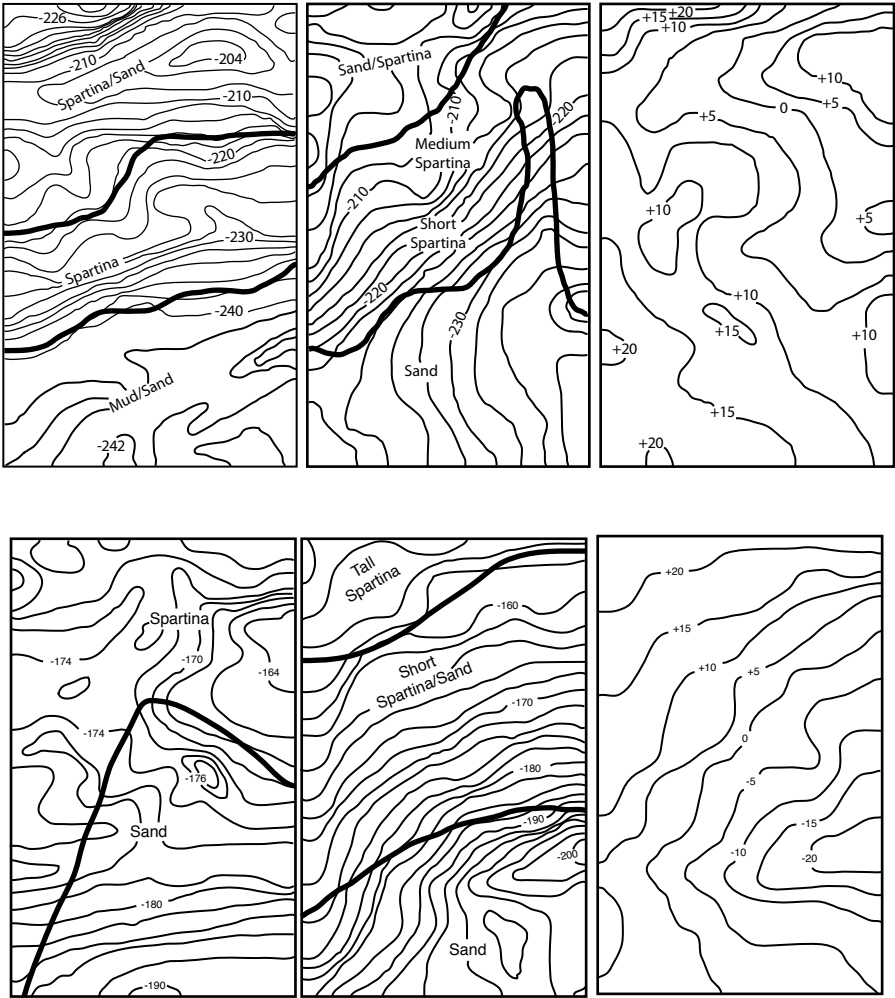


Fig. 12.4. Schematic map of Engineers Point West hard clam stations A, B, and C (adapted from Rollins, Prezant, and Toll, 2008).. Sp = *Spartina*; Oy = oyster patch; MLW = mean low water. Quadrats measure 3.5 x 6.0 m.

locations. In this regard, based on flume and field experiments, they demonstrated that “juveniles of several bivalve species are transported as bedload over distances up to tens of centimeters per hour” and noted differences in distance of juvenile dispersal related to differences in species hydrodynamic properties (e.g., density, fall velocity), but the results varied among experiments (Jennings and Hunt, 2009: 84). Uncertainty surrounding

the nature and potential adaptive significance of postsettlement transport of bivalves can be seen in a study by Huxham and Richards (2003). In an attempt to assess habitat selection by intertidal postlarval infaunal bivalves, they found that secondary settlement (i.e., relocation) by *Cerastoderma edule* and *Macoma balthica* demonstrated no ability to select sediment type, and therefore “must be related to other mechanisms,



Figs. 12.5, 12.6. Laser-level contour and isopleth maps showing substrate change at Engineers Point West *Mercenaria mercenaria* stations A and B, between Aug. 1989 (left) and Feb. 1991 (center). Figure 12.5 (top) details quadrat A, contour interval = 2 cm.; figure 12.6 (bottom) details quadrat B, contour interval = 2 cm. Contour interval of isopleths maps (right) = 5 cm..

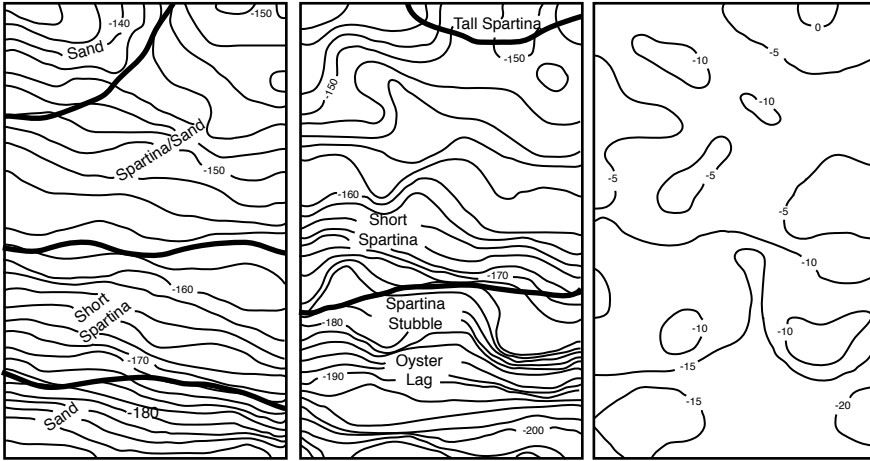


Fig. 12.7. Laser-level contour and isopleth maps showing substrate change at Engineers Point West *Mercenaria mercenaria* station C, between Aug. 1989 (left) and Feb. 1991 (center). Contour interval = 2 cm. Contour interval of isopleth map (right) = 5 cm.

possibly postsettlement predation ... and/or an ability to leave less-preferred sediments in a series of migrations until the preferred habitat is found” (Huxham and Richards, 2003: 279). We suggest that a more parsimonious explanation might be one focused upon repeated, but passive, hydrodynamic entrainment (i.e., obligatory, not facultative).

Petersen (1986: 200–201), in a study of *Mercenaria mercenaria* occupying seagrass beds in North Carolina, posed the question: “To what degree can a given biological pattern be explained as a passive response to physical phenomena without need to invoke an active biological mechanism?” and he attempted to help “resolve the controversy in marine benthic ecology over whether settlement or subsequent survivorship determines various population and community patterns.” He documented a statistically significant increase in the density of adult *M. mercenaria* individuals in seagrass beds compared to the settlement density (0-year-class recruits) of this species, and attributed this between-habitat density disparity to differential survival and not to physical transport and baffling by the seagrass beds. He speculated that differential survival was due to differential predation, stronger

in areas where the clams were not protected by vegetational root systems. Roberts et al. (1989) suggested that vertical migration, as seen in *M. mercenaria*, during ebb tides, could help prevent erosional exhumation of clams but those clams nestled among *Spartina* roots remain in place without deeper burrowing. Storm events and increasing pore water pressures, however, might bring clams to a shallower infaunal position, making them more vulnerable to entrainment and transport. Peterson’s argument against the efficacy of physical transport as an explanation for the observed pattern in density distribution hinged upon his evaluation of the hydrodynamic energy necessary to remobilize settled clams. He concluded that “physical transport of 5–25 mm clams in the Back Sound study site is highly unlikely,” citing Baggerman (1953) who “showed that physical transport of the bivalve *Cardium edule* virtually ceased when individuals reached a length of 2 mm in an intertidal locality of higher energy than the subtidal sites here.... The actual current velocities measured at the Back Sound study sites during spring tides peak at only 7 cm per sec...an order of magnitude less than the required velocities” (Petersen, 1986: 203).

Our survey of the literature revealed only

TABLE 12.1  
Actual Numbers and Average Lengths of the Original, Static, Emigrant, and Immigrant Populations of Hard Clams in Individual Quadrats along Engineers Point West

Quadrat	Immigrants		Emigrants		Statics		Original		Population total
	<i>N</i>	$\bar{x}$ mm	<i>N</i>	$\bar{x}$ mm	<i>N</i>	$\bar{x}$ mm	<i>N</i>	$\bar{x}$ mm	
A	73	55	42	57.9	56	65.5	98	58.2	129
B	54	45	38	54.5	57	58.9	95	56.1	111
C	28	48.1	60	56.1	36	59.4	97	56.6	64
$\bar{x}$	51.67	49.36	46.67	56.17	49.67	61.27	96.67	57.3	101.33

TABLE 12.2  
Statistical Analysis of *Mercenaria mercenaria* – Engineers Point West  
Post Hoc Analyses Performed on the Results of a One-Factor ANOVA  
for Repeated Measurements ( $F = 23.926$ ;  $p < 0.001$ )

Comparison of total length	Mean difference	Fisher PLSD	Scheffe F-test
Immigrants vs. emigrants	6.81	3.504 <sup>a</sup>	7.539 <sup>a</sup>
Immigrants vs. statics	11.91	3.504 <sup>a</sup>	23.06 <sup>a</sup>
Immigrants vs. original population	7.943	3.504 <sup>a</sup>	10.258 <sup>a</sup>
Emigrants vs. statics	5.1	3.504 <sup>a</sup>	4.228 <sup>a</sup>
Emigrants vs. original population	1.133	3.504 <sup>a</sup>	0.209 <sup>a</sup>
Statics vs. original population	3.967	3.504 <sup>a</sup>	2.558 <sup>a</sup>

<sup>a</sup>Significant at 95% confidence level.

one specific documentation of passive movement (and relocation) of fully grown adult hard clams, that of Dow and Wallace (1955). In 1949, they discovered two widely separated “residue” populations of the 1947 *M. mercenaria* recruitment in Maquoit Bay, Maine, and, in 1950 they initiated a detailed study of clam distribution in one of these populations. Detailed survey revealed marked redistribution of clams in the size range 27–56 mm (median diameter = 43 mm), correlated with patterns of storm activity. They noted that the remnant and redistributed population suffered 40.3% mortality over the study interval, but its areal coverage was enlarged from 3.28 acres to 6.81 acres.

Prezant, Rollins, and Toll (1990a, 1990b, 1997), Prezant et al. (1994a, 1994b) and Rollins, Prezant, and Toll (1990a, 1990b) suggested that

the hard clam repopulation dynamics presented above for Engineers Point and Long Creek might provide an additional explanation for some previous observations of the distribution and population structure of hard clams along coastal Georgia. In this region, population age class structure often lacks a range of year classes (Walker and Tenore, 1984; Walker and Rawson, 1985). This is particularly common along higher-energy habitats, such as fringing marshes along large tidal creek levees and the point bars in larger tidal creeks. Lower energy sites (e.g., ponded marsh habitats and small “gut” creeks) more often harbor cohorts with numerous age classes. Although missing year classes are generally attributed to either the vagaries of larval settlement or extreme selective harvesting/predation, Walker and Tenore (1984) suggested that passive movement

of larger adult clams, as observed in their study, may also be added to the list. It might be useful to consider the distribution of *Mercenaria mercenaria* on St. Catherines Island in terms of metapopulations and patch dynamics. *M. mercenaria* is widely distributed among different habitats on the island. Age classes differ among habitats with the oldest (and largest) clams in lower energy, muddy, larger tidal creeks. Younger and intermediate-sized clams are found along the higher energy and sandier intertidal stretches of fringing marshes. Lastly, hard clam populations along coastal Georgia have been reported to exhibit heterozygotic deficiency (Humprey, 1981), usually explained in terms of capricious larval dispersal and recruitment in a heterogeneous environment. These heterozygotic deficiencies, however, could be explained by stochastic adult repopulation without significant larval broadcasting, an extension of the fine-scale genetic heterogeneity noted by Johnson and Black (1984) in larval recruitment of the pulmonate limpet *Siphonaria jeanae*.

## CONCLUSION

The fate of postsettlement juvenile and adult bivalves under varying physical conditions has, we believe, significant meaning for the rather pervasive, if not reigning, paradigm of "supply-side" ecology (Lewin, 1987; Roughgarden, Gaines, and Pacala, 1987). Supply-side ecology predicts that larval recruitment would produce a series of age (size) classes reflecting the variable success of adult reproductive events. While certainly the dominant controlling factor for sessile biota, the numerous reports of recruitment patterns for several other sedentary (but not permanently attached) marine organisms document irregular or unpredictable settlement patterns that cannot be explained by small (planktonic) propagules (Sinclair, 1987; Beukema and de Vlas, 1989; Jokeil, 1989; Emerson and Grant, 1991; Gunther, 1991; Martel and Chia, 1991). General trends in recruitment as well as variability are discussed by Sale (1990) who emphasized that larval behavior, correlated with environ-

mental regime, largely controlled recruitment. The idea that ocean hydrodynamics can impact population distributions, especially of juvenile infaunal macrofauna, has more recently begun to be explored and there is now considerable evidence of the significance of postsettlement dispersal as a major influence on adult distribution of many groups, including bivalves (Armonies, 1994; Commuto et al., 1995; Norkko, et al., 2001; Hunt, McLean, and Mullineaux, 2003; de Montaudouin, 1997; Petuha, Lundquist, and Pilditch, 2006; Bowen and Hunt, 2009).

As noted by Hunt (2005: 143), "Although the existence of juvenile invertebrate dispersal has been recognized for at least 50 yr (e.g., Baggerman, 1953; Smith, 1955), it has received much less attention than larval dispersal, and there are critical gaps in our knowledge of this process." We suggest, based on our studies of hard clam dispersal on St. Catherines Island, that one of the major gaps in our knowledge involves the role of passive dispersal of fully grown adults. In particular, these stochastically redistributed and reproductively mature bivalves can help support and sustain locally dispersed metapopulations. The relative roles of larval recruitment, postsettlement juvenile dispersal, differential survival, and adult movement (both passive and active) have yet to be assessed under varying hydrodynamic situations. As discussed by Emerson and Grant (1991) for the softshell clam *Mya arenaria* and by Rollins, Prezant, and Toll (2008) and Rollins and Thomas (chap. 16, this volume) for the hard clam *M. mercenaria*, the proportional efficacies of these processes also influence our assessments of overfishing and recovery (past and present) of these shellfish resources.

## NOTES

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## CHAPTER 13

### THE FOUNDATION FOR SEA TURTLE GEOARCHAEOLOGY AND ZOOARCHAEOLOGY: MORPHOLOGY OF RECENT AND ANCIENT SEA TURTLE NESTS, ST. CATHERINES ISLAND, GEORGIA, AND CRETACEOUS FOX HILLS SANDSTONE, ELBERT COUNTY, COLORADO

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MEYER, AND WILLIAM A. PIRKLE

“Modern sea turtles ... spend virtually their entire life in the sea, except for the laying and development of eggs into hatchlings” (Bjorndal, 1979).<sup>1</sup> Sea turtles reproduce by laying eggs in nests excavated into the backbeach or sand dunes behind sandy beaches (Mast, 1911; Caldwell, Carr, and Ogren, 1959; Bustard, Greenham, and Limpus, 1975; Hopkins et al., 1982; Van Meter, 1992) where the eggs incubate and hatch. Sea turtle nesting is thus capable of leaving distinctive sedimentological imprints in the nearshore sedimentary record including nesting crawlways, nest excavations that disrupt “normal” backshore sedimentary structures, and hatchling crawlways made as the hatchlings make their way to the sea.

The goal of this chapter is to describe structures produced by nesting loggerhead sea turtles (*Caretta caretta* [Linnaeus, 1758]) on St. Catherine's Island, document their use for the following two chapters on sea level fluctuation (chap. 14), and their potential<sup>1</sup> use by ancient Native Americans for locating sea turtle food resources (chap. 15), and also to summarize the only known fossilized sea turtle nesting suite (Bishop et al., 1997; Bishop, Marsh, and Pirkle, 2000; Bishop and Pirkle, 2008), from the Cretaceous of Colorado, providing a model for description of sea turtle traces and trace fossils from other species and other times.

Hasiotis and Martin (1999) described reptilian nesting structures in the Triassic Chinle Formation that they attributed to turtlelike reptiles and Hasiotis et al. (2006) summarized nesting structures from the fossil record. Sea turtles are

known to have existed for at least the last 105 million years (Weems, 1988; Hirayama, 1998; Kear and Lee, 2006), from the Early Cretaceous to Holocene. The paleontological record of sea turtles is represented by more or less fragmentary body fossils comprised of skeletal body elements, and by one described trace fossil suite consisting of two egg chambers, a body pit, and a crawlway (Bishop et al., 1997; Bishop, Marsh, and Pirkle, 2000; Bishop and Pirkle, 2008). Marine turtles are significantly modified by adaptation to living an active nektonic life in the open ocean, including an increase in body size, reduction of carapace and plastron armoring, development of salt glands, and modification of appendages into oarlike flippers. While graceful in their marine habitat, sea turtles are poorly adapted for terrestrial activities because of their size and highly modified body plan and laterally oriented swimming appendages; they are clumsy moving across land.

Modern sea turtles utilize sandy beaches in the tropical, subtropical, and subtemperate regions for their nesting (Spotila, 2004). Evidence indicates that while individual sea turtles do not nest every year, when they do nest, they commonly deposit multiple clutches of eggs during a single season. Specific sequential events of nesting behavior, exemplified by the loggerhead nesting ethogram of Hailman and Elowson (1992), vary from species to species, but result in similar sedimentary structures in all extant sea turtles (providing a global suite of nesting structures used by indigenous peoples around the world to exploit these resources). Most sea turtles are

solitary night nesters, but some extant species, such as the Kemp's Ridley (*Lepidochelys kempi*), have evolved communal daytime nesting behaviors (Lutz and Musick, 1997), emerging as groups called *arribadas*. The annual nesting of sea turtles on sandy beaches for an interval of over 105 million years (Hirayama, 1998) provides ample opportunity for the preservation of nesting crawlways (Witherington, 1992), turtle nests (Brannen and Bishop, 1993; Bishop et. al., 1997, 2000), and hatchling crawlways to be incorporated into the fossil record whenever back-beach and/or backshore sediments are preserved in the fossil record. Evidence of fossil traces made by nesting sea turtles is only known from recent observations and one described fossilized nesting suite (Bishop et. al., 1997, 2000; Bishop and Pirkle, 2008).

Loggerhead sea turtles commonly nest on the Georgia Golden Isles, a string of 12 barrier islands fringing the Georgia coast (Hoyt, 1967; Frey and Howard, 1988), including on St. Catherines Island (Brannen and Bishop, 1993), a barrier island 16 km long and 2–6 km wide, situated midway on the Georgia coast between Savannah and Brunswick (chap. 1: fig. 1.1).

#### SEA TURTLE NESTING HABITAT ON ST. CATHERINES ISLAND

The literature on Georgia coastal processes, barrier island formation, and coastal ecology is so robust that no comprehensive review of it is attempted in this limited space. However, several pertinent publications stand out as unusually important. These include Hoyt, 1967; Dörjes, 1972; Morris and Rollins, 1977; Frey, Howard, and Pryor, 1978; Howard and Scott, 1983; and Howard and Frey, 1985.

St. Catherines Island consists of two distinctive depositional fabrics (chap. 3: fig. 3.2), a high-standing, rather featureless area to the west and northwest and a low-standing, highly textured area to the east and southeast (Bishop, 1990; Linsley, 1993; Bishop, Marsh, and Pirkle, 2000; Linsley, Bishop, and Rollins, 2008). The high-standing portion of the island, the core, is attributed to the Silver Bluff Pleistocene and the low-standing area is Holocene in age (see Bishop et al., this volume, chap. 3), consisting of marsh and beach ridge complexes. The Silver Bluff core is attenuated by the low-standing Holocene sediments at both ends of the island and along

the oceanic eastern margin. The eastern margin is characterized by broad marsh meadows developed behind long sand spits at Seaside Inlet, Middle Beach, and McQueen Inlet. The south end of South Beach presents a sequence of beach ridge systems that accumulated from north to south and become progressively younger seaward and southeasterly and that possess discrete dichotomous boundaries. These packages of sediment represent rapid periods of accretionary activity during the late Pleistocene and/or Holocene, interspersed with periods of erosional and depositional activity giving rise to "sedimentary accretionary terrains." The pattern of these accretionary terrains attests to the dynamic depositional history of the Holocene part of this barrier island both by their presence and their distribution and provides a powerful tool to decipher the Holocene history of St. Catherines Island and the record of sea level fluctuation in the recent past. These terrains provide ample evidence that St. Catherines has been a dynamic, rapidly changing barrier island upon whose changing coast sea turtles have been nesting for at least the last 6000 years (chap. 3, this volume).

The east side of St. Catherines Island fronting on the Atlantic Ocean is divided into three major beaches by two inlets. To the north is North Beach, separated from Middle Beach by Seaside Inlet and to the south is South Beach separated from Middle Beach by McQueen Inlet. South Beach is, in turn, separated into three beaches by two small channels, Flag Inlet and Beach Creek. These beaches and the sandy margins of St. Catherines Sound to the north and Sapelo Sound to the south provide ~20.1 km of dynamic nesting habitat (fig. 13.3) for loggerhead sea turtles. Its rapid erosion has placed stresses on nesting loggerhead sea turtles as indicated by annual habitat assessments done on St. Catherines Island (Bishop and Marsh, 1999b) and Georgia Department of Natural Resources (Dodd and MacKinnion, 2002), indicating a progressive deterioration of nesting habitat from 1999 to present, with approximately 15% of the present (2007) beach considered adequate for sea turtle nesting (see Bishop and Meyer, this volume, chap. 14).

#### GEORGIA BEACHES

Beaches on Georgia's barrier islands are dynamic systems dominated by tides, waves, winds, and organisms. Tidal energy generated by semi-



Fig. 13.1. Aerial view looking N23°E along the north end of South Beach, northward toward McQueen Inlet at low tide, showing diverse nesting habitats of loggerhead sea turtles on St. Catherines Island, including the McQueen Dune Field with its dunes, abundant washover fans, scarped dune ridges, and eroding hammocks with skeletal trees on beach. Relict marsh mud can be seen on the beach in the foreground. The remains of Beach Hammock lie just beyond the first washover fan, and the area we call "the big washover" lies north of the hammock in the middle of this image.

diurnal tides that average ~2–3 m (6.7–9.8 ft) during two high tides and low tides each lunar day and two spring tides and two neap tides per lunar month leads to daily variation in the level of the high and low tide lines across the beach. The Georgia coast is characterized by low wave energy (normal summer wave heights ~1.0 m) dissipated on barrier island beaches. Sand transfer by wind is a dominant process due to wide beaches and extensive ebb deltas exposed during low tides. Major beach modifications are made during short but intense storms, particularly hur-

ricanes and nor'easters (Davis and Dolan, 1993). Nor'easters rapidly rework the sediment of the beach, dropping the elevation of the beach, eroding a prominent scarp at the back of the beach, and removing or modifying the physical and biological sedimentary structures generated during intervals between storms. These processes give rise to broad, compact beaches, typically 100–150 m wide having a 1°–2° seaward slope separated from the island by the shoreline marked by the latest storm high tide line, and separated into the backshore lying above normal high tide line, and the foreshore, lying below the normal high tide line (fig. 13.1).

#### THE BACKBEACH

Active beach sediments deposited during the most recent storm event overlie eroded inactive sediment underlying the beach and truncate against the backbeach scarp on high areas or merge with washover fans in low areas resulting in a surface layer of horizontally interlaminated quartz sand and heavy mineral sands approximately 50 cm thick. Heavy-mineral sand deposits are often found within the active beach sediment at the back of the beach forming a 10–15 m wide band along the base of scarps or bluffs deposited as a basal bed of the active beach or interbedded with quartz sands (figs. 13.3D, 13.6) as records of smaller tidal and/or storm events (Bishop and Marsh, 1998a). Washover or washin fans form in areas backed by marshes as high-energy storms wash sediment over the backbeach berm (fig. 13.1) onto the surface of the marsh meadow or into the fringing forest.

Between storms or high spring tides, the backbeach is modified by wind-dominated processes resulting in secondary dunes and wind ripples accentuated by sorting of quartz sand from the heavy-mineral suite. Sedimentary structures produced include horizontal lamination, festoon cross-bedding (fig. 13.6), and small-scale ripple cross laminations. Storms produce heavy rains that form rills resulting in minor scour and fill structures and occasional blowouts through the upper beach. These processes lead to Georgia beaches that are comprised of sand that is very compact and very firm in contrast to soft, loamy Florida backbeaches.

#### THE FOREBEACH

Forebeach sediment redeposited by storm events is sorted daily by waves on flood and ebb

tides resulting in quartz sand interlaminated with diffuse laminae ("ghostly lamination") of heavy minerals dipping seaward at  $1^{\circ}$ – $2^{\circ}$ , on the lower foreshore; the upper foreshore is steeper (sloping at about  $2^{\circ}$ ) and becomes gentler on the lower foreshore (sloping at about  $1^{\circ}$ ), becoming more level and often rippled. Sand "waves" advance onto the foreshore from the seaward side, giving rise to beach ridge and runnel systems producing seaward, gently dipping laminated sands and shoreward-facing, steep cross-bed sets. Repeated migration of ridges onto the shoreface may result in formation of backbeach terraces, berms, and eventually erosional scarps (as the terraces are subsequently eroded). Runnels, characterized by ripple marks, are usually connected to the ocean by shallow channels crossing seaward ridges. Where beach obstructions are present and in the troughs of runnels, complex chaotic scour and fill systems form. Sounds, tidal inlets between the barrier islands, have steeper forebeaches and complex ripple-marked tidal flats with megaripples forming at midtide level at the shoulders of the island on ebb deltas.

Exposures of ancient marsh on the beaches of St. Catherine's form relict mud deposits providing powerful evidence of landward barrier island migration. The erosion of beach exposures of relict marsh mud and entrained marsh body fossils and deposition onto the surrounding beach and shoreface provides evidence of dynamic intermixing of ancient and modern shells of all types and the processes of ecological mixing and stratigraphic leaking of fossils from one age to another.

#### THE BEACH TO ISLAND TRANSITION

Behind the beach are accretional dune ridge systems and forested high-standing Pleistocene deposits, forested ridge and swale systems, and/or marsh meadows. Bluffs or scarps develop along elevated sections of shore, spits or berms along low areas. Washover fans are deposited in low areas by storms carrying sediment over the berm onto the flat surface of marsh meadows, low-lying forests, or interdune swales. Erosive forested areas develop prominent areas of skeletal trees on the beach, locally called "boneyards."

This transitional zone marking the backbeach-island transition (i.e., the spring high-tide line) is the preferred site of deposition of loggerhead sea turtle nests (see chap. 14: fig. 14.1) studied on St. Catherine's Island and the preferred site of sea turtle nesting worldwide.

#### SEA TURTLE NESTING TRACES

Nesting by sea turtles has been described as a behavioral sequence of events (Caldwell, Carr, and Ogren, 1959) that includes, but may not be confined to: (1) locating a nesting site, (2) construction of a body pit by digging, (3) digging an egg chamber and depositing a clutch of eggs, (4) covering the nest, and (5) returning to the sea. One additional event, (6) hatching and emergence of the hatchlings, should be added to complete this sequence.

The sequence and duration of behavioral nesting phases (a nesting *ethogram*) was documented by Hailman and Elowson (1992: 3) for loggerhead sea turtles nesting on Jupiter Island, Florida. Hailman and Elowson's nesting ethogram is summarized by a sequenced list of discrete nesting events that will be tied to potential and documented trace fossils in this chapter: (1) approach to the beach, (2) ascent of the beach, (3) wandering to find a nesting site, (4) construction of a body pit, (5) excavation of an egg chamber, (6) deposition of the eggs, (7) backfilling of the egg chamber, (8) covering of the body pit and egg chamber, (9) return to the ocean. Total nesting time on Jupiter Island, Florida, for loggerhead sea turtles was reported to average 63 minutes by Hailman and Elowson (1992: 3). However, time for phase 3, wandering, was not reported because this behavior is unusual on the soft, hospitable Florida beaches, but often seen on the firmly packed erosional shores of Georgia.

Traces produced by these activities that are observed from modern sea turtle nests (fig. 13.2) consist of three general types (Brannen and Bishop, 1993): (1) trackways made as the female or hatchlings cross the beach, (2) disruption of backbeach or dune stratigraphy by digging and backfilling of the nest, and (3) structures made by predators attacking the eggs. Described traces of sea turtle nesting have been lacking in the literature, because of the low preservation potential of the beach environment. However, the long geological history of sea turtles (105 million years), and the intensity of annual nesting (some Florida beaches have ~1700 nests per km), suggests that these activities do result in preservable traces in the fossil record. This was demonstrated by the description of the world's first documented sea turtle nesting structures (Bishop et al., 1997).

The typical nesting sequence predicted by the nesting ethogram involves selection of a nest-

ing site, egress of the turtle from the sea onto the beach, selection of a suitable nest site located at the backbeach, the digging of an egg chamber, covering of the nest, and reentry into the ocean (Hailman and Elowson, 1992); these behaviors

produce a predictable suite of nesting structures (figs. 13.2 and 13.3). Crawling across the beach produces distinctive *crawlways* (figs. 13.3C, 13.5A–C) with species-specific morphologies. The nest (when used in a general context, *nest*

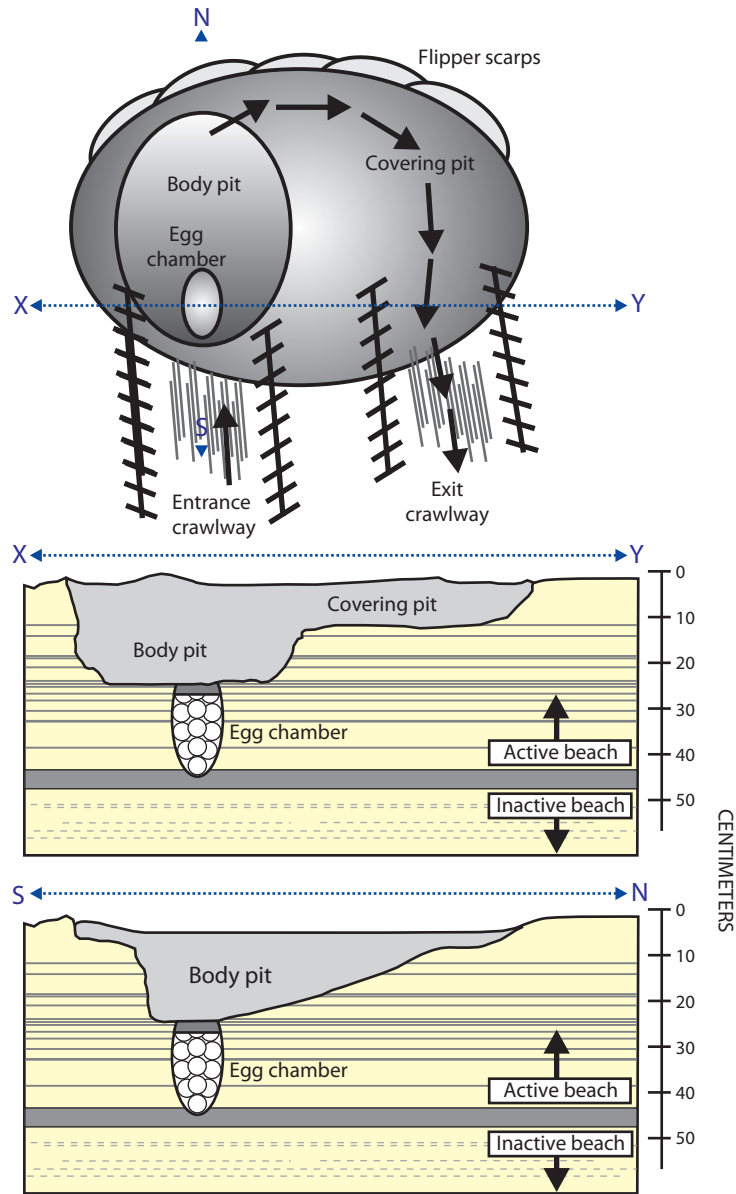


Fig. 13.2. Diagrammatic morphology of loggerhead sea turtle nest in horizontal (map) and two vertical (cross sectional) views to show bioturbated sand of egg chamber neck, body pit, and covering pit in contact with laminated backbeach sediment of the active beach, overlying the inactive beach.

will include mainly the area immediately surrounding the covering pit) is constructed by excavation of a depression about the size of the turtle (the *body pit*; also called the primary body pit by Witherington, 1992) into the loose surface sand (fig. 13.3A), which allows the turtle to then dig an *egg chamber* (figs. 13.3B, 13.6A–C) with its rear flippers into the underlying damp, cohesive sand to a proper depth to insure incubation. The total depth of the egg chamber is controlled by the length of the reach of the turtle's rear paddles; therefore, the nest depth is controlled by the stretched length of rear paddles added to the body pit depth (Carr, 1967). Once a clutch of eggs is deposited, the egg chamber is backfilled with the rear paddles and tamped (fig. 13.3D), and then the turtle goes into a covering behavior, which not only covers the body pit and its egg chamber, but significantly enlarges the nest area as the turtle scoots forward and rotates (fig. 13.5C–F). Many workers consider this to be part of the body pit, but it might be more precisely thought of as the *covering pit*, also known as the secondary body pit of Witherington (1992). The egg chamber, body pit, and covering pit constitute the nest.

Nesting loggerhead sea turtles approach the beach by swimming in from the sea. As they reach shallow water they stop swimming and begin crawling up the shoreface until they reach the backbeach. Nesting by loggerheads is initiated by temperature cues sensed from the sand. Stoneburner and Richardson (1981) reported that when a crawling loggerhead encounters a temperature gradient of 2.1°–3.6°C at a distance 0.5 m across the beach, nesting behavior is triggered. This normally corresponds to crossing the boundary from sand cooled by seawater on the last high tide(s) onto sands not cooled by tidal inundation, but rather sand warmed by receiving a full day's complement of solar heat.

Frey and Pemberton (1987) briefly described and figured a sea turtle crawlway made during its nesting on a Georgia beach (Frey and Pemberton, 1987: fig. 17). Nesting loggerhead sea turtles emerge primarily at night, apparently to escape desiccation and predation. They somehow select a nesting beach, often exhibiting great fidelity to a given location, then crawl across the exposed beach to a nesting site that is typically on the extreme backbeach or on the seaward slope of the first dune ridge (see chap. 14: fig. 14.1). The crawlway is typically a linear path of medial drag marks made by the turtle's plastron and

intermittently prostrate neck bordered by lateral tracks made by the flippers pushing backward against the beach surface. Nesting sea turtles often crawl onto the beach without completing a nest, producing a trace (fig. 13.5) called a *non-nesting crawlway*. Nonnesting crawling activity may indicate an aborted nesting attempt or could be an evolutionary behavior to distract predators by laying lines of misinformation onto the beach. Nesting crawlways often indicate an extended search by the female for an adequate nesting site as she crawls about on the back part of the beach, forming a wandering crawlway. The turtle produces a crawlway called *entrance crawlway* as she crawls to find a nesting area. A second crawlway (the *exit crawlway*) is made after nesting is completed as the turtle returns to the sea. Similar, but much smaller and much more abundant, exit crawlways are made by emergent loggerhead sea turtle hatchlings (fig. 13.3F) as they scamper en masse from the emergence crater nest site toward the sea. The length of these crawlways is dictated by the width of the beach, which in turn is controlled by the height and stage of the tide at any given point. Nesting and hatchling crawlways are extremely ephemeral traces, being easily obliterated by subsequent high tides, windblown sand, or heavy rainfalls. Hatchling crawlways are similar to nesting crawlways, differing from them by being much smaller, by being very abundant, often so abundant that they cannot be differentiated one from another, by originating and fanning from a depression (the *emergence crater*) at the neck of the egg chamber, and, hence, by being much more ephemeral.

#### SEA TURTLE NESTS ON ST. CATHERINES ISLAND

Monitoring behavior of the loggerhead sea turtles nesting on the beaches of St. Catherines Island between 1990 and 2008 has allowed the observation of approximately 2195 nests and ~6000 nonnesting crawlways made by loggerhead sea turtles involved in nesting activity. Documentation of these traces presents a database of Recent sea turtle nesting traces that eventually led to the recognition of fossil traces of nesting sea turtles. Approximately 400 nests have been photographed, sketched, measured, and documented in field notebooks and approximately 150 nests have been trenched to expose vertical relationships within the entraining beach sediment. It

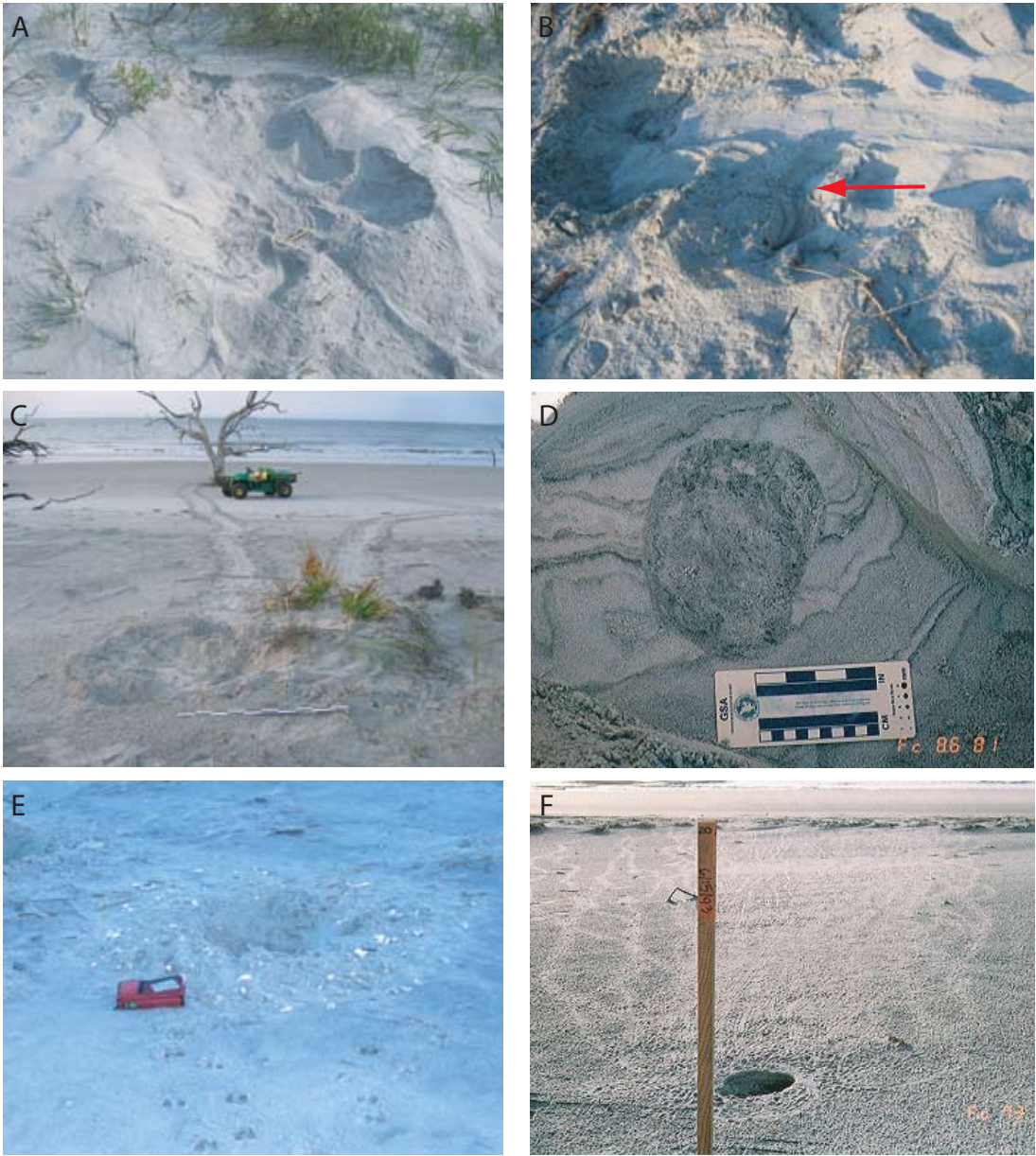


Fig. 13.3. Sedimentary structures of loggerhead sea turtle nests on St. Catherines Island. **A**, Body pit with outline of loggerhead sea turtle unsuccessfully attempting to nest on South Beach; **B**, open egg chamber (arrow) in first of four body pits made by a loggerhead sea turtle nesting on South Beach in 1906; **C**, covering pit of a simple, unobstructed, washover-fan nest [Nest 1906]; **D**, brecciated backfilling of egg chamber discontinuity surrounded by laminated backbeach sediment of a backbeach nest [Nest 1906]; **E**, depredation crater made by a feral hog depredating a simple, unobstructed loggerhead sea turtle nest (note hog tracks and shell fragments); **F**, emergence crater and hatchling crawlways of a loggerhead nest [93-033] on the morning after its emergence. Scales in C and D = 1.0 m or 10 cm.

must be emphasized that these observations are limited to nests deposited by two species on one barrier island, and ought to be interpreted with some caution and not overextended in application to the nesting by all sea turtles, fossil or living.

The nests on St. Catherines Island are protected from predation by raccoons and feral pigs by placing a  $91.4 \times 121.9$  cm ( $3 \times 4$  ft) wire or plastic (since 2006) mesh screen centered above each nest's egg chamber. In order to do this, the egg chamber and clutch are located, validating that a given crawlway is indeed a nesting crawlway and allowing the precise center of the screen to be located directly above the egg chamber. To do this the nest must be "read," i.e., the suite of nesting traces of the turtle depositing the nest is deduced from crawlways, nest size, shape, and topography. These data are then integrated with our nest search model (fig. 13.2) and tested by excavating the covering pit to locate the egg chamber in the underlying body pit that was obscured by the covering activity.

The first step in reading a nest is to ascertain the probability that the turtle actually nested. Evidence of nesting is indicated by the presence of a covering pit, often with a swirled appearance, flipper scarping along the covering pit margins, thrown sand surrounding the covering pit, and (on ebb tides) significant differences in lengths of short entrance and longer exit crawlways. The turtles' direction of crawling into the nest is determined by crawlway clues, including Vs (produced by the dragging ends of flippers) opening in the direction of the crawling, push marks (asymmetric steep faces on backside of push marks) facing the direction of crawling, crosscutting relationships of the crawlways (exit crawlway crossing entrance crawlway), and crawlway drags across the covering pit (exit crawlway forming a smoothed exit ramp from the nest; see chap. 15, this volume). This information is recorded in the field notebook in the form of a description and sketch, photographs, and/or videotape, before validation by digging begins. This preserves as much information as possible before evidence presented on the surface is destroyed by excavation of the nest. The sketch and a verbal description of the turtle's nesting activity also allows us to develop major and alternative hypotheses as to the most probable position of the egg chamber before the surface evidence is compromised.

Data taken on covering pit size, orientation, and morphology are integrated with crawlway

data to ascertain the direction from which the turtle entered the nest area. This usually suggests the relative position of the egg chamber (about half-turtle length [40–50 cm] on the midline of the entrance crawlway into the nest), because most turtles will pit and nest once they enter a suitable area. The probable position of the egg chamber can then be validated by excavation using a small entrenching shovel, trowel, or stem of a palm frond (see chap. 15, this volume). The soft sand of the covering pit and body pit will be bioturbated and churned up by the nesting activity. On St. Catherines Island this mottled, bioturbated sand usually stands in stark contrast to the highly laminated, firmly packed quartz and heavy mineral sands of the backbeach that underlie the covering pit. This stratigraphic relationship allows the position of the egg chamber to be determined by carefully excavating to expose undisturbed laminations of the backbeach sediment beneath the bottom of the body or covering pit, then carefully digging laterally, scraping the bottom of the body pit until the neck of the egg chamber is encountered as a circular *egg chamber discontinuity* (fig. 13.3D; see also figs. 15.2–15.4) cutting through the laminated sands beneath the body pit. The bioturbated filling of the egg chamber neck often appears marbled or brecciated and usually stands in remarkable contrast to the contourlike patterns of the surrounding, nearly horizontal interlaminated quartz and heavy mineral sands of the backbeach. Less contrast is evident in nests deposited in the more homogeneous sands of the dunes. The geometry of the body pit, usually deepest posteriorly, often assists in locating the egg chamber as one follows the bottom of the body pit downward toward the egg chamber discontinuity. Nests deposited in heavy mineral sands are often masked beneath the heavy mineral deposit, which often obscures the egg chamber discontinuity.

Subsequent to hatching, approximately 15% of the loggerhead nests on St. Catherines Island have been excavated by trenching to investigate their stratigraphic relationships. A flat sand shovel and trowel are used to excavate a trench in front of nests, the back face is leveled into a vertical wall, and the back face is shaved back until the egg chamber is encountered. The wall is then shaved back to approximately the center of the nest's egg chamber on both sides and carefully carried into the egg mass in an attempt to define the nest boundaries and enclosing stratigraphy.

Trenches usually expose (fig. 13.9D, F, H) approximately 50–80 cm of active beach overlying older, inactive beach sediments.

Information on loggerhead egg chamber morphology has been gathered since 2007 using casting techniques of Billes and Fretley (1992) and Raymond Carthy (personal commun. from <http://www.flmnh.ufl.edu/natsci/herpetology/Uf-herp.htm>). Open egg chambers (i.e., those dug but not filled by eggs [figs. 13.3B, 13.4A] or backfilled by sea turtles in aborted nesting attempts), or egg chambers left open after relocation of clutches of eggs are filled with expandable Polyurethane foam (Great Stuff™ Gap and Crack Filler by Dow Chemical Corp.) to produce an impression of the interior of the egg chamber (actually a mold of that interior surface). Because we relocate a substantial proportion of our at-risk or doomed nests on St. Catherines Island, those emptied egg chambers are often replicated by casting (fig. 13.4B–D). Upon extraction by excavation, the mold surface retains grains of the entraining sediment and forms a three-dimensional sedimentary peel, providing evidence of beach microstratigraphy. The size and geometry of egg chambers can thus be rapidly preserved and, after study, are used as manipulatives in K–12 classrooms of our teacher-interns (fig. 13.4C, D).

Hatchling loggerhead sea turtles emerging from nests on the backbeach or seaward-facing dune slopes emerge forming *emergence craters*, rapidly orient toward the sea, and form narrow *scamper ramps* toward the ocean, which take the form of triangular aprons (fig. 13.3F) with diverging sides as the hatchlings approach the surf zone.

Nests that are depredated may retain some of the physical evidence of nesting, but usually are strongly modified by digging activities of the egg predator. Small predators disrupt them less, such as ghost crabs that burrow into them and raccoons (*Procyon lotor*) that commonly dig one or more exploratory holes until they locate the egg mass (Anderson, 1981). Large predators, such as feral hogs (*Sus scrofa*) (Hayes, Marsh, and Bishop, 1995), root the entire nest area (fig. 13.3E) into a cone-shaped depression, destroying much of the evidence of nesting activity.

#### BEACH CHARACTERISTICS AFFECTING NEST MORPHOLOGY

The characteristics of beaches on the Georgia coast are very different than those of beaches

on the eastern coast of Florida. Georgia beaches are comprised of finer-grained sand, have less shell entrained as particles, and contain significant amounts of heavy minerals. The beaches of Georgia have a much higher tidal range, ~2–3 m (6.7 ft–9.8 ft) vs. 0.61 m (2 ft) than those at Juniper Beach, Hutchinson Island, a somewhat higher wind regime (waves average ~1.0 m at St. Catherines Island), and are far less urbanized than Florida beaches. As a result, Florida beach profiles tend to be narrower, steeper, and softer with a soft loamy sand substrate backed by continuous linear dune ridges. Georgia beaches tend to be wide, gently inclined and backed by numerous transitional environments and are largely erosional. They have a very compact, firm surface from the low tide line to the dune line or storm scarp. These differences account for nest variation that reflects differing beach conditions.

#### GEORGIA LOGGERHEAD SEA TURTLE NESTING STRUCTURES

##### LOGGERHEAD SEA TURTLE CRAWLWAYS

Crawlways of nesting loggerhead sea turtles (Frey and Pemberton, 1987: 342, fig. 17) consist of large, linear plastron drags paralleled by rows of alternating paddle prints made by the sea turtle's flippers as they push and pull the large animal across the beach toward backbeach nesting habitat (fig. 13.5A–C). These traces are the size of mature loggerhead turtles, approximately 60–110 cm in width, extending from water's edge at the time of ocean emergence onto the backbeach. Trails of turtles entering the beach (entrance crawlways) can be distinguished from trails made moving off the beach (exit crawlways) by evidence provided by the direction of V-like patterns front flippers make in the sand (Vs open in direction of crawling), by rear flipper push marks (steep faces of imprint face the direction of crawling), differing length of the traces (shortest crawlway is entrance crawlway on ebb tides), and by crosscutting relationships (exit crawlway often crossing over entrance crawlway). Each species of extant sea turtle produces a slightly different crawlway morphology (Witherington, 1992). Crawlways are extremely ephemeral traces, especially those lying below the high tide lines that are immediately obliterated by the subsequent high tide.

Crawlways of hatchlings (fig. 13.3F) mirror the morphology of those of nesting females, dif-



Fig. 13.4. Open egg chambers are often replicated by filling with expandable polyurethane foam to produce a mold of the size and geometry of the interior of the egg chamber and produce a three-dimensional peel of beach microstratigraphy. **A**, Natural open egg chamber of aborted loggerhead nesting attempt on South Beach (emergence 06-132); **B**, polyurethane foam impression of open egg chamber, shown in **A** (emergence 06-132); **C**, polyurethane foam impression being produced by K-12 teacher-interns in St. Catherines Island Sea Turtle Program for research and for use as a classroom manipulative [08-117w]; **D**, teacher-intern Cindy Hatala carrying *her* manipulative (foam egg chamber cast) back to her classroom to teach her students about sea turtle nesting ecology.

fering from them by being much smaller, by generally being unidirectional, by occurring in large groups rather than as individual crawlways, and by originating from emergence craters and fanning out toward the sea. The crawlways are linear trails or drags made by the plastron paralleled by two pairs of paddle prints on either side of the plastron drag. The patterns made by the hatchlings in their scamper for the sea are subparallel, but often have a braided, anastomosing pattern made as the hatchlings cross one another's trails. The pattern of individual crawlways becomes obliterated by interweaving as the number of hatchlings approaches 20 or 30 crawls.

#### VARIATION OF GEORGIA LOGGERHEAD NEST MORPHOLOGY

Loggerhead nesting trace assemblages (figs. 13.2, 13.3, 13.4A, 13.5, 13.6C, D, and 13.9B, D, F, and H) typically consist of the entrance and exit crawlways that lead to and from the nest, which consists of an elliptical area of several square meters. The nest consists of the circular or elliptical area of disturbed or bioturbated sand with a swirled appearance on the surface of the nest caused when the turtle generally moves forward and rotates clockwise or counterclockwise before exiting the nest, usually passing over the covered egg chamber during covering activity. The nest thus consists of the body pit and its subjacent egg chamber as well as the covering pit, resulting in a surface layer of disturbed sand about 20 cm thick. The egg chamber extends from the bottom of the body pit to a depth of approximately 34 cm. Once egg deposition is completed, the egg chamber is backfilled with bioturbated sand. The surface of the covering pit is typically swirled and of variable relief, which is rapidly modified by wind and rain until its presence is virtually undetectable on the beach surface, usually within hours or days.

The nesting area is increased significantly by a covering activity, clearly an evolutionary adaptation to protect the egg chamber from depredation by increasing the area of search while spreading scent clues over a much wider area. Data taken during 1994 on 70 nests (table 13.1) indicates that the average size of the egg chamber neck was 318.2 cm<sup>2</sup> and the average size of the nest was 3.72 m<sup>2</sup>, yielding a target of cross-sectional area for predation of 1.01%.

Because the level of high tide varies on a monthly cycle, the thermal gradient across the

beach varies in its position; thus the stimulus for nesting varies in position with tidal cycles. During neap tides the high tide on St. Catherines is approximately 0.67 m lower than on spring tide. Therefore, turtles depositing nests during neap tides may receive proper stimuli for nesting, but they nest significantly further out on the beach, resulting in a nest situated some distance in front of the back boundary of the beach. This position will place them in jeopardy of tidal inundation or erosion on subsequent high tides, producing a doomed nest (fig. 13.6C).

#### CLASSIFICATION OF LOGGERHEAD NESTS

Loggerhead sea turtle nests can be classified by their complexity, position on the beach, and surface conditions overcome during nesting. Classification allows one to define commonalities in nest morphology and begin to understand their differences. In the SCISTP (the island sea turtle program) we have classified nests for many years according to this scheme. Two levels of complexity are recognized.

##### COMPLEXITY OF NESTS

**SIMPLE NESTS:** Nests in which the turtle crawls onto the beach, excavates her body pit in loamy sand facing shoreward, deposits her eggs, and exits as she covers by rotating 180° either over her egg chamber or by making a loop shoreward of the nest, forming an elliptical covering pit with entrance and exit crawlways at opposite ends of the nest (fig. 13.5C, E, F).

**COMPLEX NESTS:** Nests in which the turtle crawls onto the beach, often multiple times, wanders about, excavates her body pit in firm sand facing virtually any direction, deposits her eggs, and exits as she covers by rotating around over her egg chamber, forming an elliptical covering pit with entrance and exit crawlways on the ocean side of the nest (fig. 13.5B).

##### POSITIONS OF NESTS RELATIVE TO THE BEACH

In addition to simple and complex nest configurations, sea turtle nests may be classified by four positions relative to the beach, nests deposited on the dunes, the backbeach, washover fans, and forebeach.

**DUNE NESTS:** Dune nests are formed when turtles nest on the front, top, or behind the first sand dunes on the beach; body pits are deep due to dry surface sand; subtle stratigraphic layering masks the position of the egg chamber (figs.



Fig. 13.5. Types of loggerhead nests deposited on St. Catherines Island. **A**, Nonnesting crawlway indicating loggerhead turtle turned around without nesting; **B**, complex, obstructed, backbeach nest [06-086] with complex wandering crawlway made by loggerhead searching for a nesting site, Yellow Banks Bluff; **C**, simple, unobstructed backbeach nest [94-038] with elliptical covering pit showing entrance and exit crawlways, margin of St. Catherines Sound; **D**, simple, unobstructed, loggerhead nest on top of sand dune, north end of South Beach (McQueen Inlet in background); **E**, simple, unobstructed, loggerhead nest in low, ephemeral dunes (a “Florida nest”) at northern end of South Beach; **F**, simple, unobstructed, washover loggerhead nest on a washover at Seaside Spit, North Beach. Scale = 10 cm.

13.3C, 13.5D).

Loggerheads often cross the backbeach boundary onto sand dune fields (if they are present). Nests deposited in this habitat, herein called dune nests (fig. 13.5D) are primarily controlled by topography, as the orientation of the nesting turtle is easily changed by small variations in

slope. Because dune sand is finer grained, drier, and softer than sands of the backbeach, body pits in this substrate tend to be randomly oriented and much deeper, often with egg chambers dug deeply beneath the surface. The orientation of the body pit tends to be extremely random. Egg chamber discontinuities are difficult to observe because the

TABLE 13.1  
Loggerhead Sea Turtle Nest Dimensions

Nest bearing	Length, m	Width, m	Area, m <sup>2</sup>	Egg chamber bearing	Egg chamber length, cm	Egg chamber width, cm	Egg chamber area, cm <sup>2</sup>	Depth top egg	Target %
—	3.20	2.40	6.032	N 49 W	20.0	17.0	267.036	20.5	0.44%
—	1.44	1.53	1.730	N 68 W	19.0	19.0	283.529	29.0	1.64%
—	3.12	2.80	6.861	N 40 W	21.5	19.5	329.279	14.0	0.48%
—	2.48	2.35	4.577	S 88 W	23.0	17.0	307.091	40.0	0.67%
—	2.64	1.68	3.483	S 2 W	24.0	15.2	286.514	21.5	0.82%
—	1.64	1.43	1.842	N 8 E	19.8	15.5	241.039	22.8	1.31%
—	1.30	1.30	1.327	—	29.1	18.6	425.106	18.1	3.20%
—	2.94	1.80	4.156	—	23.0	17.6	317.930	26.5	0.76%
—	2.10	3.15	5.195	—	24.5	15.4	296.331	21.1	0.57%
—	2.26	1.87	3.319	—	24.0	16.5	311.018	23.8	0.94%
—	1.40	2.10	2.309	—	24.0	20.0	376.992	39.0	1.63%
—	2.55	1.54	3.084	—	21.5	21.0	354.608	18.6	1.15%
—	2.38	2.12	3.963	—	20.4	14.2	227.515	33.0	0.57%
—	4.24	1.77	5.894	—	25.2	18.0	356.257	25.4	0.60%
—	4.80	2.20	8.294	—	27.5	23.0	496.766	25.7	0.60%
—	2.48	1.47	2.863	—	22.0	21.0	362.855	27.0	1.27%
—	2.40	1.63	3.073	—	24.0	18.4	346.833	24.4	1.13%
—	2.10	1.90	3.134	—	21.0	17.5	288.635	41.0	0.92%
—	1.90	1.83	2.731	—	19.0	15.0	223.839	23.2	0.82%
N 21 E	1.65	2.10	2.721	S 86 W	18.0	13.5	190.852	29.0	0.70%
N 69 E	2.60	2.20	4.493	N 26 E	28.5	20.0	447.678	15.6	1.00%
S 12 W	1.65	1.80	2.333	N 80 W	20.9	13.6	223.242	38.1	0.96%
—	2.40	2.20	4.147	S 68 W	22.5	18.0	318.087	19.5	0.77%
N 19 E	1.75	1.40	1.924	S 33 W	21.5	15.8	265.956	15.5	1.38%
N 16 E	1.92	2.00	3.016	N 67 W	21.5	19.4	327.590	27.5	1.09%
S 26 W	2.31	2.22	4.028	N 81 W	20.5	18.9	304.303	30.8	0.76%
N 26 E	1.70	3.00	4.006	N 28 W	24.0	22.0	414.691	36.0	1.04%
Average	2.35	1.99	3.72	—	22.6	17.8	318.2	26.2	1.01%

stratification of the dune sand is relatively subtle compared to that of backbeach. Upon emergence, hatchling loggerheads tend to head down slope on the dune surface and may wander in interdune swales until they reorient toward the sea.

**BACKBEACH NESTS:** Backbeach nests are formed when turtles nest at, or above, the spring high tide line, often in, or below, fresh or old wrack mats, and/or in heavy mineral layers (fig. 13.5B, C).

The backbeach is the preferred location for nesting by Georgia loggerheads (see Bishop and Meyer, chap. 14: fig. 14.1). Most turtles crawl and nest between the spring high-tide line and the storm high line, depositing their clutch immediately shoreward of the normal reach of tidal inundation. Because this is also the location for the accumulation of beach debris as flotsam, the location of skeletal tree "boneyards," and scarps or ephemeral dunes, these nests will often be obstructed, complex nests. In areas undergoing erosion where scarps or bluffs lie behind the beach, turtles will often attempt to crawl up the scarp face, then be turned by its steepness or height, and crawl for some distance along the base of the scarp before they nest.

Backbeach nests are vulnerable to tidal inundation on spring tides, which normally does not significantly affect the nest except for decreasing hatching success. However, these nests are extremely vulnerable to saltwater or freshwater inundation and/or erosion during nor'easters, thunderstorms, and hurricanes. These normal effects of the habitat, along with depredation, may be the driving force for the evolution of deposition of multiple clutches by sea turtles.

**WASHOVER FAN NESTS:** Washover fan nests are formed when turtles nest on a washover fan; nests are deposited in laminated sands and egg chambers are often deposited in damp or wet sand susceptible to repeated inundation and to being washed out or buried by the formation of accreting ephemeral sand dunes (fig. 13.5F).

Washover fans are typically areas where the eroding beach is backed by marsh meadows and, on high spring tides and especially during storm surges, the eroding beach washes over the backbeach berm and/or through the ephemeral sand dunes. When loggerheads nest on beaches backed by washover fans, they often cross onto the washover fan, dig a washover fan nest, and become disoriented, especially after nesting and attempting to return to the sea. This disorienta-

tion results in excessive wandering as the nesting turtle apparently attempts to reorient to the sea without slope clues provided by the beach surface. Turtles observed nesting in this habitat have been documented wandering as far as 465 m (1535 ft) after nesting (nest 94-026). Upon emergence, hatchlings usually radiate over 360° in searching for a beach slope to lead them to the sea, and exhibit extensive disorientation across the surface of the washover fan, often ending up in the marsh.

**FOREBEACH NESTS:** Forebeach nests are formed when turtles nest above high tide level on a neap tide; the nest is deposited below spring high tide line level and will be inundated by spring high tides and storm tides; this part of the beach is very firm and often wet below, eggs are deposited in shallow egg chambers, often barely covered (fig. 13.6C).

Forebeach nests are deposited seaward of the spring high tide line. This occurs during neap tides when the sand above high tide level is solar heated, allowing the turtle to trigger as she crosses from wet, tidally inundated sand onto the warm, solar-heated sand above the high (neap) tide line. The differential position of the high tide line on neap and spring tides in the Georgia Bight at St. Catherines Island is 0.6 m, translating to a lateral distance of approximately 6 m. Because the underlying beach sand is firm and well packed, nests on the forebeach are often small and shallow, barely having a covering pit. Clutches of eggs are close to the surface and vulnerable to depredation as well as certain inundation by the sea.

#### OBSTRUCTED AND UNOBSTRUCTED NESTS

Two conditions relative to surface obstructions on the beach produce different styles of nests, those that were obstructed in some way during deposition and those that were not obstructed.

**OBSTRUCTED NESTS:** Turtles often encounter obstructions (wrack, grasses, exposed or buried logs, buried soil, root zones, or peat) as they attempt to dig a body pit or egg chamber, often resulting in wandering crawlways, multiple attempts to dig egg chambers, and chaotic nesting behaviors; this results in complex nests, clutches of eggs often placed in odd places (outside the covering pit beneath the wrack mat, beneath clumps of grass, beneath and alongside logs), and thin bioturbated covering layers (fig. 13.5B).

Loggerheads nesting on the backbeach often

encounter obstructions when they attempt to nest. These obstructions may consist of trees in skeletal "bone yards," the backbeach storm scarp, or wrack mats. Each of these obstructions to nesting interrupts and introduces chaos into the turtle's nesting behavior. Such nests are much less predictable than unobstructed nests, primarily because the turtle is turned from her entrance orientation and often wanders along or among the obstructions until she finds a suitable nesting site. When such a site is found, the nesting behavior begins regardless of direction the turtle is facing and regardless of nearby obstructions. Obstructed nests tend to involve larger areas and be extremely unpredictable in orientation during egg laying. Under such conditions, nests are often deposited against, or under, buried logs, beneath the edge of surrounding wrack mats, and in other unexpected areas. One of the most common nesting obstructions on St. Catherines Island is a prominent backbeach storm scarp that has formed on virtually all high areas of the island whether on dune fields, linear accretional dune ridge systems, or Pleistocene island core.

Turtles often nest in sand overlying buried wrack mats or in the wrack mat overlying beach sand. When they do so, they usually complete their nesting ethogram; however, the presence of a wrack mat interferes significantly with nesting activity, causing the egg chamber to be often isolated from the covering pit and underlie the turtle's crawlway or even be deposited in the surrounding wrack mat. These nests are easy prey for raccoons but difficult for humans to locate due to lack of visual clues. Hatchling turtles can be trapped beneath the wrack mat and may be unable to reach the surface.

**UNOBSTRUCTED NESTS:** Turtles may encounter no significant obstructions to nesting, resulting in elliptical nests with clearly defined entrance and exit crawlways, flipper scarps, and a hummocky bioturbated surface covering layer (fig. 13.5C, E, F).

Loggerheads nesting on open beaches crawl onto the beach until they sense that conditions are correct for nesting and dig an unobstructed nest. At that point the turtle begins wallowing out a body pit (fig. 13.3A) that is roughly the shape and size of her body, shallow at the front and deeper behind. Because the turtle is usually facing away from the ocean as she crawls, unobstructed nests will almost always have the egg chamber centered on the seaward side of the entrance crawl-

way just inside the nest area. Once the turtle deposits her clutch and backfills the egg chamber, she will characteristically enter a covering behavior in which she moves forward and rotates as she throws sand with her flippers, this activity increases the size of the bioturbated nest area and camouflages the body pit and egg chamber with the scent of the turtle. The nest thus becomes a large elliptical area partially overlying the body pit, or if the turtle turns as she moves forward in her covering behavior, forming a U-shaped nest. In some cases the rotation is so complete that the turtle exits across the body pit and egg chamber almost on line with her entrance crawlway. When the turtle exits the nest area she often crawls parallel to or even crosses her entrance crawlway, forming a large crosscutting crawlway X (fig. 13.5A, C), allowing the exit crawlway to be easily identified as the younger of the two crosscutting crawlways.

#### SUMMARY OF GEORGIA LOGGERHEAD NEST MORPHOLOGY

Loggerhead nest traces in Georgia consist of entrance and exit crawlways, and the nesting structure or covering pit at the surface, hiding the buried components of the nesting suite, the body pit, the egg chamber, and the egg chamber discontinuity (see fig. 13.2). Loggerhead nests on St. Catherines are typically 55 cm deep, normally reaching only a few centimeters into the basal heavy mineral bed or into the inactive sediment underlying the active beach. The upper half of the nest consists of a broad depression having diffuse, disjunct, gently dipping boundaries. The lower half of the nest is a bulbous, cylindrical egg chamber about 18–27 cm in maximum diameter, with near vertical to undercut, sharply defined boundaries. The eggs are deposited in the urn-shaped egg chamber, usually restricted to the lower 20–30 cm (fig. 13.6A, B) of the egg chamber. Most of the egg chamber is occupied by eggs prior to hatching and, upon hatching, a volume decrease opens a small air chamber at the top of the egg chamber, which subsequently backfills with sand as the emerging turtles bump into it with their heads, forming a shrinkage stope that acts like an elevator allowing the hatchlings to mine their way to the surface, and eventually emerge.

Typical nest morphology (fig. 13.2) has thus been constructed from direct observation of new

nests and from trenched hatched nests. This morphology consists of a nesting depression (the body pit) wallowed out by the turtle in loose surficial sand (upper part having gentle, poorly defined sides) until she reaches damp sand into which she can dig an egg chamber (the lower part having vertical walls and containing the egg clutch) with her rear flippers. The nest is subsequently backfilled by the female with homogenized surface bioturbated sand, and subsequently disrupted further as the hatchlings work

their way upward through the sand plug during their emergence. Both processes lead to vertical cylindrical sedimentary structures approximately 20 cm in diameter and 20–30 cm high, which dramatically cut across horizontally laminated sedimentary structures of the backbeach and dunes and are characterized by being filled with mottled (bioturbated) sand that stands in stark contrast (in both horizontal and vertical aspects) to the surrounding laminated sands (fig. 13.3D).

The upper, active layer of backbeach sedi-



Fig. 13.6. Eroded loggerhead sea turtle nests on St. Catherine's Island exposed in vertical aspect giving a geological perspective expected in fossilized sea turtle nests. **A**, Active dune nest [06-119a] on north end of South Beach, McQueen Dune Field, with clutch exposed in scarp formed by 9/11 nor'easter of 2006; **B**, inactive dune nest [2005] with shells of hatched eggs eroded by September nor'easter of 2005; **C**, doomed forebeach nest [06-024] deposited in front of storm scarp 14 m below spring high tide line (foreground); **D**, a trenched, unobstructed forebeach loggerhead nest [97-072] deposited about a meter in front of the scarp on South Beach, showing covering pit and egg chamber (back-filled with white quartz sand) in laminated back beach sediment (floored by 30 cm heavy mineral deposit). Scale = 10 cm.

ment often consists of predominantly quartz sand floored by a thick, basal heavy mineral layer (fig. 13.6D), which is horizontally laminated, having sparse layers of quartz sand and may be cut by quartz sand-filled ghost crab burrows. Normally overlying the basal heavy mineral layer is 20–40 cm of quartz sand horizontally interlaminated with sparse layers of heavy mineral sand. The upper layer usually consists of approximately 10–30 cm of quartz sand interlaminated with festoon cross beds marked by thin laminations of heavy mineral sand.

The sequencing of postdepositional erosional events is important in producing a suite of final sedimentary structures after each nesting event. A typical nest may be modified significantly by beach erosion, with deposits of interlaminated quartz and heavy mineral wave-deposited sand often deposited across the body pit or the egg chamber. Beach deposition often covers nests with prograding dunes, giving rise to the possible preservation of more or less complete sea turtle nest sequences under prograding conditions. Both scenarios should lead to sea turtle nesting suites (sedimentary structures) in Cretaceous and Cenozoic rocks, which might be easily overlooked or misinterpreted by sedimentologists.

Nearly all nests deposited in a given year are located along the line of the backshore either at the base of spring-tide storm scarps, on the front face of primary dunes, or just over the top of backbeach berms or washovers, all within a few meters of the backshore boundary (fig. 13.6). Upon hatching, the hatchlings work their way en masse to the surface and emerge in the cool of the night when sand temperature drops. The emergence may be synchronous as a single cohort of emergent hatchlings, or consist of several emergences spaced over several days. Occasionally the mass of turtles working their way toward the surface are caught by a rain event that dampens the surficial sand, causing it to become cohesive and resulting in an enlarged air cavity, or stope, above the hatchlings. Normal emergence is marked by formation of an emergence crater at the surface and an apron of hatchling crawlways fanning outward toward the sea from this crater.

#### CONCLUSIONS REGARDING GEORGIA LOGGERHEAD NESTING STRUCTURES

The following points about Georgia loggerhead nesting structures can be made:

(1) Nesting sea turtles leave a suite of distinc-

tive traces on the beaches used for nesting, consisting of ephemeral crawlways and more permanent nesting structures.

(2) Nesting females leave large crawlways on the beach as they unsuccessfully (nonnesting crawls) or successfully nest on the backbeach.

(3) Nests consist of a body pit that forms a broad depression in the drier sand, a narrow, cylindrical egg chamber with vertical walls, and a covering pit.

(4) Nest morphology varies with substrate and obstructions presented to nesting, and by species.

(5) Nests form discordant sedimentary structures with a homogenized, bioturbated texture cutting across and downward into backbeach structures characteristic of nearshore dunes and backbeach sediments.

(6) Nests may be preserved intact or attenuated by erosion into very small structures.

(7) Hatchlings leave unidirectional, small scale, subparallel crawlways on the beach when they scamper for the sea.

(8) Crawlways would be difficult to recognize in vertical exposures while egg chambers should be easily recognizable.

(9) Suites of traces of nesting structures allow the rapid assessment of nesting and the location of the clutch of eggs.

#### SEA TURTLE NESTS AND THE FOSSIL RECORD

Turtles have a geological record that extends back to the Triassic, 200 million years into the past (Lee, 1993). Sea turtles have a geological record that dates back 105 million years at least into the Early Cretaceous (Pritchard, 1979; Hirayama, 1998; Kear and Lee, 2006). In spite of this significant fossil record, only one fossil sea turtle nest has thus far been described in the literature. There may be several reasons for this near lack of known fossil sea turtle nests, including low preservation potential of backbeach sediments, difficulty in recognition of fossil sea turtle nests by geologists, and/or low numbers of preserved nests.

In contemplating the paleontological record, the question was posed, “What would the nest of a Cretaceous sea turtle look like?” The range of Cretaceous sea turtles includes small turtles the size of modern sea turtles (i.e., *Toxochelys*) as well as giants such as *Archelon*. The nests of smaller sea turtles would probably look much like logger-

head nests described from St. Catherines Island (Brannen and Bishop, 1993). The sedimentary structures produced by the larger species such as some the Protostegids and *Archelon ischyros*, a sea turtle 3.5 m in carapace length and with a flipper span of 5 m would be spectacular and on a scale difficult to envision, perhaps having a crawlway 4–5 m wide, a body pit 2 m wide and 3 m long, bottomed by an egg chamber 1.5 m deep and 50 cm in diameter, covered by a pit of enormous size, 15 m wide and 30 m long. The resultant suites of sedimentary structures might be difficult for even a seasoned sea turtle worker to recognize.

### SEA TURTLE NEST STRUCTURES OF THE FOX HILLS FORMATION

The Fox Hills Formation is a body of marine and marginal marine sand, silt, and clay deposited along the prograding Cretaceous shoreline as the sediments from the emerging Rocky Mountains were carried eastward into the Western Interior Seaway by eroding streams (Roehler, 1993). The Fox Hills is underlain by the marine Pierre Shale, consisting predominantly of offshore mud and sand lithosomes, and overlain by the terrestrial Laramie or Lance formation consisting of mudstone, sand, and coal beds, deposited on the terrestrial edge of the prograding shoreline.

The Fox Hills consists of fine- to medium-grained sandstone deposited within the shore facies of the Western Interior Seaway in a very dynamic, shallow marine environment marked by abundant burrows (*Ophiomorpha nodosa*) of ghost shrimp, and sedimentary structures characteristic of shallow marine sedimentation.

#### A CRETACEOUS BEACH

A prominent ridge occurs in the eastern 1/2, sec. 23 and the NE 1/4 of sec. 26, SW 1/4 sec. 24, and NW 1/4 of sec. 25, T 8S, R 58 W, Elbert County, Colorado, on land owned by Frasier Farms and United Pacific Minerals. Outcrop exposures (fig. 13.8B) are found along the top of the ridge, particularly on the northeast side, and in a prominent bluff at its north end. Sediments of the ridge consists of a sequence of horizontally bedded quartz sands (occasionally containing *Ophiomorpha* burrows), overlaid by interlaminated quartz and heavy mineral sands, a thin sandy clay that is usually covered, capped by festoon cross-bedded sandstone. On January 18, 1997, an unusual sedimentary structure in the outcrop was

called to the senior author's attention by James Barron. Subsequent fieldwork done in January and February 1997 documented the local stratigraphy and validated the sedimentary structure as the first, and thus far only, recognized suite of fossil sea turtle nesting structures.

A section measured on the east face of the prominent ridge about 100 m south of its north face documents that this sedimentary sequence consists of: (1) a basal sandstone with faint horizontal and cross-bedding (fig. 13.7C), (2) a strongly laminated sequence of heavy mineral layers interbedded with bioturbated sands overlain by a bed of anatomizing sandstones with scour-flute casts on their bases, and (3) a thin homogeneous interval capped by festoon cross-bedded sandstone. This sequence is interpreted to represent a forebeach, backbeach, and backbeach dune field (as depicted in fig. 13.7A). Three complete and a partial fourth sedimentological couplets were delineated within the interlaminated facies of the backshore; each sedimentological couplet consists of a basal interlaminated quartz and heavy mineral layer overlain by a bioturbated bed with indistinct burrowing marked by a mottled pattern stained limonite brown. Samples were examined and collected for petrological and palynological analysis; channel flute orientations in the upper channel facies were measured and found to average N26°E ( $N = 7$ ) while two large channels in the forebeach facies have an orientation of approximately N85°W, and orientations of swash lineations exposed on float blocks from the interlaminated facies averaged N75°E. Sections were subsequently measured at the north face of the prominent ridge and approximately halfway down the length of the ridge to further document the changes in this facies tract.

Although the unusual sedimentary structure was immediately recognized in the field as a sea turtle nest, its origin was initially intentionally denied as alternative hypotheses of formation were formulated and evaluated. A subsequent critical evaluation of photographic evidence in the laboratory attempted and failed to invalidate the structure as a sea turtle nest; the initial deduction was further validated by comparison with photographs of trenched sea turtle nests on St. Catherines Island (fig. 13.9).

#### FOSSIL SEA TURTLE NESTING STRUCTURES

After initial interpretation of the sea turtle nest structure, the outcrop was revisited and

mapped (fig. 13.8) and a second nest structure discovered in a float block broken from the cliff face 4.6 m (15 ft) to the northeast (fig. 13.8D), a dichotomous scour and fill structure (without the expected cross-bedded fill) at a level consistent with it being the body pit of another sea turtle nest at approximately the same horizon 1.5 m (5 ft) to the east (fig. 13.8B). A curious foldlike structure 9 m (30 ft) to the southwest constrained within otherwise horizontal backbeach sediments is interpreted as a nesting sea turtle's crawlway seen in cross-sectional view parallel to the crawlway path, cutting across the flipper push-marks (fig. 13.8A).

Neither the body pit structure nor the crawlway structure by itself would have presented incontrovertible evidence for sea turtle nesting, but when placed in context with two fossil egg chambers, the two structures provide the first trace fossil evidence of nesting by sea turtles. This evidence can now be used to interpret similar structures in the fossil record. During March 1997, the outcrop was revisited to plan for collection of the sea turtle nest structure and the taking of outcrop peels. Collection was accomplished during May 1997 by the Museum of Geology, South Dakota School of Mines and Technology. It yielded six surface peels, two collected nest structures, and documentation of the nest structures, a body pit, a crawlway, and two associated sets of backshore sedimentary structures.

The sedimentary structures, which represent the first described suite of fossil sea turtle nesting structures (figs. 13.8, 13.9A, C, E, G) were documented using techniques developed to document Recent sea turtle nests on St. Catherines Island (Brannen and Bishop, 1993). Six beds are involved in the larger sedimentary structure recording the collapse of otherwise horizontal beds into a cavity within the beach facies. The ledge exposing the structure has a small reentrant beneath the nest, which exposed the bottom of the cavity where open voids are present, and when probed were found to be elliptical holes, inferred to be egg molds (fig. 13.9G). The lower four beds involved in the collapse structure are slightly laminated quartz sandstone and burrow-mottled quartz sandstone; the uppermost mottled bed has sagged into the underlying sand layer and becomes indistinguishable from it within the structure. The bed overlying the mottled layer, a laminated sand layer, has sagged as a coherent layer forming two downward-pointing foldlike structures. The next two beds above it,

the first beds of the active beach facies, with interlaminated quartz and heavy mineral sands, have collapsed downward, forming a single foldlike structure. An overlying light-colored quartz sand layer maintains a horizontal upper surface but has also formed a small foldlike structure above the nest's egg chamber and is overlain by a brownish, mottled sand that has been disrupted on its upper surface by a overlying thick chevron truncating horizontal layers on either side. Continuous horizontal layers of the backbeach facies immediately overlie this bed. A smaller nest structure was found on a float block that had broken off the cliff and could be matched against its breakage fracture on the cliff face. This is a scour and fill structure, representing a washed-out nest that preserves only the lower few centimeters of the egg chamber.

#### COMPARISON OF FOSSIL AND RECENT SEA TURTLE NEST STRUCTURES

The nest structures from the Fox Hills (figs. 13.8, 13.9A, C, E, G) are comparable in morphology, size, and origin to structures seen in loggerhead sea turtle nests excavated by trenching on St. Catherines Island (fig. 13.9B, D, F, H). Nest 93-049 was deposited on July 10, 1993, on North Beach, St. Catherines Island by a loggerhead entering the beach and crawling 67 m in a sinusoidal path southward along the beach toward a dune, turning toward the backbeach, rotating north, pitting, nesting and covering, then crawling northward and looping back 180° and making what initially looked like a major body pit, then crawling back across her nest, and exiting eastward into the ocean. The entrance crawlway was 15–20 m shorter than the exit crawlway.

The clutch of eggs from Nest 93-049, failed to hatch after a normal incubation interval of 50–60 days, was trenched on September 10, 1993, to assess the reasons for its unsuccessful development. This clutch of 117 nonviable eggs was in an advanced stage of development when they died. The trench showed (fig. 13.9F) the unhatched eggs in the egg chamber packed tightly by sand filling in the normal porosity of the egg mass. The sand filling was apparently derived from surrounding and overlying laminated sands of the backbeach facies that had become fluidized by rising groundwater from a set of spring tides that had allowed waves to wash across the nest on four occasions, and from heavy rain and heavy surf during an early September nor'easter. The resulting sea turtle nesting structure exhibits

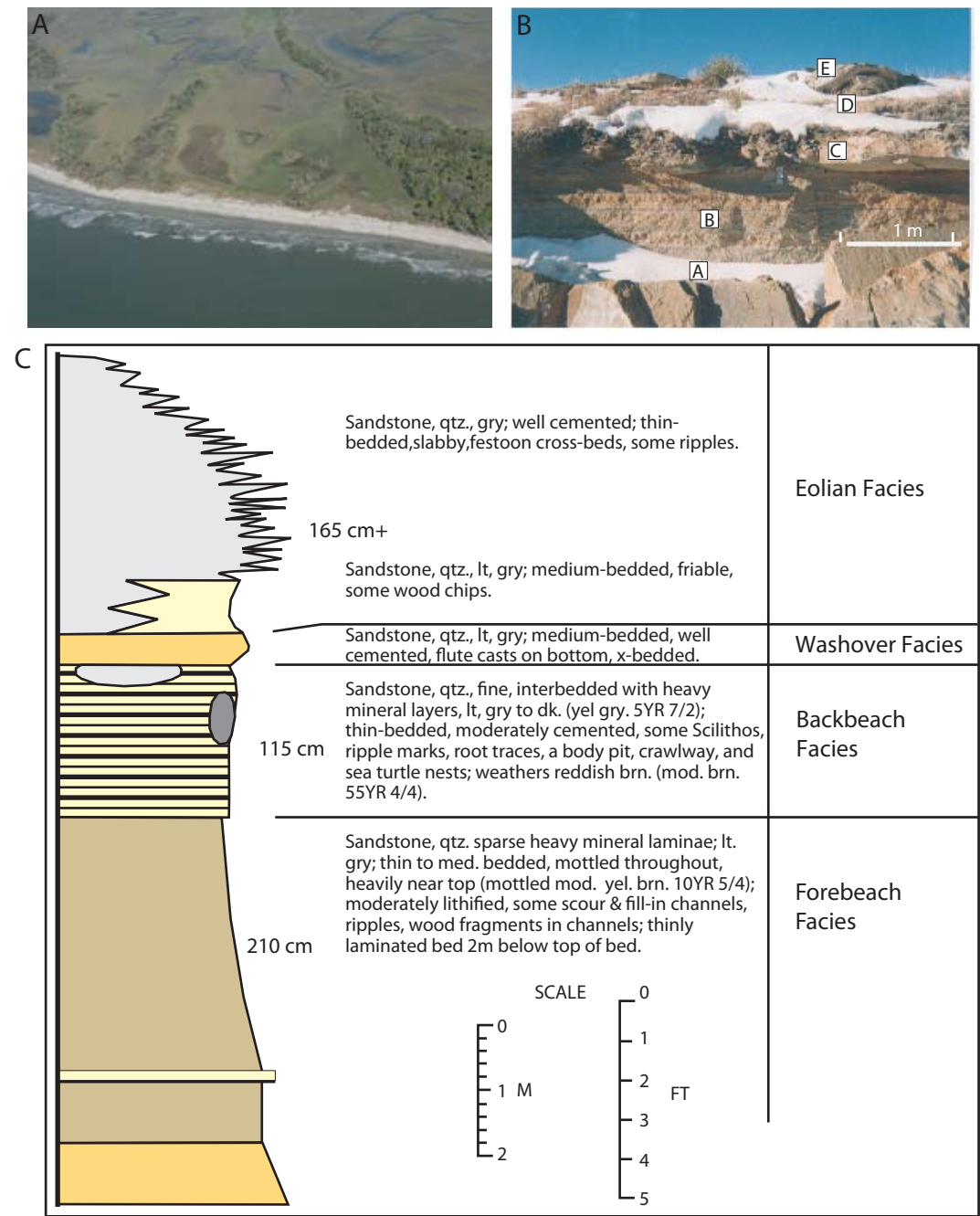


Fig. 13.7. Photograph of analogs: **A**, Beach facies tract on South Beach, St. Catherines Island; **B**, outcrop of beach facies tract, Elbert County, Colorado (labels: A, foreshore; B, backshore; C, washover fan; and D, terrestrial dunes); **C**, diagrammatic measured section at “Titanium Ridge,” Elbert County, Colorado; all illustrating Walther’s law.

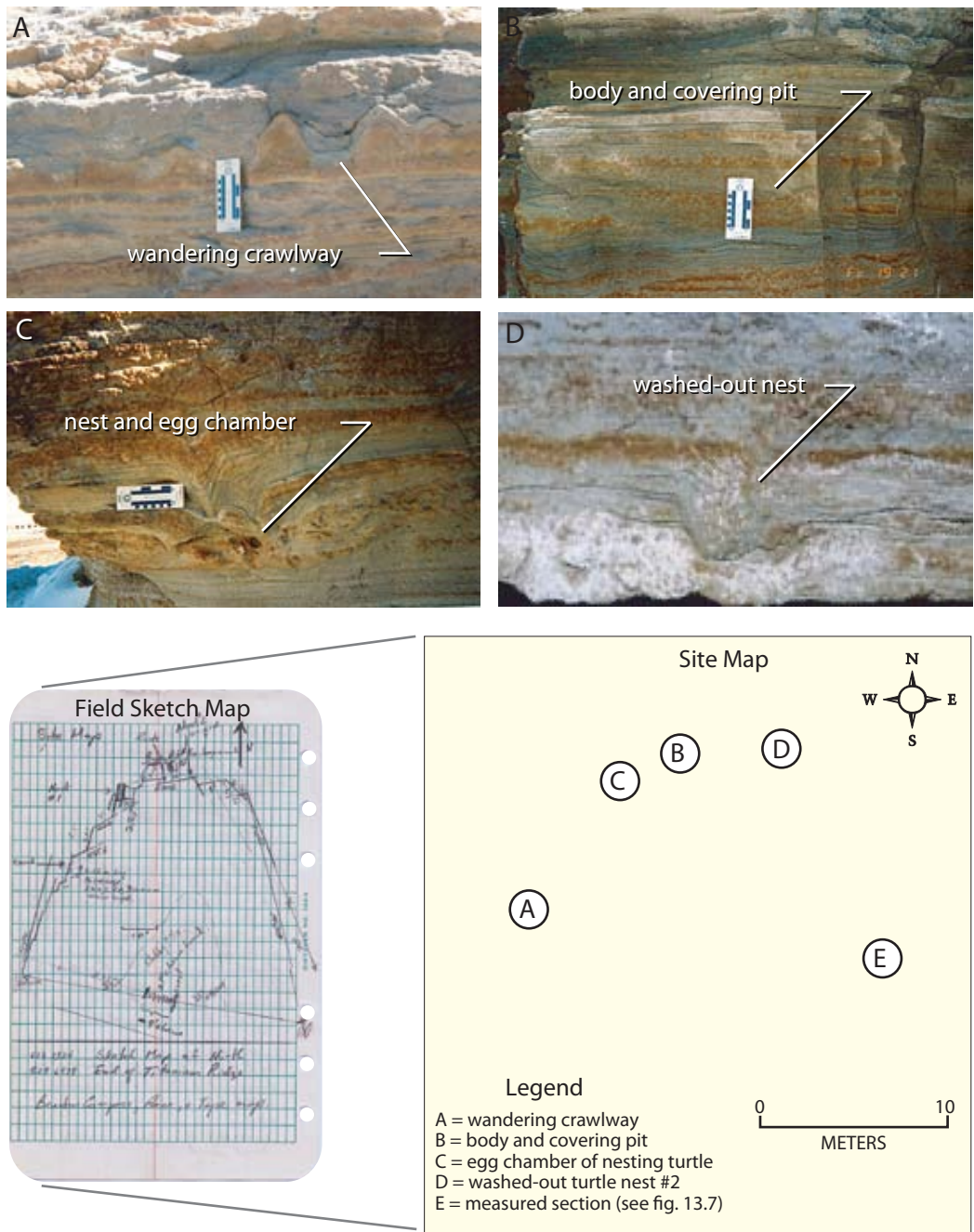
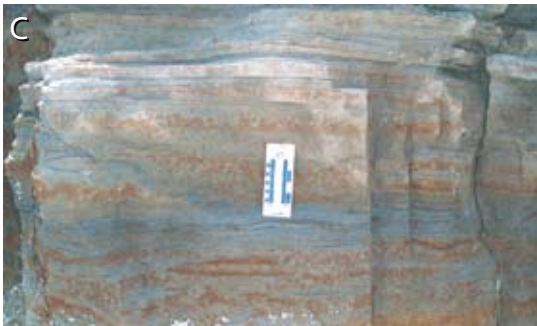


Fig. 13.8. Map view of sea turtle nesting structure suite at north end of "Titanium Ridge," Elbert County, Colorado, showing relative positions of **A**, wandering crawlway; **B**, body and covering pit, in situ; **C**, egg chamber of nesting Cretaceous sea turtle; **D**, position of talus block with second (washed out) sea turtle nest. Bottom figures show field sketch of the north end of "Titanium Ridge," (left) and the locations (right) of the elements of the sedimentary structure suite shown in figures 13.8A-D).



the egg mass of the clutch still intact with the egg chamber delineated into ghostly laminated inactive beach overlain by the sag structure of the laminated quartz and heavy mineral sands of the backbeach facies.

The covering pit structure from the Fox Hills (fig. 13.9C) is a scourlike depression 103 cm across at the top and 25 cm deep at its center, cut into the laminated backbeach facies and filled by bioturbated sand. Comparison with a Recent loggerhead nest 97-079 (fig. 13.6D) shows a favorable correlation (figs. 13.8, 13.9) in the sedimentary structure morphology, lithology of the sediment involved, and the size of the nesting components. In the Recent nest, the eggs were moved and the egg chamber backfilled with white quartz sand that contrasts with a 33 cm heavy mineral placer into which the eggs were deposited.

The Fox Hills crawlway structure, exposed in vertical cross section (fig. 13.9A), is 106 cm long and consists of a series of six "chevron folds" representing six flipper push marks with maximum amplitude of 9.5 cm. This is comparable to crawlway structures made by loggerhead sea turtles crawling across soft sand flats on St. Catherines (fig. 13.9B), which, if buried, would result in a similar structure if seen in vertical exposure.

## CONCLUSIONS

The sedimentary structures in the Fox Hills of Elbert County interpreted as sea turtle nesting traces, including two egg chambers (one with egg molds), a covering or body pit, and crawlway, compare favorably in morphology, size, and association with loggerhead nest structures previously documented on St. Catherines Island, Georgia. Both sets of traces are associated with backbeach sedimentary features including hori-

zontal, interlaminated quartz and heavy mineral layers, washover fans structures, root traces, and desiccation features. The presence of these Fox Hills sea turtle nest structures in Elbert County documents the exact position of the Cretaceous seashore at that time of geological history.

Although sea turtle nest structures will always be ephemeral structures, their geological range and abundance should have preserved numerous examples in the stratigraphic record. Each documented example will locate the exact position of an ancient shoreline.

## NOTES

1. The authors wish to thank Frasier Farms, Union Pacific Land Company, and E.I. Dupont de Nemours and Company for their assistance in documenting the sedimentary structures representing the first described fossilized sea turtle nest found by J. Barron, F.L. Pirkle, and R.S.U. Smith. The citizens of the Limon area, without whose help this project could not have been accomplished, expedited the project. The manuscript was read by Fredrick Rich, Department of Geology and Geography, Georgia Southern University; James Fox, Department of Geology, S.D. School of Mines and Technology, Royce Hayes, St. Catherines Island, Mike Harris and Brad Winn, Non-Game Wildlife Division, Georgia Department of Natural Resources, and Katherine McCarville prior to submittal for publication. All mistakes of commission or omission remain the responsibility of the authors. This research has been supported directly by Georgia Southern University's Faculty Research Committee, the St. Catherines Island Research Center funded through the Edward John Noble Foundation and the American Museum of Natural History, the Eisenhower Higher Education Program for Mathematics and Science Education (51%), the Turner Foundation, JST Foundation, and the Georgia Department of Natural Resources. Special thanks are extended to Royce Hayes and the staff of St. Catherines Island for their support and assistance in facilitating this research, and a special acknowledgment is extended to the memory of the late Robert W. Frey, who encouraged this research.

Fig. 13.9 (*left*). Direct comparison of Fox Hills nest structures (*left*) with analogous recent loggerhead nest structures (*right*). **A–B**. Sea turtle crawlway structures: **A**, Fox Hills crawlway seen in vertical view showing cross section of flipper push marks; **B**, loggerhead crawlway in soft back beach sand seen in oblique view showing deep flipper push marks. **C–D**. Vertical cross sections of ancient and modern sea turtle body and covering pits. **C**, Fox Hills body pit excavated into backbeach sandstone; **D**, loggerhead nest showing body pit excavated into backbeach sand about 1 m in front of storm scarp. **E–F**. Egg chamber structures of ancient and modern sea turtle nests: **E**, Fox Hills sea turtle nest with collapse structures into egg chamber at bottom; **F**, recent loggerhead sea turtle nest filled by fluidized, collapsed sand into egg chamber. **G–H**. Egg molds in ancient nest and eggs in egg chamber of modern nest. **G**, Slightly compressed egg molds in Fox Hills nest; **H**, uncompressed eggs exposed in scarp eroded 9/08/06 into loggerhead nest [06-119]. Scales = 10 cm; bar scales = ~1.0 m.





## CHAPTER 14

### SEA TURTLE HABITAT DETERIORATION ON ST. CATHERINES ISLAND: DEFINING THE MODERN TRANSGRESSION

GALE A. BISHOP AND BRIAN K. MEYER

Loggerhead sea turtles (*Caretta caretta* [Linnaeus, 1758]) nesting on Georgia's Golden Isles (Brannen and Bishop, 1993; this volume, fig. 1.1) have shown a significant, continuous decline since 1964 (Magnuson et al., 1990).<sup>1</sup> Although officially listed worldwide as "threatened," loggerhead sea turtles in the Carolinas and Georgia are a distinct subpopulation that is considered by the state of Georgia as endangered. The decline in loggerhead nesting in Georgia is exacerbated by continually rising sea level (Demarest and Kraft, 1987), entrapment of fluvial sediment in southeastern dams, and deepening of ship channels in southeastern ports leading to sediment deprivation of the southeastern coast. These conditions result in profound and rapid coastal erosion causing deterioration of backbeach nesting habitat used by sea turtles (Georgia Ports Authority/Department of the Army, Corps of Engineers, 1998). These deleterious habitat effects have been studied for 20 years on St. Catherines Island (Bishop et al., 2009), one of the most erosional of the Sea Islands (Griffin and Henry, 1984), and will act as a predictor of the fate awaiting the other southeastern barrier islands.

The target area for nesting loggerhead sea turtles (fig. 14.1) lies at the juncture of the beach and the backbeach area along and just above the spring high tide line (Bishop, 2003; Spotila, 2004; Gulko and Eckert, 2004; McCurdy, 2009). Some turtles will nest behind this line in the dunes or other backbeach area (Rodrigues and Shimizu, 1995). Because of the differing tidal height of neap and spring tides, some turtles that nest above high tide, responding to difference of temperature between cool tidal beach and solar

heated backbeach (Stoneburner and Richardson, 1981), end up nesting below the higher level of the spring high tides, depositing "doomed" nests that are certain to be inundated and drowned on the next spring tide set (fig. 13.6C, this volume). Even those nests deposited at the highest spring high tide level are often inundated by storm tides or surges on nor'easters or associated with hurricanes and are considered "at risk" (see fig. 13.6A, B, this volume). All doomed or at-risk nests on St. Catherines are normally relocated into natural nesting habitat above the storm high tide line, nesting habitat used by naturally nesting loggerhead sea turtles. Conservation of in situ and relocated nests on St. Catherines protects them from abiotic destruction (inundation and washout) and biotic destruction (predation), increasing their hatch success from an estimated 5% (if not conserved) to an actual success rate of ~72%–76% with conservation measures applied (Dodd and Mackinnon, 2006; Engeman et al., 2006; Hayes, Marsh, and Bishop, 1995). The unexpected emergence of sea turtles from 5–11 "wild nests" per year (i.e., nests that were missed during normal daily monitoring and successfully hatched on their own) indicates that there is some significant level of success for unprotected nests, but the very fact that these were missed by daily monitoring by humans probably also means that normal predators (raccoons, hogs, ghost crabs) (Anderson, 1981; Bishop, 2003) would have also missed them for the same reasons (storms, rain, exceptionally high tides with very short crawlways). The total number of unsuccessful wild nests remains unknown.

The nesting ethogram of loggerhead sea tur-

ties (Hailman and Elowson, 1992) is a genetically controlled pattern of nine sequential behaviors that result in the production of a sea turtle nest, a suite of sedimentary structures that disrupts the normal sedimentary fabric of the beach. A typical loggerhead nest on the coast of Georgia consists of entrance and exit crawlways and a covering pit (Brannen and Bishop, 1993; Bishop and Brannen 1993; Bishop 2007); the covering pit hides underlying structures consisting of a body pit and egg chamber (fig. 14.2). Because of the fluctuating high tide line that varies with semidiurnal tides having a difference in tidal range of 2.0 m (6.5 ft) to 2.8 m (9.2 ft), nests deposited at the high tide line during neap tides will be "doomed" (see fig. 13.6C) and drowned by subsequent higher high tide levels on the spring tide sets. The Hailman and Elowson (1992) ethogram has also been applied to the only known fossilized sea turtle nesting structures in the Cretaceous Fox Hills Sandstone of Colorado (Bishop, Marsh, and Pirkle, 2000; Bishop and Pirkle, 2008; Bishop et al., this

volume, chap. 13).

Active processes shaping the Georgia beach include waves, tides, storms, longshore currents, and littoral drift of sediment (Clayton et al., 1992). The normal processes produce a winter beach that tends to be erosional and a summer beach that tends to be accretional. The dominant erosional agent of the Georgia beach is periodic northeasterly windstorms (nor'easters), which may have little or no impact on inland areas (and normally go unrecognized even in coastal weather forecasts except for "high surf advisories"). These storms frequently occur in the winter and move incredible amounts of sediment from the nearshore environment (Davis and Dolan, 1993), lowering the beach surface and eroding a back-beach scarp (fig. 14.3; see also fig. 13.6A). Hurricanes occur less frequently on the Georgia coast; however their erosional effects can be more profound, even with near misses. During the summer, the sand system of the Georgia coast usually moves sand back onto the beaches as a series of

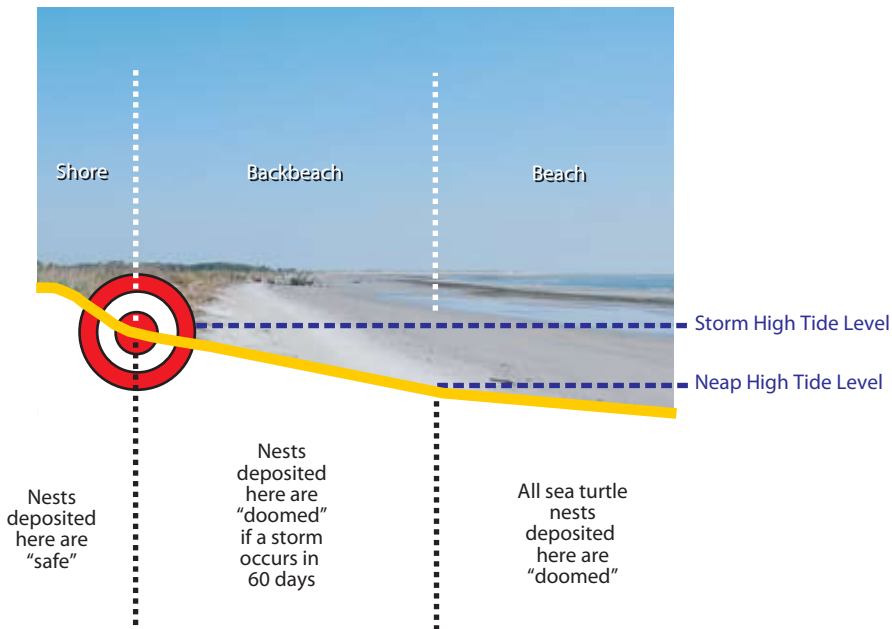


Fig. 14.1. Habitat nesting target of loggerhead sea turtles lies at the boundary between the shoreline and back-beach storm high tide line. Nests deposited between the storm high tide line and spring high tide line are susceptible to tidal inundation during storms, but will normally hatch, although with decreased success. Nests deposited below spring high tide line are inundated on spring high tide sets and storms, and are doomed to failure.

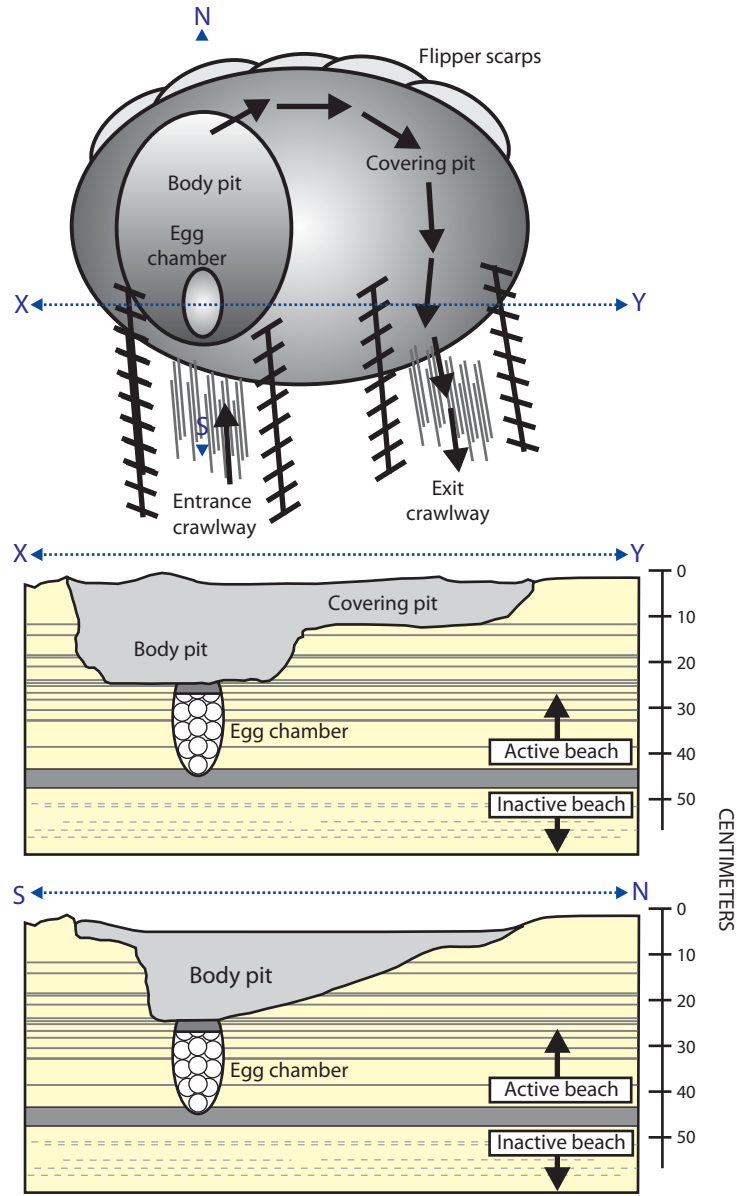


Fig. 14.2. Morphology of loggerhead sea turtle nests deposited on St. Catherines Island; with map view (top) and two cross sections running east-west (X-Y) and north-south (S-N) to show complete suite of sedimentary structures expected in sea turtle nesting. Note that the egg chamber and body pit are covered and obscured by the bioturbated sediment of the covering pit. The boundary between the horizontally laminated active beach is marked by a heavy mineral sand placer (black) and overlies the inactive beach characterized by diffused, ghostly horizontal laminations. Horizontal scale = 1.0 m.

ridge and runnel systems. This seasonal pattern of erosion and deposition is normal and often masks more profound changes, particularly for sporadic observations of occasional beach visitors (Henry, Farrell, Cofer-Shabica, 1993).

Erosional areas on the beach are often marked by a series of one or more features that indicate removal of beach sediment. These areas present themselves as a suite of geomorphic features that can be "read" in the field (Chamberlin, 1890; Bishop and Marsh, 1999b; Frodeman, 1995, 2003). Although the time frame of erosion (time of erosion and rate of erosion) usually cannot be determined with any degree of certainty without direct observation, the many clues that erosional conditions may be present in the environment can be read from even sporadic observational criteria. Short-term evidence of erosion (fig. 14.4) is indicated by lowering of the active beach (fig. 14.4B, C), backbeach scarping (fig. 14.4B), formation of washover fans (fig. 14.4D, E), and exposure of fresh roots in new scarps (fig. 14.4B). Long-term effects include evidence of beach retreat, exposure of relict marsh mud on the beach (fig. 14.4C), and formation of tree "boneyards" left behind as the shoreline migrates inland (fig. 14.4A).

Potter (personal commun.; see also chap. 7, this volume) discussed erosion of St. Catherines Island and surmised that:

At Engineers Road on the north shore, a 0.8 m/yr southward migration of the beach into a forested Holocene dune field has left dead standing pines below the high tide mark. Growth of a large sand bar at the northeastern tip of the island has coincided with up to 20 m of lateral accretion below a 5 m-high Pleistocene bluff on the northern stretch of the east shore. In contrast, the southern 0.7 km-long stretch of this Pleistocene bluff has eroded at rates ranging from 1.3m/yr to 2.4 m/yr. South Beach extends 4.8 km southward from McQueen Inlet and has the highest rates of erosional retreat. Flag Pond was breached by 10.4 m of lateral erosion during a 1992 winter storm, and its freshwater flora and fauna has been replaced by saltwater species. Retreat of 2.1 m/yr at Beach Pond over the past six years has made the breach of this last fresh water pond along the eastern shore imminent.

Washover of beach sand into marshes is common along much of South Beach, Middle Beach, and North Beach, resulting in exposure of marsh muds on the beach face as erosion progresses inland.

## HABITAT DESCRIPTION

The sea turtle nesting habitat of St. Catherines Island is situated along the beachfront, sound margins, and small hooklike beaches lying behind the back shoulders of the island on the intra-coastal waterway. This habitat consists of a mosaic of sediment packets that are largely erosional (figs. 14.4 and 14.5) with lesser units of neutral or accretional areas (fig. 14.5). This mosaic of habitats changes over time and continues to change dramatically from year to year (fig. 14.11). The shoreline of St. Catherines Island (bounded by St. Catherines Sound, Sapelo Sound, and the Atlantic Ocean) consists of approximately 21,141 m. Of this, 18,818 m (89%) are currently (1993–2006) undergoing erosion and 2323 m (11%) are currently (1993–2006) undergoing accretion. There are some extremely small transitional areas that seem to balance between erosion and accretion, but they are relatively insignificant.

Beaches of St. Catherines Island are predominantly composed of a firm, fine to very fine sub-angular quartz sand with interlaminated layers of heavy mineral sand, concentrated along the backshore (Bishop, 1990; Darrell, Brannen, and Bishop, 1993). The upper beach has a seaward dip of approximately 2° and the lower beach has a dip of approximately 1°. Interspersed along the beach are patches of relict marsh mud that may be covered by a thin veneer of sand or exposed (fig. 14.4C), depending upon the state or erosion of the beach. Small tidal flats are present at the northeast and southwest shoulders of the island, comprised of fluidized muddy sand. The St. Catherines Sound margin is currently highly erosional because the sound is apparently migrating southward, cutting into St. Catherines Island. Ebb deltas (fig. 14.5B) are present at St. Catherines Sound (where a large exposed bar is present along with ebb delta shoals), at the mouth of Seaside Inlet (Seaside Ebb Delta), at the mouth of McQueen Inlet, and at the mouth of Flag Inlet (as the very small Flag Ebb Delta). The north margin of Sapelo Sound has formed as a hook from St. Catherines beach, which swings westward to enclose a small lagoon (which we

call south lagoon).

**EROSIONAL HABITATS:** When the removal of sediment exceeds its accumulation by deposition, an area will recede or erode (called transgression). On St. Catherines Island, erosional areas are usually marked (fig. 14.4) by bluffs, scarps,

relict root zones, tree boneyards, relict marsh mud, and washover and washin fans.

**RELICT MUDS:** Barrier islands, being narrow accumulations of sand that fringe coastlines, are often associated with broad, protected marshes behind them and in Georgia often have seaside



Fig. 14.3. The erosional power of nor'easters is impressive when viewed up close during the storm event, with gale force (20–50 mph) winds, a moderate storm surge of 1 to 2 ft, and a 9 to 10 ft surf. **A**, Atlantic Ocean during nor'easter battering Yellow Banks Bluff, and washing over Seaside Spit forming washover fans. **B**, A nor'easter breached Flag Pond Isthmus forming a new lagoon (Flag Lagoon) and inlet (Flag Inlet) during the winter of 1992–1993.



Fig. 14.4. Erosional habitats usually offer clear evidence of the erosion. **A.** Yellow Banks Bluff not only exhibits a prominent erosional scarp, but also harbors an impressive “boneyard” of skeletal trees. **B.** As storms such as nor’easters impinge on the shore they excavate the beach, form pervasive scarps, and expose root balls and clean roots on coastal vegetation. **C.** When the beach is lowered by erosion, buried relict mud deposits are exposed, or lie just beneath a masking veneer of beach sand. **D.** In areas backed by low-lying maritime forests, sand may be washed over the backbeach area and into the forest, forming wash-in fans. **E.** In areas backed by low-lying marsh meadows, the sand washed over the backbeach forms washover fans.



Fig. 14.5. Neutral habitats, where erosion and deposition are in equilibrium, include ebb deltas and accretional terraces. **A.** Seaside Inlet seen at mid-ebb tide—neutral habitat of this ebb delta is submerged (and would be deleterious to a sea turtle nest!). Note the washover fans on Middle Beach (left) and North Beach, and small dune trying to maintain itself on the north flank of Seaside Inlet. **B.** St. Catherine's Sound seen from east at mid-ebb tide—neutral habitats include St. Catherine's Bar (ebb delta in foreground) and accretional terrace in front of and to right of small tidal pond on north end of North Beach (left background) (aerial photography by Artist in the Sky, April 24, 2008).

marshes on the oceanward side protected by spits (fig. 14.6A) or hooks. These marshes trap suspended mud and host a distinctive flora (e.g., *Spartina* grasses) and distinctive marsh fauna differing from those of the sandy coast or the terrestrial mainland. The sediment consists of variable mud textures with interspersed channel lag deposits of tidal streams and fringing bioherms built by lagoonal organisms (e.g., the oyster *Crassostrea virginica*) (Morris and Rollins, 1977). Root zones characteristic of marsh meadows and homogeneous muds often border tidal streams. As a coastline begins to retreat by erosion, the sands of the beaches are removed laterally or washed over the backbeach forming a bermlike wave of sand that progressively moves shoreward as washover or washin fans. If this erosion encounters marsh sediments, the sand will be dumped on top of the edge of the marsh and the marsh exposed as part of the "beach." These mud exposures (Morris and Rollins, 1977) are said to be relict marsh muds (fig. 14.4C) because they antedate the beach and are therefore older than the beach sediments with which they are associated. Relict marsh mud is exposed on the beach as patches of mud surrounded and veneered by beach sand. Marsh features clearly recognizable include *Spartina alterniflora* root peats, *Crassostrea virginica* oyster bioherms, in situ quahogs (*Mercenaria mercenaria*) and mussels (*Geukensia demissa*), and abundant burrows of fossorial shrimp (*Callinectes major*) and crabs.

**RELICT ROOT ZONES:** As the veneer of sand is rolled back over the front of an island in a series of washover fans or as a migrating berm, it buries the backbeach marsh beneath it, killing the marsh grasses (fig. 14.4E). As erosion continues, the buried soil zones reappear on the backbeach marked by zones of rooted stubble of grass and shrub stalks.

**TREE "BONEYARDS":** Hammocks or maritime forests inundated by the transgressing sea are first buried in the advancing sand wave if they are low-lying features or are undercut by wave notching and subsequently flounder by mass wasting onto the backbeach. The trees rapidly die and begin to decompose, losing bark and root ball soil, eventually forming skeletons of trees buried in the sand. These skeletal trees, called "boneyards," may topple or remain standing and can be moved about during high tides or storms (figs. 14.3A, B; 14.4A, B, D). They may accumulate along the shoreline scarp (fig. 14.4B)

or bluff (fig. 14.4A) as an intertwined mass of wood or remain as discrete entities along the backbeach (fig. 14.4D) where they form armor on the beach and are slowly eroded by breakage and abrasion.

**SCARPS:** Scarps are small-scale nearly vertical erosional drop-offs that often mark the boundary between the backbeach and island; they are formed by the erosion caused by the waves of the highest storm tides (fig. 14.4B). Scarps form by wave erosion and subsequent mass wasting. Newly formed scarps are characterized by "clean" exposed roots and nearly vertical facies, often showing sedimentary structures of the eroding backbeach facies. As scarps mature they become subdued; sedimentary structures become less obvious as the scarp is washed over by cascading sand carried in runoff or by sand-blasting by wind blown sand, often burying the toe of the scarp in a talus from above and from small secondary dunes deposited along the backbeach.

**BLUFFS:** These are large-scale, nearly vertical drop-offs (fig. 14.4A) that mark the backbeach boundary in areas with considerable relief, or areas of high dunes or high land, as in the island core of St. Catherine's Island (Bishop, 1990; Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008; Reitz et al., 2008). The processes of formation are the same as for scarps, but erosional effects are magnified by their greater height so the slope angle of the bluff and the talus at its toe are more readily apparent.

**WASHOVER FANS:** Washover fans form wherever the beach is backed by marsh meadows. Normal beach processes build a berm that often becomes vegetated, and subsequently the vegetation often catches sand in its wind shadow (the area baffled by grass decreasing the wind velocity, so suspended and saltating sediment drops out of suspension), causing small dunes or dune ridges to form. During exceptionally high water levels, spring tides, or storms, berms and dunes are overwashed by breaking waves and sediment is carried behind the beach as a series of tongue-like washover deposits (fig. 14.4E) up to ~20 cm thick. These washover deposits often form as a series of interbraided sand tongues thrown over the berm by subsequent high tides or coalesce into single, broad, ramplike landward-dipping washover fans (fig. 14.4E). Occasional reversal of density stratification has been observed with heavy minerals deposited on the washover surface over less dense quartz sand.

**WASHIN FANS:** On highly erosional islands, such as St. Catherines Island, washover fans develop along low backbeach margins bordered by maritime forest (fig. 14.4D). If the sand washes over the back of the beach and into the forest, it forms a type of washover fan that can be called a “washin fan.”

#### NEUTRAL HABITAT

Neutral habitats occasionally occur that are neither erosional nor depositional. Among these are channels of tidal creeks or inlets emptying into the ocean as at Beach Creek at the southern tip of St. Catherines. Neutral habitats are (at least temporarily) in equilibrium with sediment movement along the coast (fig. 14.5). The ebb deltas of St. Catherines are treated herein as if they are sediment neutral, although they are one of the most dynamic of coastal environments, rapidly changing size and shape as tidal currents and storm currents move the sand in and out of the sounds and inlets as it is being transferred along the coast from north to south.

**EBB (AND FLOOD) DELTAS:** Ebb deltas are formed from transported sand as strong tidal currents flow on the outgoing, or ebbing, tide (fig. 14.5). Normal ebb delta features include a bulge of sand built seaward from the inlet with bars, shoals, and distributary channels. At low tide, the ebb delta is almost fully exposed and wind, particularly nor'easters, blowing across the wide expanse of sand often will move great quantities as saltating grains into dune fields that build downwind of the deltas. As the tide changes and begins to flood, sand is carried by the rising tide back through the inlet and deposited as flood deltas (fig. 14.3B) within the tidal creeks.

#### DEPOSITIONAL HABITATS

When the delivery of sediment exceeds its removal by erosion, an area will accrete, building forward into the adjacent ocean (called progradation or regression by geologists). On St. Catherines Island, accretional areas (fig. 14.6A) are usually marked by accretional terraces, progressively younger beach ridge systems, dune fields, and accretional terrains (fig. 14.6B).

**TERRACES:** Terraces build as accretional waves of sand move onto the shore as a series of “ridge and runnel systems.” Each progressive sand wave is moved onto the beach until it reaches equilibrium with the wave swash and is added to the backbeach as the beachfront builds seaward as an

accretional area. This process often results in the establishment of a level backbeach area termed an “accretional terrace.” Accretional terraces (fig. 14.5) build where the beachfront has prograded seaward, often at bends in the beach due to sounds, inlets, or offshore ebb-delta channels. These accretional areas are extremely vulnerable to rapid erosion during spring tide storms.

**BEACH RIDGES:** The wind can be seen moving sand grains across the low-tide beach on backbeaches with accretional terraces, dropping the sand building small dunes on wrack, clumps of vegetation, and flotsam. These small, ephemeral dunes are extremely dynamic, building rapidly and being just as rapidly destroyed by subsequent winds with different orientation. As the backbeach broadens, the dunes may coalesce into a low ridge of secondary dunes along the edge of the backbeach, which can rapidly build during wind storms as sand is blown off the exposed broad low-tide beach and moves as a sand “ground blizzard” along the flat beach surface and is lifted over the dune and rapidly falls into the wind shadow on the lee side of the accreting dune. In this way scattered backbeach dunes can evolve into a linear dune ridge along the edge of the backbeach (figs. 14.6, 14.9A).

**DUNE FIELDS:** The wind blowing across the low-tide beach on wide backbeaches behind ebb deltas have a large source area in which to pick up drying sand on ebb tides. In these situations, particularly on nor'easters or southeasterly winds, great quantities of sand are moved inland and often form very dynamic sand dune fields, as at McQueen Dune Field (fig. 14.9B) behind the ebb deltas (Shadrui, 1990). This habitat is high and dry and makes excellent nesting habitat except for the dynamics of moving sand that can rapidly expose or bury sea turtle nests.

**ACCRETIONAL TERRAINS:** As an island rapidly accretes seaward due to drop in sea level and/or increased sediment supply, it does so by “fits and spurts,” rapidly accreting, then eroding back due to the effects of storms or changes in sediment supply. This gives rise to accretional wedges, called accretional terrains (Bishop, Vance, and Meyer, 2007), which are geomorphological units that have similar surface ridge patterns, similar parallel orientations, and similar internal structure (fig. 14.6). Accretional terrains are obvious on aerial photographs and orthophotomaps and can be sequenced by position on the island and crosscutting relationships

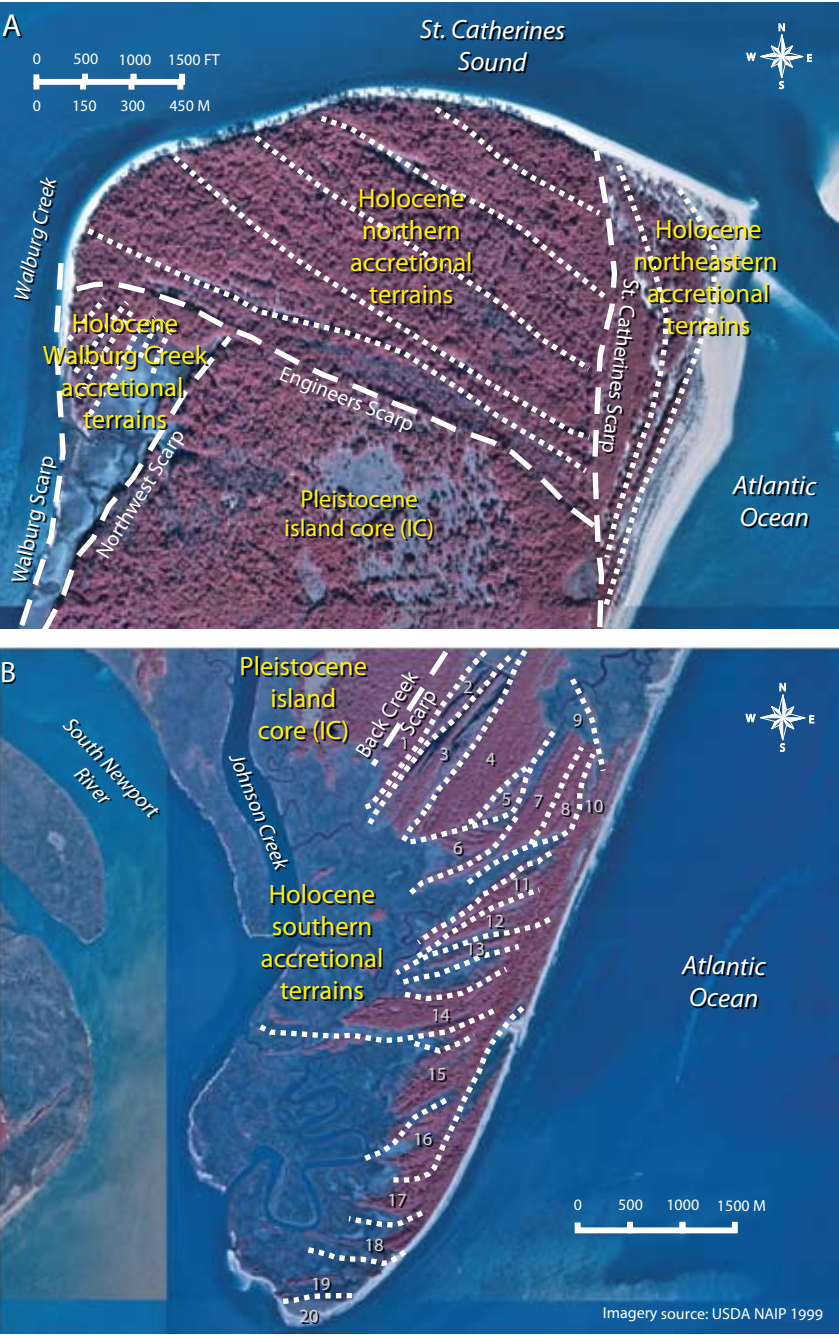


Fig. 14.6. Depositional habitats include accretional terraces, progressively younger beach ridge systems, modern dune fields, and accretional terrains: **A.** On the north end of St. Catherines Island showing the Pleistocene island core (IC), accretional ridge systems deposited by migration of Walburg Creek and St. Catherines Sound, and one of the only accretional areas on St. Catherines Island on northeast corner (compare this image taken on December 31, 1999 with fig. 14.6B, taken April 24, 2008). **B.** Holocene accretional terrains on the southeast part of St. Catherines numbered in sequential order, 1 is oldest and 20 youngest.

(fig. 14.6B). Absolute ages, often difficult to determine, can sometimes be established by radiometric dating of entrained shell, wood, or minerals within the depositional wedge as recovered by vibracoring (see chap. 10, this volume).

METHODOLOGY

In 1998 a qualitative assessment of the deteriorating sea turtle nesting habitat on St. Catharines Island was initiated. This documentation (Bishop and Marsh, 1995, 1998b) consists of a longitudinal survey of beach characteristics on a computer-generated longitudinal GPS grid (fig. 14.7) with a 0.001° point spacing overwritten with a sketch showing the nature of St. Catharines’ beaches (fig. 14.7) (Leslie and Roth, 2003; Stanesco, 1991). At latitude of 30° north (or south), each degree subtends a distance of 68.881 mi of arc. Using arithmetic, the distance subtended by 0.001° of arc = 110.85 m per 0.001°.

The transitional methodology for habitat surveys developed in 1998 and modified in 1999 involved physically surveying the beach with a 100 m spacing with flagging and “permanently” marking points each 1 km. Beach benchmarks (beach entrances, channels, etc.) were subsequently located with GPS, and a longitudinal spreadsheet grid was constructed using a 0.001° spacing along the beach including the beach benchmarks. The spreadsheet, with each grid point printed as rows and beach criteria listed as columns, was printed (fig. 14.7) and carried in the field. A Rapid Habitat Assessment rubric was designed (table 14.1) to rapidly determine and quantify the nesting habitats presented along the beaches. This quantitative assessment has been done annually since 2000 on St. Catharines Island (Bishop, Vance, and Meyer, 2007).

The assessment technique involved a traverse of all beaches from one end of the island to the other, usually done within a few days time to avoid natural variation due to storms or seasonal changes. The surveys were done by driving an all-terrain vehicle from end to end, stopping every 0.001 degrees (~ 111 m), scoring beach condition against the rubric criteria (table 14.1), and recording the condition of the beach as sea turtle habitat on the spreadsheet pages in the notebook. The Rapid Habitat Assessments done in 1998 and 1999 were qualitative, done on a GPS grid, with a sketch map of the beaches actually drawn directly on the grid (fig. 14.7). In 1999 the Rapid Habitat Assessment

tool was refined (Bishop and Marsh, 1999b) and a general set of erosional criteria was established with the scale expanded to 10 divisions (closely linked to “likely percentage of hatching success”). The annual habitat assessment (table 14.2) thus became thought of as a “chance of success” (or risk) assessment for a sea turtle nest deposited at the back of the beach at each GPS point. During most years, a sketch map was also constructed as scoring was noted, showing the presence of bluffs, scarps, ridges, maritime forest, washover and washin fans, terraces, relict marsh mud, ebb deltas, channels, and tree boneyards.

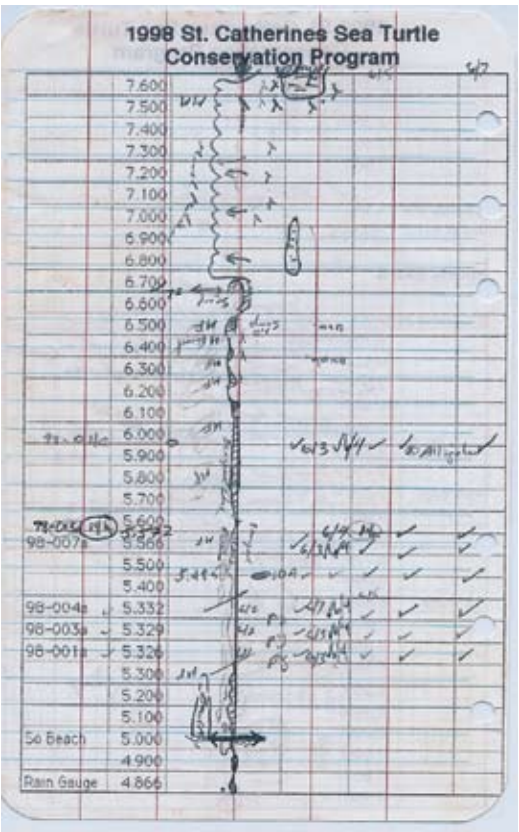


Fig. 14.7. Scanned image of 1998 sketch map depicting sea turtle habitat conditions that were documented as a qualitative sketch, oversketched onto the GPS monitoring grid to illustrate early attempts at characterizing deteriorating nesting habitat, with beach conditions drawn directly onto the grid.

TABLE 14.1  
Rubric for Evaluation of St. Catherines Habitat Assessment

Geomorphic Feature	Normal Scoring Range	Assessment Factors
Channel	0	no hatch possible
Erosional Bluff	0-1-2	highly erosional, at risk
Erosional Scarp	0-1-2-3-4-5-6	erosional, at risk
Erosional Washover Fan	0-1-2	inundation, at risk
Erosional Relict Mud	0-1-2-3-4-5-6-7-8-9-10	depends on backbeach
Sub-surface Problem	0-1-2	define in untested areas?
Neutral Shoreface	3-4-5-6-7-8-9-10	adequate-abv avg-excellent
Accretional Terrace	3-4-5-6	adequate-abv avg-excellent
Accretional Ridges	3-4-5-6-7-8-9-10	adequate-abv avg-excellent
Dune Field	0-1-2-3-4-5-6-7-8-9-10	blowout possible, at risk

In order to better assess the deterioration of sea turtle nesting habitats on the beaches of St. Catherines Island, one of us (Meyer) constructed a shoreline map from historical documents, maps, and aerial photographs for the interval spanning 1859–2006. Data were captured electronically as digital imagery and superimposed over an aerial image of St. Catherines Island (from Google Earth™). The distance over which the shoreline has fluctuated was analyzed and compiled as a series of histograms along the beaches of St. Catherines Island to delineate the overall pattern of erosional and depositional (accretionary) conditions (fig. 14.11).

HABITAT ASSESSMENT RESULTS

Annual rapid sea turtle habitat assessments clearly document the decline in backbeach habitats along the entire length of the front of St. Catherines Island with less than 15% of beach-front considered to be adequate habitat for sea turtle nesting. Escalating erosion has been documented independently by physical measurement of shoreline retreat (see chap. 7, this volume) and indirectly by rapid habitat assessments of sea turtle habitat on St. Catherines beaches.

The quantification of habitat status remains somewhat subjective because the process is one of judgment by the habitat assessor. The quality of the process is dependent upon unbiased assessments (and thus would be difficult to substantiate). The data presented herein were taken annually and not assembled into a comparative format (table 14.2) until December 23, 2008, except for a prior comparison of cumulative beach index information for 2000 and 2001, leading us to believe that no prejudices are built into the technique.

The overall average of habitat quality on all of the beaches on St. Catherines Island has declined significantly over the last decade (fig. 14.8). It was 2.490 in 2000 and 2.516 in 2001 and declined rapidly to 1.994 in 2002 (notes are unavailable for 2003, so that value was computed as the average of values for 2002 and 2004), 1.942 in 2004, and continued to decline to 1.703 in 2005, 1.605 in 2006, and dramatically dropped to 1.207 in 2007, but rose to 1.543 in 2008 and 1.896 in 2009. This decline is largely attributed to an islandwide episode of erosion that has caused rapid retreat of the beaches (fig. 14.11; Potter, Padgett, and Trimble, 2007; Potter, this volume, chap. 7) along much of the front of St. Catherines

**TABLE 14.2**  
**Sea Turtle Habitat Scores by Year for St. Catherines Island's Beaches**

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
En Rd West	31.698	—	—	—	—	—	—	—	—	—	—
En Rd East	81.143	—	0	—	0	—	1	0	0	—	—
SC Sound	81.142	—	0	0	0	—	0	0	0	0	0
SC Sound	81.141	—	0	0	0	—	0	0	0	0	0
SC Sound	81.140	—	0	0	0	—	0	0	0	0	0
SC Sound	81.139	—	0	0	0	—	0	0	0	0	0
SC Sound Margin	81.138	—	5	0	0	—	0	0	0	0	0
SC Sound Margin	81.137	—	5	4	0	—	0	0	0	0	0
SC Sound Margin	81.136	—	6	3	0	—	1	0	0	0	0
SC Sound Margin	81.135	—	6	4	0	—	1	1	0	0	2
SC Sound Margin	81.134	—	6	7	1	—	2	0	0	1	1
SC Sound Margin	81.133	—	7	4	1	—	1	2	2	3	1
SC Sound Margin	81.132	—	5	5	1	—	2	1	4	5	4
SC Sound Margin	81.131	—	5	6	5	—	2	6	—	4	4
NE Shoulder	81.131	—	—	—	—	—	—	—	—	—	—
NE Shoulder	31.696	—	2	7	—	—	—	—	—	—	—
Sand Pit Rd Rookery	31.695	—	1	6	5	—	3	3	3	8	5
Sand Pit Rd Rookery	31.694	—	5	5	1	—	2	5	2	3	0
Sand Pit Rd Rookery	31.693	—	5	4	3	—	2	6	0	1	0
Sand Pit Rd Rookery	31.692	—	5	3	3	—	2	0	0	0	0
Sand Pit Rd Rookery	31.691	—	7	5	3	—	1	1	4	0	6
Sand Pit Rd Rookery	31.690	—	8	8	7	—	4	7	5	3	4
Sand Pit Rd Rookery	31.689	—	9	9	7	—	4	3	7	8	5
Sand Pit Rd Rookery	31.688	—	8	9	7	—	7	5	5	7	7
Sand Pit Rd Rookery	31.687	—	9	7	8	—	6	7	7	8	6
Sd Pit Rd	31.687	—	—	7	—	—	—	—	—	—	—
Sand Pit Rd Rookery	31.686	—	7	5	9	—	5	10	6	7	4
Sand Pit Rd Rookery	31.685	—	5	6	8	—	5	6	3	5	5
Sand Pit Rd Rookery	31.684	—	4	5	8	—	1	2	3	3	3
Sand Pit Rd Rookery	31.683	—	3	4	5	—	2	1	1	3	2
T-Pipe	31.683	—	—	—	—	—	—	—	—	—	—
Yellow B Bluff	31.682	—	3	3	2	—	0	0	1	1	0
Yellow B Bluff	31.681	—	0	2	0	—	0	0	0	0	0
Yellow B Bluff	31.680	—	0	0	0	—	0	0	0	0	0
Yellow B Bluff	31.679	—	0	0	0	—	0	0	0	0	0
Yellow B Bluff	31.678	—	0	0	0	—	0	0	0	0	0

TABLE 14.2 — (*Continued*)

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Yellow B Bluff	31.677	—	0	0	0	—	0	0	0	0	0
Yellow B Bluff	31.676	—	0	0	0	—	0	0	0	0	0
Seaside Ramp	31.676	—	—	—	—	—	—	—	—	—	—
Seaside Spit	31.675	—	0	0	0	—	0	0	0	0	0
Seaside Spit	31.674	—	0	1	0	—	0	0	0	0	0
Seaside Spit	31.673	—	0	1	0	—	0	0	1	0	0
Seaside Spit	31.672	—	1	1	0	—	1	0	2	0	1
Seaside Spit	31.671	—	1	1	0	—	0	0	0	0	0
Seaside Spit	31.670	—	0	1	0	—	0	0	0	0	0
Seaside Spit	31.669	—	0	0	0	—	0	0	0	0	0
Seaside Spit	31.668	—	0	0	0	—	0	0	0	1	0
Seaside Spit	31.667	—	0	0	0	—	1	0	0	0	0
Seaside Spit	31.666	—	0	0	0	—	1	0	1	0	0
Seaside Spit	31.665	—	0	0	0	—	0	0	0	1	0
Seaside Spit	31.664	—	0	0	0	—	1	0	0	0	0
Seaside Spit	31.663	—	0	0	0	—	0	1	0	0	0
Seaside Spit	31.662	—	0	0	0	—	0	1	0	0	2
Seaside Spit	31.661	—	0	2	0	—	1	2	2	0	1
SS Inlet	31.661	—	—	—	0	—	—	—	2	2	—
SS Inlet	31.658	—	—	—	—	—	—	—	—	—	—
Middle Beach	31.659	—	0	—	0	—	0	0	—	0	0
Middle Beach	31.658	—	0	0	0	—	1	2	0	0	0
Middle Beach	31.657	—	1	2	0	—	2	2	0	1	1
Middle Beach	31.656	—	1	0	2	—	4	5	2	2	1
Middle Beach	31.655	—	2	0	0	—	2	1	1	1	1
Middle Beach	31.654	—	0	1	0	—	1	2	1	2	2
Middle Beach	31.653	—	0	0	0	—	3	4	3	3	1
Middle Beach	31.652	—	0	1	0	—	0	0	2	2	2
Middle Beach	31.651	—	0	0	0	—	0	1	3	1	1
Middle Beach	31.650	—	0	0	0	—	0	0	0	0	0
Middle Beach	31.649	—	0	0	0	—	2	1	1	1	1
Middle Beach	31.648	—	0	1	1	—	3	1	3	0	0
Middle Beach	31.647	—	0	2	4	—	4	1	2	1	1
Middle Beach	31.646	—	1	2	3	—	2	2	1	0	0
Middle Beach Berm	31.645	—	2	3	5	—	5	6	4	0	0
Middle Beach Berm	31.644	—	3	3	5	—	6	4	5	1	1

TABLE 14.2 — (Continued)

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Middle Beach Berm	31.643	—	3	4	7	—	6	1	3	0	0
Middle Beach Berm	31.642	—	1	4	8	—	5	3	0	0	0
Middle Beach Berm	31.641	—	2	1	1	—	1	5	1	0	0
Middle Beach Berm	31.640	—	3	6	5	—	1	3	5	0	0
Middle Beach Berm	31.639	—	4	5	6	—	5	2	1	1	1
Middle Beach Berm	31.638	—	4	5	6	—	4	2	0	3	1
Middle Beach Berm	81.137	—	2	—	6	—	2	2	0	1	0
Middle Beach Berm	81.138	—	—	—	5	—	8	1	0	3	0
Middle Beach	81.139	—	—	—	3	—	1	1	1	1	0
Middle Beach	81.140	—	—	—	0	—	—	—	1	1	0
McQueen Inlet	stump	—	—	—	—	—	—	—	0	—	1
McQueen Margin	—	—	—	—	—	—	—	—	—	—	1
McQueen Margin	—	—	—	—	—	—	—	—	—	1	3
McQueen Inlet	—	—	—	8	7	—	—	—	6	0	3
McQueen Rookery	31.633	—	3	8	8	—	2	1	9	5	4
McQueen Rookery	31.632	—	8	7	9	—	7	6	9	9	8
McQueen Rookery	31.631	—	9	7	9	—	8	8	5	8	8
McQueen Rookery	31.630	—	9	8	10	—	7	9	4	7	10
McQueen Rookery	31.629	—	9	10	10	—	10	9	6	0	10
McQueen Rookery	31.628	—	9	9	9	—	8	9	7	0	9
McQueen Rookery	31.627	—	10	10	9	—	9	9	7	2	10
McQueen Rookery	31.626	—	10	9	9	—	10	9	8	9	10
McQueen Rookery	31.625	—	8	3	5	—	5	10	9	9	10
McQueen Rookery	31.624	—	5	2	1	—	3	5	1	7	7
McQueen Rookery	31.623	—	8	5	7	—	6	8	8	4	5
Big Washover	31.622	—	5	3	3	—	2	3	3	1	2
Big Washover	31.621	—	0	0	0	—	0	0	0	0	0
Big Washover	31.620	—	0	1	1	—	1	0	1	2	2
Big Washover	31.619	—	0	3	5	—	0	3	5	1	3
Big Washover	31.618	—	0	1	0	—	2	0	0	0	0
Big Washover	31.617	—	0	2	1	—	2	2	5	1	1
Big Washover	31.616	—	0	0	0	—	0	0	1	2	3
Big Washover	31.615	—	0	1	0	—	4	2	4	1	2
Big Washover	31.614	—	1	2	0	—	3	1	3	2	1
Big Washover	31.613	—	0	0	0	—	1	0	3	2	3
Big Washover	31.612	—	0	1	0	—	0	0	4	3	1

TABLE 14.2 — (Continued)

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Big Washover	31.611	—	1	2	0	—	0	0	0	0	1
—	31.610	—	1	2	1	—	0	0	0	2	1
—	31.609	—	2	2	1	—	1	0	0	0	0
—	31.608	—	1	2	2	—	0	0	0	0	0
—	31.607	—	2	2	1	—	1	0	1	1	1
—	31.606	—	1	1	3	—	1	0	3	1	—
—	31.605	—	3	1	3	—	2	1	0	0	0
Turtle Bowl Nurtury	31.604	—	7	7	2	—	1	0	0	0	2
Turtle Bowl Nurtury	31.603	—	6	4	2	—	1	1	0	0	1
Rattlesnake Rookery	31.602	—	7	6	5	—	2	0	0	0	0
Rattlesnake Rookery	31.601	—	7	4	4	—	6	5	5	1	1
Rattlesnake Rookery	31.600	—	7	4	0	—	3	0	0	0	0
Rattlesnake Rookery	31.599	—	9	8	0	—	3	0	0	0	0
Rattlesnake Rookery	31.598	—	6	7	0	—	3	3	0	0	0
Rattlesnake Rookery	31.597	—	5	7	0	—	0	3	0	0	0
So Beach Ent	31.596	—	—	—	—	—	—	—	—	—	—
South Beach Nurtury	31.596	—	8	8	1	—	1	2	3	0	1
Rain Gage Nurtury	31.595	—	7	6	2	—	6	4	0	0	0
Rain Gage Nurtury	31.594	—	6	2	1	—	1	0	1	0	0
—	31.593	—	4	1	1	—	6	1	0	0	0
High Dune Nurtury	31.592	—	5	1	1	—	2	2	0	0	0
—	31.591	—	4	1	2	—	2	3	0	0	0
—	31.590	—	4	1	1	—	2	4	0	0	0
—	31.589	—	3	0	1	—	3	2	0	0	0
—	31.588	—	2	3	2	—	5	2	3	0	0
—	31.587	—	1	1	3	—	3	0	1	0	0
—	31.586	—	0	0	1	—	1	0	0	0	0
—	31.585	—	1	1	0	—	1	0	0	0	0
—	31.584	—	0	0	0	—	0	0	0	0	1
Flag Inlet	31.583	—	—	—	0	—	—	0	—	1	—
—	31.583	—	0	0	0	—	0	0	0	0	0
—	31.582	—	0	0	0	—	1	0	1	0	0
—	31.581	—	1	2	1	—	0	0	1	1	0
—	31.580	—	1	1	1	—	0	0	0	1	0
—	31.579	—	1	1	2	—	0	0	0	0	0
—	31.578	—	0	0	2	—	0	0	0	0	0
—	31.577	—	0	1	2	—	1	1	0	0	0

TABLE 14.2 — (Continued)

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
—	31.576	—	0	0	0	—	0	1	0	0	0
—	31.575	—	0	1	0	—	0	0	0	0	0
Jungle Road	31.575	—	—	—	—	—	—	—	—	—	—
—	31.574	—	0	0	0	—	0	0	0	0	0
—	31.573	—	0	1	1	—	0	1	0	0	0
—	31.572	—	1	0	1	—	1	0	0	0	0
—	31.571	—	2	1	0	—	1	1	0	0	0
—	31.570	—	0	0	0	—	0	0	1	0	0
—	31.569	—	0	0	0	—	1	0	0	1	0
—	31.568	—	0	0	0	—	0	0	0	0	0
—	31.567	—	0	0	0	—	0	0	0	0	0
—	31.566	—	0	0	0	—	1	1	0	0	0
—	31.565	—	1	1	0	—	1	0	2	0	1
—	31.564	—	1	2	2	—	1	2	2	3	1
South Ridge Nurtury	31.563	—	2	2	3	—	1	1	5	3	9
South Ridge Nurtury	31.562	—	2	0	0	—	4	0	0	0	3
South Ridge Nurtury	31.561	—	2	2	2	—	3	0	1	0	3
—	31.560	—	1	1	1	—	3	0	0	0	1
—	31.559	—	0	1	0	—	1	0	1	0	1
Beach Cr	31.559	—	0	—	0	—	—	—	—	0	—
Beach Cr	31.559	—	—	—	—	—	—	—	—	—	4
—	81.559	—	1	0	0	—	0	0	0	0	0
—	81.176	—	2	2	2	—	3	0	0	0	0
—	81.177	—	0	1	1	—	3	1	0	0	1
—	81.178	—	1	2	0	—	1	1	1	0	1
South Lagoon	81.179	—	2	5	6	—	2	4	3	3	4
South Lagoon	81.180	—	3	0	1	—	0	1	5	1	6
South Lagoon	81.181	—	1	0	3	—	0	—	3	0	4
—	81.182	—	—	2	0	—	0	—	—	4	2
—	81.182	—	—	4	0	—	—	—	—	0	0
—	81.183	—	—	3	0	—	—	—	—	0	0
—	81.183	—	—	0	—	—	—	—	—	0	0
—	81.183	—	—	—	—	—	—	—	—	0	0
—	81.184	—	—	—	—	—	—	—	—	0	—
Little Brunson Creek	—	—	—	—	—	—	—	—	—	—	—
—	—	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
—	average	—	2.490	2.516	1.994	1.753	1.942	1.703	1.605	1.207	1.497

Island (fig. 14.9). However, some areas of stability have remained as remarkably viable nesting habitat (fig. 14.9A, B), particularly the area north of Sand Pit Road entrance (Sand Pit Road rookery [fig. 14.9A]) and the dune field south of McQueen Inlet (McQueen rookery [fig. 14.9B]). Both these areas have undergone erosion and are retreating (Potter, this volume, chap. 7), but because of their former larger size and geomorphic configuration behind large ebb deltas, have provided a consistently high-quality habitat over the last decade and thus form the major sea turtle rookeries found on St. Catherines Island.

Deterioration of sea turtle nesting habitat on St. Catherines Island has been directly measured for over a decade (table 14.2) and could have been predicted by the erosion map presented by Griffin and Henry (1984). It is directly confirmed by the map and graph of the erosional history of St. Catherines Island 1859–2006 (fig. 14.11). This map and graph of erosion/accretion depicts the position of historical shorelines and quantifies the amount of erosion or accretion as

a continuous histogram constructed along the beaches of St. Catherines Island, showing areas of accretion at the north end of North Beach and at the north end of South Beach at the previously mentioned dune field accretionary ridge systems lying behind the St. Catherines Ebb Delta bar and behind McQueen Ebb Delta. Except for these areas, the rest of the front of St. Catherines Island is erosional.

The shoreline dynamics of St. Catherines Island have been studied and evaluated by several researchers (Griffin and Henry, 1984; Potter, Padgett, and Trimble, 2007; Meyer et al., 2009) utilizing varying methods and chronological datasets. The research results have been consistent and successful in demonstrating both spatial and temporal variations during the recent history of the mean high-water shoreline. The recent history of the shoreline of St. Catherines Island is one that may be characterized by widespread retreat or erosion across the vast majority of the island with two small, isolated areas of accretion. These small accretional areas are located on the northeastern portion of the island and south of McQueen Inlet (fig. 14.10A, B). In the northern portion of the island, the rate of erosion on the St. Catherines Sound shoreline has been estimated to vary temporally from 0.8 m/yr to 1.4 m/yr during the time interval of 1859–2006. Erosion on North Beach immediately south of the aforementioned accretional area has caused a westward retreat of the shoreline at rates from 1 m/yr to over 3 m/yr, reaching a maximum of 3.3 m/yr along Seaside Spit and resulting in large washover fans being deposited over the marsh surface to the immediate west. The erosion on the eastern or seaside of the spit and deposition on the western or marsh side of the spit has caused the spit to migrate over 450 m to the west and exposed former marsh mud on the current beach surface and in the shallow subtidal area off North Beach. The Middle Beach portion of the island located between McQueen Inlet and Seaside Creek has shown consistent erosion rates of 2.2 m/yr to 3.1 m/yr for the years of 1859–2006. The most southern portion of the island has also experienced widespread and uninterrupted erosion. This area has undergone erosion rates ranging from 0.9 m/yr to 4.6 m/yr with the most severe rate of 9.2 m/yr at the southern terminus adjacent to Sapelo Sound. The retreat of the shoreline along South Beach has been responsible for inundation of Flag Pond, formerly

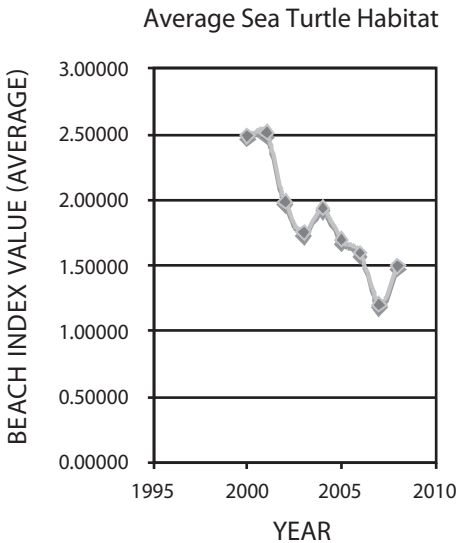


Fig. 14.8. Habitat quality of the beaches on St. Catherines Island has declined significantly over the last decade as indicated by average of all scored habitat values along the beaches from 1999–2008. Value for 2003 was calculated from average of 2002 and 2004 to smooth graph.



Fig. 14.9. Two extant sea turtle rookeries remained on St. Catherines Island in 2008: **A**, Sand Pit Road rookery on the north end of North Beach stretching from Yellow Banks Bluff northward for ~1.1 km to St. Catherines Sound (foreground). **B**, McQueen Dune Field rookery on the north end of South Beach stretching ~1.4 km from the big washover to McQueen Inlet (foreground) (aerial photography by Artist in the Sky, April 24, 2008).



Fig. 14.10. Small patches of beach habitat appear as erosion proceeds, exposing interdune swales and dune facies to access for nesting by sea turtles or for relocation of doomed or at-risk nests: **A**, small area, approximately 5.5 m wide, called “the Blowout,” supported up to 11 relocated sea turtle nests on South Beach for several years until 2002; **B**, a second nearby area ~20 m long, called “the Turtle Bowl,” supported up to 14 nests in 1998 and was still in use in 2009; **C**, South Ridge nursery between 31.56378° N and 31.56260° N formed an area one dune wide near the south end of South Beach in 2008, but was barely in use by 2010. Scale: A, B, stakes are exposed ~1 m; aerial photography by Artist in the Sky, April 24, 2008.

a freshwater ecosystem, into Flag Lagoon (fig. 14.3B) that is currently a marine and saltwater marsh ecosystem. Accretion has occurred in two distinct and separate areas in the recent 150

years. The shoreline in the northeastern portion of the island has moved eastward over 550 m since 1859, resulting in accretion rates of 3.8 m/yr. The area immediately south of McQueen In-

let has prograded eastward or accreted to the east at a rate of 1.9 m/yr to 4.9 m/yr.

#### ST. CATHERINES SEA TURTLE ROOKERIES

The high-quality habitat of the Sand Pit Road dune ridges (table 14.1: Sand Pit Road rookery) consists of ~0.73–1.1 km (as measured on Google Earth™ and computed from table 14.2, respectively) of parallel dune ridges in this accretional terrain. Although the quality of this habitat is stable and consistently high, its utilization by sea turtles for nesting is also affected by the width of interswale terraces that form wide backbeaches as respective ridges are eroded in this fluctuating, accretional area. Because of its proximity to the ebb delta of St. Catherines Sound with its pervasive bars and shoals, the tidal currents, presence of St. Catherines bar, and offshore shoals often block access to this otherwise high-quality nesting beach (fig. 14.9A). South of Sand Pit Road entrance, subsurface conditions (a buried peat and marsh mud) dam island drainage into a high-standing water table capable of flooding interdune swales and flooding any nests deposited at or near sea level (see chap. 3, this volume). However, high dune ridges that occasionally grow across this terrain often provide an excellent habitat with sufficient elevation to consistently hatch clutches of eggs. The adequate to excellent habitat in this rookery has declined from 1443 m in 2001 to approximately 666 m (a devilish number!) in 2008.

The McQueen Dune Field (see fig. 14.9B; table 14.2, McQueen rookery) once consisted of an extensive area covered by multiple dunes and dune ridges (Shadrui, 1990) that was formed by northeasterly winds blowing across McQueen Ebb Delta and has since been dramatically eroded into a much smaller dune field, but has remained the best sea turtle nesting habitat available on St. Catherines Island for over two decades. The linear extent of this habitat measured parallel to the beach is ~1.07–1.44 km (as measured on Google Earth™ and computed from table 14.2, respectively), but its extent perpendicular to the beach has been reduced to a narrow strip one dune ridge wide at its south end to a maximum width of 85 m near its north end (in 2008). The adequate to excellent habitat in this rookery has declined from 1332 m in 2000 to 1110 m in 2008 (see this volume, chap. 8).

Two formerly stable rookery areas were present on St. Catherines until 2002. The south mar-

gin of St. Catherines Sound was bordered by good nesting habitat, the St. Catherines Sound margin rookery, which essentially disappeared in 2002 as St. Catherines Sound migrated southward, eroding that habitat away. A second stable rookery was located north and south of South Beach entrance on South Beach, which we called the rattlesnake dune rookery to the north, which at that time extended for approximately 1.44 km in 1998, but was nearly completely eroded away by 2002, except for sporadic pocket nurseries (two of which we informally called the Turtle Bowl and the Blowout [fig. 14.10A, B], the South Beach Dune, and the South Beach Rain Gage Nurseries are all gone, as of 2010). An ephemeral rookery with a total length of approximately 99 m appeared on Middle Beach in 2001 and reached its maximum length in 2002, but was gone by 2006.

Some areas of persistently poor habitat are also remarkably stable. These include Yellow Banks Bluff, Seaside Spit, and the washovers we call the Big Washover (table 14.2), and the south half of South Beach, from south of the beach entrance nearly to the south tip of the island.

#### ST. CATHERINES SEA TURTLE NURTURIES

The beach to the south of McQueen Dune Field is occupied by a series of washovers (which we have called the Big Washover) that generally consists of poor-quality nesting habitat, except for ephemeral dunes that periodically build on this surface on annual cycles. Nests deposited in them are at risk because the prevalent landform remains a massive washover fan that is periodically reactivated during storm events.

South of the Big Washover is an area that previously formed an interval of good to excellent habitat developed on the edges of large dunes and dune ridges (informally called rattlesnake dunes) until about 2001 or 2002, when erosion became so pervasive that only small separated areas provided adequate nesting habitat. These patches provided small, but significant nurseries (fig. 14.10A, B) for several years (including small patch nurseries we called the blowout, turtle bowl, South Beach Entrance dune, high dune, and swale ridge) between the Big Washover and Flag Pond.

South Beach from the Big Washover to the south end of the island is now (2009) highly erosional and hosts only two small patches of adequate habitat (South Ridge nursery [fig. 14.10C] and Lagoon Ridge on South West Beach). These small areas are very short, ~154 m and ~238 m,

respectively, and each consists of a single dune ridge approximately 5–10 m wide that is extremely susceptible to erosion during storms, but each provides the little habitat left for hatching sea turtle clutches on the south end of South Beach.

Using the criteria established in 1998 and 1999 for rapid assessment of sea turtle habitat, the St. Catherines Island habitat has been measured annually with adoption of the standards set by the Coastal Resources Division of the Georgia Department of Natural Resources in 2001 (Dodd and McKinnon, 2006, personal commun.) In addition to habitat assessment in terms of estimated probability of hatching success, the data can be characterized as a beach index by computing total scored points for each year and normalizing to the number of stations measured (see table 14.2).

#### CONCEPTUALIZATION OF ST. CATHERINES SEA TURTLE NESTING HABITATS

Sea turtle nesting habitat seen on St. Catherines Island that remains unsuitable for hatching sea turtle clutches (~85% of the beaches in 2008) either lacks sufficient elevation to hatch clutches of sea turtle eggs or is so susceptible to erosion that it is unlikely to successfully hatch clutches of sea turtle eggs during any given season. These areas tend to be situated along low boundaries between the sea and the island: spits, channels, above buried mud layers that cause perched water table, or along obviously erosional areas marked by tree boneyards, bluffs, scarps, or washover or washin fans.

Sea turtle habitat seen on St. Catherines Island that is most suitable for hatching sea turtle nests (~15% of the beaches in 2008) usually possesses some elevation above the storm high tide line, is often marked by the presence of an indicator species, Sea Oats (*Uniola paniculata*), or lies on the face of the first sand dune or accretionary dune ridges backing the shoreline. Two types of adequate sea turtle nesting beaches comprise this 15° of beachfront: sea turtle rookeries that are persistent and stable dune or ridge fields that have been intact for nearly two decades (fig. 14.9A, B) and sea turtle pocket natural nesting sites, called nurseries, that represent small, ephemeral patches of habitat that are temporarily exposed as back-beach dunes or interdune swales or as narrow backbeach berms or ridges built by winds blowing across the beach (fig. 14.10) as the beaches continue to retreat due to erosion. These “pocket habitats” possess elevation sufficient to incubate clutches of sea turtle eggs, but are remarkably

susceptible to erosion by storm surges during nor’easters or passing hurricanes (see Bishop et al., chap. 13; see also fig. 13.6A).

It should be emphasized that the successful hatching of clutches of sea turtle eggs is always stochastic. During mild (nonstormy) nesting seasons clutches deposited in low-success habitat may successfully hatch. During stormy seasons clutches deposited in high-quality habitat will be susceptible to being washed out or drowned. However, the overall chance of hatching success is always enhanced by relocation from low-quality to high-quality habitat. This is true as long as this relocation is done carefully and the relocations are placed back into natural habitats that are being used by sea turtles as natural nesting sites (hence the origin of the term *nurtury*, “to nurture,” as in relocation to assure hatching of clutches of eggs).

The observations of 18 years of changes in sea turtle nesting habitat on St. Catherines Island have led to the conclusion that this very dynamic habitat can be remarkably stable for long intervals of time (months or even years) then suddenly change overnight due to nor’easters or passing hurricanes. These changes are dramatic and significant and can be characterized in the form of an erosion index. This said, it also must be emphasized that these pervasive changes that occur on the beach due to storm surges and wind may go completely unrecognized by observers immediately behind the beach (in the maritime forest) or on the mainland. In an attempt to emphasize this, we have constructed a coastal erosion index.

#### GEORGIA BARRIER ISLAND EROSION INDEX

Public concern for erosional conditions and dangerous rip tides on Georgia barrier islands has caused us to establish a qualitative and semiquantitative beach erosion index tool (table 14.3) to consistently characterize beach erosion from observational criteria and wind speed/direction data. Erosion is categorized as slight (2), moderate (4), strong (6), extreme (8), or catastrophic (10) based upon lowering of the beach to expose relict marsh mud and root zones, degree of scarping exposing new roots and/or causing the downing of trees and shrubs, activity of washover and washin fans, and effects on coastal structures and boats.

Since 2006, public awareness of beach ero-

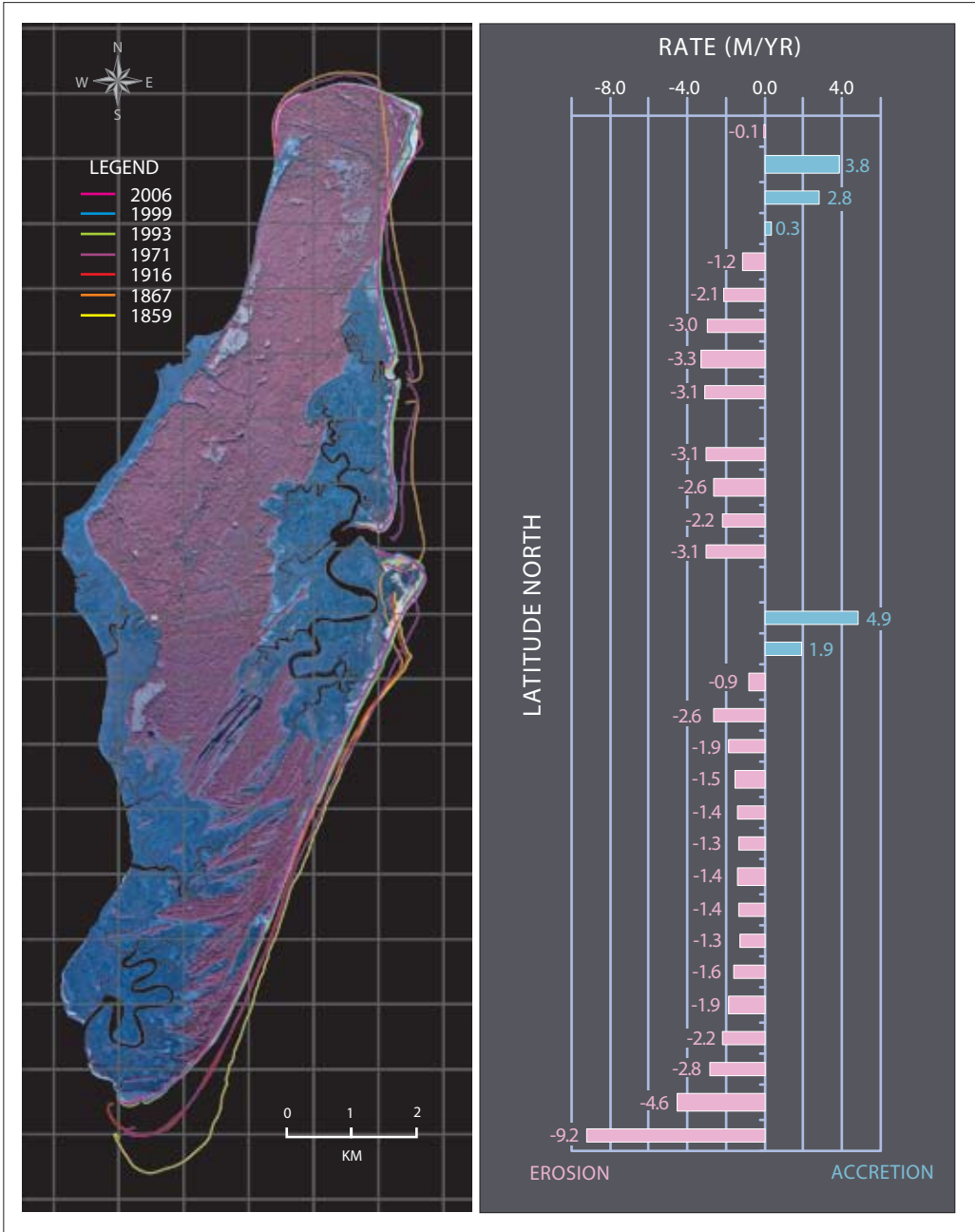


Fig. 14.11. Map and graph of the depositional and erosional history of St. Catherines Island from 1859 to 2006 showing limited accretional areas behind the ebb deltas at St. Catherines Sound and McQueen Inlet.

sion increased and NOAA Coastal Services Center contacted the St. Catherines Island scientific community to establish a formal reporting system for beach erosion and rip tides. In attempting to perform this function in 2007, it became apparent that criteria needed to be established to more precisely characterize habitat erosion on the beaches of Georgia in a consistent manner. The tentative beach erosion index is constructed based upon observational conditions previously documented in the annual Rapid Habitat Assessment and by direct observation on the beaches.

Using the Beaufort Observational Wind Scale as a model, a chart was constructed to characterize erosional effects on St. Catherines Island, linked to both observational criteria and to the

Beaufort Observational Wind Velocity Scale. Erosion is characterized as slight, moderate, strong, extreme, or catastrophic based upon observable criteria listed in table 14.3.

CONCLUSIONS

- The data presented indicate that the following conclusions can be supported:
- (1) Deterioration of sea turtle habitat on St. Catherines Island indicates that the island is undergoing global inundation due to sea level rise against the island, a transgression.
  - (2) As the sea rises against the island, beaches are undergoing rapid erosion and the shoreline is retreating to the west.

TABLE 14.3  
Observational Beach Erosion Chart for Georgia’s Barrier Islands

Status	Observational Criteria	Wind Regime
No Erosion	High Tide below scarp or storm tide level; Sand waves arriving on beach forming Runnels; Backbeach sand is tracked by animals and burrowed by crabs.	0–12 knots
Slight Erosion	High Tide reaching base of storm scarp or storm tide line; Washovers and washins slightly over-topped; Beach lowered, some erosion at toes of scarps.	13–30 knots
Moderate Erosion	High Tide inundating scarps and impinging on storm tide line; Washovers and washins over washed; Beach lowered, often to inactive beach with roots and relict mud exposed; Active scarping on sand beaches, existing scarps exhibiting “clean” new roots; Trees and logs moving in surf.	Nor’easter 20–40 knots
Strong Erosion	High Tide over-topping scarps and storm tide line; Washovers and washins strongly overwashed; Beach lowered often showing inactive beach with roots and relict mud exposed; Active scarping exhibited by scarped sand and “clean” new roots on scarps; Trees downed; Trees and logs moved laterally in surf. Mud “rollers” form on beach behind relict mud.	Nor’easter 30–50 knots
Extreme Erosion	Tide overtopping scarps, and well above storm tide level; Washovers and washins very strongly overwashed; Beach lowered often showing inactive beach with roots and relict mud exposed for great distances; Active scarping and scarp migration exhibited by “clean” new roots on scarps; Live trees downed from scarps; Trees and logs moved along surf forming jumbles.	Nor’easter/Gales/ Hurricane CAT I–II
Catastrophic Erosion	Barrier Island overtopped by surge and/or surf; Saltwater inundates most freshwater habitats; Permanent structures inundated and/or destroyed; Boats grounded or sunk.	Hurricane CAT III–V

(3) Beach erosion is indicated by formation of scarps, the exposure of root zones, exposure of relict marsh mud, and development of tree boneyards in high areas and development of washover and washin fans in low areas.

(4) As erosion progresses the highly variable backshore presents a dynamic mosaic of nesting habitats that change on an annual, seasonal, monthly, and even daily schedule; a few of these present good to excellent, but very limited, sea turtle nesting habitats each year.

(5) Approximately 15% of St. Catherines beaches are classed as adequate to excellent sea turtle nesting habitat, areas largely confined to stable dune fields and dune ridges backing the shoreline at Sand Pit Road entrance on North Beach and McQueen dune field on the north end of South Beach.

(6) Loggerhead sea turtle nests deposited in erosional areas or below the spring high tide line are "doomed" or "at risk," and are relocated into the closest habitat (that is also still being used by nesting sea turtles) to increase their chance of hatching, i.e., into nurseries.

(7) As sea level continues to rise against the land in the Georgia Bight, more and more of Georgia's sea turtle habitat will deteriorate; what has happened to St. Catherines Island should migrate progressively up and down the coast of the eroding the Golden Isles.

(8) An index to erosion on Georgia barrier islands is developed and presented.

## NOTES

1. Many organizations have supported the St. Catherines Island Sea Turtle Program over the last 19 years, including our major sponsors, the Georgia Higher Education Eisenhower/Improving Teacher Quality Program (~60% of funding) and the St. Catherines Island Foundation. Essential support of the teachers' programs has also been provided by Georgia Southern University, GeoTrec LLC of Fayette, Iowa, and the Georgia Department of Natural Resources (Non-Game Division). Occasional grants have been received from the Edward J. Noble Foundation (administered through the American Museum of Natural History), the St. Catherines Island Scientific Research Advisory Committee, the Turner Foundation, the JST Foundation, the M.K. Pentecost Ecology Fund, and the Partnership for Reform in Science and Mathematics (PRISM), an NSF-sponsored initiative designed to improve teachers' science and math content knowledge.

So many individuals have contributed to our program that we hesitate to name them for fear of leaving somebody out who deserves to be acknowledged; if we have done so, please accept our apology! We thank the St. Catherines Island staff for their day-to-day support for 18 years, especially Jeff Woods, Spyder Crews, Alan Dean, Richard Bew, Fred Harden, Lee Thompson, Ian Dutton, Kerry Peavler, Veronica Greco, Dr. Terry Norton, Jen Hilburn, and Mary-Margaret Pauley Macgill. Royce Hayes, Ed Davis (along with Doris Davis), Kelly Vance, Fred Rich, Brian Meyer, and Nancy Marsh provided service far above and beyond the line of duty in helping in so many ways over so many years. Georgia Department of Natural Resources personnel who have helped with the program include Charles Maley, Mike Harris, Brad Winn, Mark Dodd, and Adam Mackinnon. The board members of the St. Catherines Island Foundation are collectively thanked for their continuing support of the St. Catherines Island Sea Turtle Program.





## CHAPTER 15

### MODELING INDIGENOUS HUNTING AND HARVESTING OF SEA TURTLES AND THEIR EGGS ON THE GEORGIA COAST

GALE A. BISHOP, DAVID HURST THOMAS, AND  
BRIAN K. MEYER

Marine turtles have captivated the human imagination for millennia.... There is no doubt that marine turtles, at different places and in different times, have enriched the human spirit in countless ways.

—Jack Frazier (2003: 29)

As Jack Frazier so cogently expresses it, people have long interacted with sea turtles and they still do (Bjorndal, 1979; Wing and Reitz, 1982; Frazier, 1996, 2006; Schaffer and Thunen, 2001; Frazier, 2003; Spotila, 2004; Bishop and Thomas, 2008).<sup>1</sup>

When Columbus encountered the Cayman Islands in 1503, he named them *Las Tortugas*, because the ocean was so filled with green turtles (perhaps as many as 100,000,000 individuals), with loggerhead numbers reaching into the “tens of millions” (Spotila, 2004: 63). Columbus is said to have watched Native Americans hunting hawksbills along the southeast coast of Cuba in 1494. Early mariners captured green sea turtles in the Caribbean, holding them tipped over in holds as a source of food (Spotila, 2004: 68). This exploitation, particularly when sea turtle meat entered the cash market beyond indigenous exploitation, decimated sea turtle populations around the world, including the Caribbean and Gulf of Mexico (de Oviedo, 1526).

In this chapter, we review historical and contemporary patterns of sea turtle behavior and exploitation, then meld these data into a new model for anticipating the archaeological record of St. Catherines Island and elsewhere.

#### THE MODERN HUMAN SEA TURTLE TAKE

Sea turtles are hunted and captured around the world and utilized for their meat. Hunting techniques range from capturing nesting females on the beach by tipping them over on their backs, through various fishing techniques, to true hunting from canoes or boats. “Adult loggerheads in the southeastern United States have a mean straight carapace length of 92 cm (36.2 in.) and weigh about 113 kg (249 lbs)” (NMFS, USFWS 1991). The loggerhead sea turtle was listed on July 28, 1978, as a threatened species under the Endangered Species Act of 1973 (43 FR 32800). “Internationally, it is considered endangered by the International Union for Conservation of Nature and Natural Resources (IUCN) and is listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).”

Many cultures continue to exploit sea turtles and sea turtle eggs as food items (Schaffer and Schaffer, 2008). In Myanmar (Burma) “beaches were leased by the Colonial Administration to local businessmen, who harvested and sold eggs. About 1.5 million olive ridley turtle eggs and 1.6 million green turtle eggs were harvested annually (Thorbjarnarson, Lagueux, and Bolze, 2000; Thorbjarnarson, Platt, and Khaing, 2000).

Thorbjarnarson, Lagueux, and Bolze (2000), Thorbjarnarson, Platt, and Khaing (2000), and Campbell (2003: 312) have marshaled an impressive listing of countries currently exploiting sea turtle meat, including (in no particular order), the United States, Ecuador, Peru, Madagascar, Nicaragua, Venezuela, Seychelles, India, Sri Lanka,

Japan (fishing from others' waters), Indonesia, Australia, Torres Strait, Papua New Guinea, Bangladesh, Liberia, Egypt, Equatorial Guinea, Cuba, Costa Rica, Belize, Mexico, and the Caribbean islands of Antigua, Barbuda, Bahamas, British Virgin Islands, Cayman Islands, Grenada, Haiti, Saint Kitts, Nevis, Trinidad, Tobago, and Turks and Caicos.

Hunting turtles is a manly activity in many traditions and provides a rich, although seasonal, source of protein to indigenous societies to be distributed through cultural tradition across the local population, providing status and rank to the clan or tribe. Havea and MacKay (2009: 16) report that during 2007 in the Kingdom of Tonga in the South Pacific an estimated 608 sea turtles were taken by hunting methods that included spearing (harpooning), netting, and live capture by swimming. In both O'ua and Ha'afeva the average catch was 7.6 turtles per fisherman while in Tungua it averaged 23.9 turtles per fisherman with four fishermen catching from 30 to 100 turtles per year (perhaps reflecting a new commercial market for sea turtle meat).

The cultural significance of sea turtle hunting runs deep. In the culture of the Miskito Indians of Nicaragua (Nietschmann, 1973, 1979; Campbell, 2003) the sharing of green sea turtle meat with kin and friends was a significant component of social relationships, satisfying cultural obligations and responsibilities. The Miskito Indians of Costa Rica captured green sea turtles offshore at the mouth of the Tortuguero River for consumption and the sea turtle's importance in legend is celebrated by the rock called the Turtle Mother and *Cerro Tortuguero* at the mouth of the Tortuguero River (Rudloe, 1979). Lefever (1992) cites the restocking of European vessels with sea turtles as early as the 17th century. Consumption of turtle meat continued, at least, into 1999, and undoubtedly operates illegally yet today during poor years. The Seri (Comcaac) Indians on the Sonoran coasts of Mexico have integrated sea turtles into their culture (Nabhan et al., 1999) as "turtles are not just food, but 'the symbolic foundation of their marine resource based culture.'" In Venezuela the Wayuu Indians relate sea turtles to fertility, thinking consumption of meat and blood enhances masculine fertility (Campbell, 2003: 314), while turtle crania are hung in fruit trees to enhance their growth. Suarez and Starbird (1996) describe leatherback hunting in the Kai

Islands of Indonesia forming a body of tradition, ritual, and beliefs (*adat*) that guide the hunt. Meat harvested in *adat* is used for subsistence purposes and is not sold. In Papua New Guinea (Spring, 1995) sea turtles form the basis of oral history, legend, and material items used in bride-price traditions. In the Caroline Islands, McCoy (1979) reported that sea turtles are hunted from dugout canoes and their cultural importance exceeds the significance of the protein harvested. In Australia, indigenous populations still hunt sea turtles for noncommercial uses (Kowarsky, 1995; Rick, Kennett, and Erlandson, 2005). Harpooning turtles in the Gulf of Carpentaria and hunting green sea turtles is still important in the traditional life of the Yanyuwa people of Borroloola (see [www.ozoutback.com.au](http://www.ozoutback.com.au)).

These traditions survive into modern day in many societies, as, for example, in Lenten consumption of sea turtles in Pacific Mexico (Nichols and Palmer, 2006), who state: "When turtle meat is shared among families and friends the process is imbued with symbolism—consciously or not. An offer of a turtle feast is considered among the highest honors and displays of trust" (Delgado and Nichols, 2005: 89–104).

There is an equally extensive listing of countries that today harvest sea turtle eggs (Thorbjarnarson, Lagueux, and Bolze, 2000; Thorbjarnarson, Platt, and Khaing, 2000): virtually all countries on the Atlantic coast of Central America, Mexico, Iran, Saudi Arabia, India, Thailand, Malaysia, Indonesia, Philippines, Papua New Guinea, Suriname, Costa Rica, Guatemala, Panama, Honduras, Bangladesh, and Myanmar (Campbell, 2003). Gathering of sea turtle eggs in many indigenous societies remains a seasonal tradition usually done by the women and children. The ingestion of turtle eggs provides a rich protein resource and has developed an aura of aphrodisiac in many cultural settings. The value of sea turtle eggs as a sustenance source of protein almost certainly is significant regardless of the "reason" for their ingestion. A legal, commercial egg collection has been allowed at Ostinal, Costa Rica, where 70% of households derive primary cash flow from the take (Campbell, 2003).

Overall sea turtle "take" includes not only meat from hunting the animals and the eggs from rookeries, but also turtle products (skin, bone, etc.) derived from killing the turtles. One of the traditional products of this take is "tortoiseshell," the source of ornamental artifacts made from the

carapace of hawksbill sea turtles (*Eretmochelys imbricata*). Tortoiseshell (bekko) ornaments, combs, hairpins, bowls, etc., are especially highly sought in Japan.

Much of this take is now illegal as all species of sea turtles are either listed as endangered or threatened, however, some legal cultural take is allowed in indigenous societies under the CITES treaties. "It should not be surprising," write Nichols and Palmer (2006: 8) "that recently enacted laws against killing sea turtles and collecting their eggs would fail to halt the centuries old traditions of consuming turtle meat and eggs." Sea turtle conservationists are striving to maintain sustainable world sea turtle populations while accommodating indigenous take (e.g., Kowarsky, 1995; Hunter and Williams, 1998; Prince, 1998; Kennett et al., 2008).

#### ANTICIPATING THE ARCHAEOLOGICAL RECORD

Thomas (2008; see also chap. 1, this volume) has discussed how the overarching theoretical framework of human behavioral ecology has helped archaeologists develop a series of specific and testable hypotheses about the subsistence and settlement practices of aboriginal St. Catherines islanders who, for 5000 years, called this place their home.

##### THE DIET-BREADTH (PREY CHOICE) MODEL

Particularly relevant is the diet-breadth (or prey choice) model, which poses a deceptively simple question (Thomas, 2008: chaps. 6–9; see also O'Connell and Hawkes, 1981, 1984; Hames and Vickers, 1982; Kaplan and Hill, 1992; Smith, 1991; Hawkes et al., 1992): *Which foods should an efficient forager harvest from all those available on St. Catherines Island?*

To provide an answer to this question, one must first estimate the postencounter return rates inherent in the various prey taxa available to aboriginal foragers—meaning to measure (or estimate) how long it takes to collect and process a given resource, then calculate the net energetic return from these activities ("if I spend an hour harvesting and processing a food item, how much energy will I realize on my 60-minute investment?"). With these metrics in hand, it is possible to rank-order the available foodstuff on St. Catherines Island according to their energetic potential. Specifically, if you are a forager with an hour

to invest, we found that the "most efficient" thing to do is to hunt, kill, and process a black bear; you will receive a payoff of 37,352–61,434 kcal of energy for each hour of effort. By contrast, if you spend an hour collecting and processing marsh periwinkles, your payout will be 26–135 kcal. Take your pick. The diet-breadth model predicts that an energy-efficient forager will always harvest the highest ranked resources encountered. When lower ranking prey are included in the optimal set, the energy-conscious forager will always take any higher-ranking taxon first, whenever encountered.

Thomas (2008: table 8.27) ranked leatherback turtles extremely high in the energy hierarchy available to St. Catherines Island foragers. Male and female leatherbacks return an estimated 26,825–62,792 kcal/hr—second only to black bears, with American alligator running a distant third (at 22,000 kcal/hr). Loggerhead turtles (male and female) wind up fourth on the energetic hierarchy, returning an estimated 21,360 kcal/hr (only slightly trailing American alligators) and well ahead of white-tailed deer (at 12,096–19,895 kcal/hr).

The upshot? The diet-breadth model predicts, simply stated, that anytime a sea turtle was encountered near St. Catherines Island, the forager seeking to maximize net energy return should take it—every single time. But how are these postencounter return rates derived?

Thomas (2008: 131) relied on quantitative return-rate calculations for Meriam people hunting green turtles in the Torres Strait (Bliege Bird and Bird, 1997; Bliege Bird, Smith, and Bird, 2001: 11; Bliege Bird et al., 2002). In the past, when the Meriam spotted an appropriate turtle, they pursued in dugouts, armed with harpoons, ropes, and sometimes turtle hooks (modern Meriam hunters employ outboard motorboats). The captured turtle was brought alongside, then hoisted into the boat, alive, to be butchered and cooked later. The all-male Meriam turtle hunters spent hours doing this, demonstrating considerable skill, experience, and courage to all.

Although several species of sea turtle pass through Georgia waters—including hawksbill (*Eretmochelys imbricata*), Kemp's Ridley (*Lepidochelys kempii*), leatherbacks (*Dermochelys coriacea*), and green (*Chelonia mydas*) turtles, Thomas (2008: 131) relied on the loggerhead (*Caretta caretta*) for transplanting the Meriam model to St. Catherines Island. He assumed that

4 person-hours would be required to pursue and subdue a swimming turtle and further estimated that 2 person-hours would be required to butcher each adult loggerhead so captured. The estimated return rate (for male and female loggerheads) ranges between 8010 and 13,350 kcal/hr (Thomas, 2008: table 8.10).

#### CENTRAL PLACE FORAGING

Postencounter return rates are an elementary, yet critical, aspect of diet-breadth modeling. Thomas (2008: 211) also asked another simple, correlative question: "To what extent can we expect past diet-breadth decisions to be accurately reflected in archaeological midden deposits?" Drawing again on ethnoarchaeological research, Douglas Bird and Rebecca Bliege Bird discovered that, among contemporary Meriam islanders, significant problems existed between correlation of take and midden remains when return rates and direct observations of foraging behavior were translated into interpretation of the shell middens that the Meriam themselves created.

The prey choice model predicts that Meriam foragers should always harvest the highest ranked resources (in this case, the large tridacnid clams and *Lambis*) upon encounter, and they almost always do so. But Bird (1997; Bird and Bliege Bird, 1997) found that these high-ranking prey types were dramatically underrepresented in the shell middens created by modern Meriam people, with the lowest ranking rocky shore resources dominating the archaeological assemblage. In other words, if an archaeologist were to extrapolate Meriam subsistence based strictly on shell counts from the middens, the results would be spectacularly incorrect. Bird and Bliege Bird ultimately concluded that differential field processing strategies were likely the most critical factor in shaping the archaeological record of Meriam shellfishers.

Thomas (2008: chap. 10) also applied central place foraging theory to investigate the time/energy spent processing resources at temporary camps before transport to a residential base (Orians and Pearson, 1979; Stephens and Krebs, 1986; O'Connell, Hawkes, and Blurton Jones, 1988, 1990; Jones and Madsen, 1989; O'Connell and Marshall, 1989; Metcalfe and Barlow, 1992; Barlow and Metcalfe, 1996; Bettinger, Malhi, and McCarthy, 1997; Bird, 1997; Grayson and Cannon, 1999; Bliege Bird et al., 2002; Zeanah, 2004).

At its heart, central place foraging theory addresses the tradeoff between increasing the utility of a load (through field processing) and increasing the amount being harvested (which involves foraging and travel time; see Bettinger, Malhi, and McCarthy, 1997: 888). While field processing can decrease the amount of waste that is transported, doing so increases the time expended per unit of useful material at the foraging location (and decreases the time that could be spent on greater collection and transportation of a resource). Barlow and Heck (2002: 138) emphasize two particular predictions that derive from the field processing/transport model: (1) more field processing is expected as distance from residence increases; and (2) inherent, innate differences between prey taxa should influence the relative efficiency of various processing behaviors and condition the location of such processing.

It follows, then, that field processing decisions hinge on (1) the amount of processing time required; (2) the degree to which processing increases the utility of the material being transported; and (3) the distance from procurement locus to the central place.

#### FIELD PROCESSING/TRANSPORT MODELS

The field processing/transport model provides a way to approach this problem, by positing that prey taxa will be transported whole if they meet the following conditions: (1) they are relatively difficult to field process (measured as time), (2) they provide little increase in proportion of edible flesh when field processed, and (3) they were gathered near the central place. Using equations derived from Metcalfe and Barlow (1992), Bird and Bliege Bird (1997) computed several *processing thresholds*—the time/distance at which field processing is expected to occur—for various shellfish resources exploited by the Meriam.

The Meriam example is compelling. By applying the field processing/transport model, Bird and his colleagues have derived explicit, empirical expectations regarding shellfish discard behavior in the Torres Straits. They have also observed firsthand how the procurement, the processing, and the discard of shellfish directly condition the resulting archaeological record:

Variability in intertidal prey choice is reflected archaeologically only through a filter of differential field processing and transport, the constraints on age-linked

foraging efficiency, and patch utilization.... The Meriam data go a step beyond cautionary tales to test basic foraging models ethnographically in order to evaluate their archaeological potential and demonstrate circumstances where their assumptions are warranted. (Bird, Bliege Bird, and Richardson, 2004: 195)

We will never have the opportunity to observe the aboriginal sea turtle hunters of St. Catherines Island. But we can employ the transport and field-processing model as first-order heuristics to anticipate the nature of the surviving archaeological evidence. Lacking the requisite ethnohistoric and experimental evidence, we will estimate the various processing times, load utilities (reflecting the proportion of edible to inedible portions of each resource), and resource distributions necessary to compute the transport thresholds relevant to St. Catherines Island. We hope that these rough-and-ready estimates will provide an appropriate baseline that will allow, in time, for investigators to improve both the predictive models and the archaeological observations.

Thomas (2008: 223–224; table 10.5) computed terrestrial transport thresholds for loggerheads and leatherback taken at sea, employing an estimated live weight as the average weight differential between adult males and females. These terrestrial  $z$ -scores are rather unrealistic, of course, since watercraft are mandatory for procuring turtles at sea. He also computed a separate  $z$ -value for female loggerheads that were taken while nesting.

On St. Catherines Island, sea turtles nest only on sandy beach margins, a habitat type that is restricted to the extreme eastern (and northeastern and southeastern) margins of the island. If foragers conducted their turtle hunts strictly on foot, then terrestrial transport is a distinct possibility, with the turtle meat and turtle eggs (if any) carried back to the central place. However, since all beaches selected by nesting loggerheads are likewise accessible by native watercraft, it is entirely feasible that nesting females could have been kept alive and transported by boat. As discussed below, marine watercraft can significantly lower the transport thresholds computed for terrestrial travel.

Thomas (2008: 230, table 10.7) concluded that for male and female leatherback turtles (with a one-way terrestrial transport threshold of

400–667 m), hunters would only “sometimes” field process the carcass before returning to the residential base. He also concluded that for male and female loggerheads (with field transport thresholds of 2206–3677 m), the carcasses would “almost never” be field butchered before returning to residential base. In archaeological terms, then, this conclusion meant that nearly all loads of sea turtle meat would be transported in bulk for processing at the central base. If this model holds true, then the discarded, inedible parts of sea turtles should be abundant in the middens associated with residential bases, and virtually absent elsewhere.

#### ACTUALISTIC RESEARCH ON SEA TURTLE EGG HARVESTING: ST. CATHERINES ISLAND

This is where things stood when Thomas published his assessment of Native American foraging on St. Catherines Island (Thomas, 2008). Under the direction of Bishop and Meyer, the St. Catherines Sea Turtle Program has continued to monitor sea turtle nesting behavior and a number of additional observations are now possible, allowing us to refine and expand the previous optimal foraging models.

Under climatic conditions similar to today, sea turtle eggs could be harvested along the Georgia coast from May to August—either by directly catching them as they were deposited in egg chambers at night or by postnesting excavation during daylight (see fig. 15.2). The latter case would likely be preferred due to the difficulty of nighttime activity on the beach when darkness and insect activity prevails. Using torches would have negatively impacted nesting, spooking potential nesting females before they began to lay eggs. The hypothesized exploitation (fig. 15.3) scenario during early morning light, when the beach is also cooler, would have included “reading of sign” (fig. 15.1) in nest areas above crawlways from the sea, digging for eggs (see fig. 15.2) with “found tools” (fig. 15.3), and the transportation of the eggs to temporary or permanent seasonal camp sites on the seaward side of the island.

Indigenous peoples were astute observers of their environment, including seasonality, especially as marked by the appearance or disappearance of their food resources or particularly hazardous times of the year (Baity et al., 1973;

Powers, 1975). Celestial events form the basis of many ancient religions and, in societies in which they were not officially documented, certainly were important as temporal markers throughout the year. In the case of sea turtle nesting on St. Catherine's Island, there is a remarkably close approximation of historical peak nesting to the summer solstice, about June 20 or 21. Indigenous St. Catherine's islanders undoubtedly understood the timing of sea turtle events, the northward migration of leatherback sea turtles in April, and the peak nesting by loggerheads at the summer solstice. Timing the collection of eggs with the summer solstice would have assured a maximum return for the investment of walking the beaches

at that particular time.

The identification of loggerhead crawlways (see chap. 14, this volume) by following the shoreline (table 15.1) would have allowed the egg gatherers to locate potential nests that could then be identified by nesting criteria (differential lengths of entrance and exit crawlways, the presence of thrown sand radiating from an elliptical covering pit). Locating the egg chamber beneath the disrupted surface layer stirred up during covering would either have been based upon locating the egg discontinuity, comprising 1.01% of the covering pit (table 15.1), or by probing or by excavation through the surficial, bioturbated sediment overlying the egg chamber

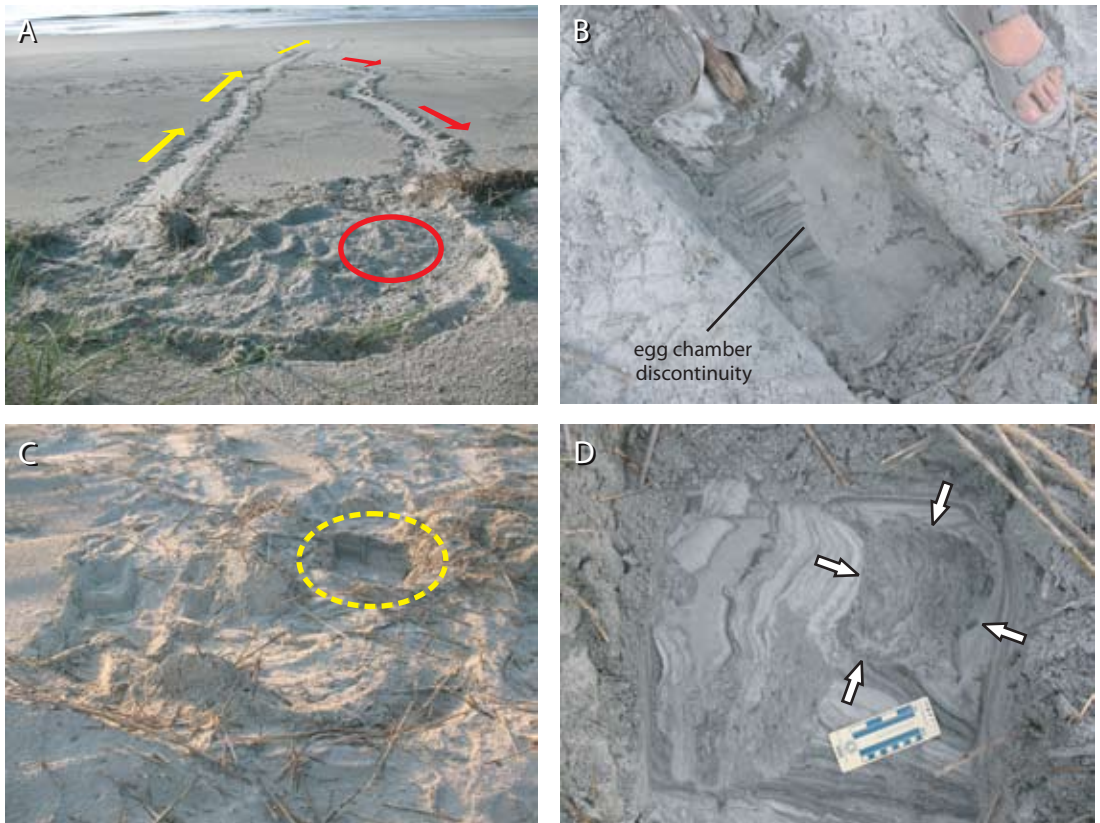


Fig. 15.1. The search for loggerhead sea turtle eggs in the St. Catherine's Island Sea Turtle Program entails **A**, reading the nest [Nest 07-048] to identify where the turtle *probably* dug her egg chamber; **B**, carefully removing loose sand from the covering pit [Nest 07-030]; **C**, using a magic titanium square-ended sand shovel to excavate beneath the target site (yellow oval in this nest [08-023]); **D**, defining egg chamber discontinuity [Nest 08-001]. Scale = 10 cm.



Fig. 15.2. Neo-Native search for loggerhead eggs on St. Catherines Island. **A**, Probing for eggs with shaft of sawtooth palmetto in 2005. Using found tools to validate clutches of eggs: **B–C**, shell of the giant Atlantic cockle; **D**, decorated shell of a knobbed whelk; **E**, a paddlelike, keeled segment of the frond shaft of a cabbage palm. Scale = 10 cm.

until the neck of the egg chamber was located. The eggs could then have been easily harvested by following the egg chamber neck downward to the clutch of eggs.

During the 18 years of monitoring, the St. Catherines Island Sea Turtle Project had record-

ed 2093 sea turtle nests deposited on the ~20 km of sandy beaches of St. Catherines Island. Loggerhead nests comprise the vast majority of these, in fact, constituting 2087 of the known nests, (99.71%) on St. Catherines Island, while five leatherback nests have been observed (0.24

%), and one green sea turtle nest (0.05 %) has been documented.

Thomas previously (Thomas, 2008: chap. 8, table 8.9) presented an overview of historical nesting on St. Catherines Island and we can update these data with numbers of nests for 2005 (115 nests), 2006 (124 nests), 2007 (51 nests), 2008 (146 nests), 2009 (102 nests), and 2010 (152 nests). Clutch size remains close to an average of 113 eggs per clutch and hatch rates at ~72%. Because of the continuing deterioration of the sea turtle habitat (Bishop and Marsh, 1994) on St. Catherines Island (see Bishop and Meyer, chap. 14), the success rate of nesting attempts by loggerhead sea turtles has dramatically declined, reducing the ratio of nonnesting to nesting attempts (1:1) seen in the mid-1990s to 2.62:1 in 2008. New data collected in 2006–2008 indicate that an average loggerhead on the Georgia coast deposits 5.2 clutches per year (determined

by mDNA run on one loggerhead egg from each clutch deposited on the Georgia barrier islands; Brian Shamblin, personal commun.).

Overall, then, we know that sea turtle egg resources currently available on St. Catherines Island consist of an average of 112 loggerhead sea turtle nests/year and an average clutch size of 113 eggs/clutch. Thomas discussed the harvesting of loggerhead sea turtle eggs (2008: chap. 8: 159) and we believe these nests were easily exploited and represent a significant, seasonal high-protein food resource. They were undoubtedly harvested by foragers along the Georgia coast. An average egg weighs ~30.2 g, providing a total nutrition package of 3.412 kg/nest when harvested. The reported (USDA) nutritional value of each green sea turtle egg is 89 kcal/100 g, while loggerhead eggs tested in 2005 (Silliker Inc., Laboratory Report 12/06/05) returned a nutritional value of 200 kcal/100 g



Fig. 15.3. The preferred Native American digging tool consists of stem fronds of cabbage palm used to locate clutches of eggs of the loggerhead sea turtle. They can be manufactured from **A**, green fronds of cabbage palm, or from fronds that have dried out naturally; **B**, and are then; **C**, broken into segments approximately 14 in long.

TABLE 15.1  
**Maximum Nesting between South Beach Entrance and McQueen Inlet**

Species	Crawlway #	Emergence Type	Nest ID	Latitude	Longitude	Relocated = R In-Place = I	Hatch Date	No. of Eggs	No. Hatched	% success
CC	1	N	08-056a	31.681	81.137	R	8/17/2008	159	99	62.3%
CC	2	N	08-050	31.630	81.130	I	8/15/2008	124	111	89.5%
CC	3	N	08-051	31.627	81.133	I	8/13/2008	128	91	71.1%
CC	4	N	08-052a	31.625	81.134	R	8/14/2008	113	106	93.8%
CC	5	N	08-053a	31.622	81.136	R	8/17/2008	103	74	71.8%
CC	6	FB	—	31.618	81.137	—	—	—	—	—
CC	7	FB	—	31.618	81.137	—	—	—	—	—
CC	8	N	08-054a	31.616	81.139	R	—	100	67	67.0%
CC	9	N	08-055	31.614	81.140	R	8/13/2008	91	65	71.4%
CC	10	FB	—	31.608	81.144	—	—	—	—	—
CC	11	FA	—	31.608	81.144	—	—	—	—	—
CC	12	FA	—	31.607	81.144	—	—	—	—	—
CC	13	FA	—	31.607	81.145	—	—	—	—	—
CC	14	FA	—	31.604	81.145	—	—	—	—	—
CC	15	FA	—	31.603	81.146	—	—	—	—	—
CC	16	FA	—	31.597	81.149	—	—	—	—	—
CC	17	FA	—	31.596	81.150	—	—	—	—	—
CC	18	FA	—	31.595	81.150	—	—	—	—	—
CC	19	FA	—	31.594	81.151	—	—	—	—	—
CC	20	FA	—	31.577	81.159	—	—	—	—	—
CC	21	FA	—	31.567	81.164	—	—	—	—	—
					Total Eggs Collectable		818			
					Average Number of Eggs/Nest		117			

(Thomas, 2008: chap. 8: 161). This means that a clutch of 113 eggs (weighing an average of 32.7 g/egg with a nutritional value of 200cal/100g) provides a total caloric value of 291.4 kcal (Thomas, 2008: chap. 8; table 15.1: 136).

Anecdotal evidence suggests that the numbers of loggerhead turtles nesting on St. Catharines Island was significantly greater in the past, perhaps substantially greater in the precontact

past, and that some sea turtle eggs have been gathered until the mid-20th century for local use and barter trade.

#### LOCATING THE EGGS

Understanding the loggerhead nesting ethogram (Hailman and Elowson, 1992; and see Bishop et al., this volume, chap. 13) makes the search for clutches of eggs a relatively easy endeavor as

the pattern of sedimentary structures produced by the ethogram is very consistent and can be read by the observant searcher using “sign” to predict the location of the clutch of eggs buried within the beach. The nesting structures of loggerhead sea turtles consist of two discrete units, a suite of surface structures (fig. 15.1A) that are readily apparent to the observer (entrance crawlway, covering pit, and exit crawlway) and a hidden, or buried suite of structures (fig. 15.1B, D) disguised by the covering pit (the body pit, the egg chamber with its clutch of eggs, and an egg chamber neck that has been backfilled with sand by the female).

By reading the signs of nesting the probable presence of a nest can be discerned, most apparent by crawlways emerging from and back to the edge of the sea, forming tirelike markings from the edge of the water to the nest (if one is present). Entrance crawlways (those leading from the water onto the beach) and exit crawlways (those leading from the nest back to the sea) can be identified by V-like patterns made by the front flippers (Vs opening in the direction of crawling), by crosscutting relationships with the last crawlway (the exit crawlway) crossing over the earlier or entrance crawlway, or by differential lengths of the entrance crawlway (short) and the exit crawlway (long) if the turtle nested on an ebbing tide. The presence of a nest is indicated by an elliptical disturbed area at the head of the crawlways made by the covering activity of the turtle camouflaging the site of her clutch after nesting. In addition to the covering pit, there is almost always evidence of thrown sand scattered away from the covering pit as the turtle flipped sand with her front flippers. The covering pit is formed by the turtle rotating and stirring the surface sand layers with her body and flippers, forming a disturbed, or *bioturbated*, surface layer of loose sand 20–30 cm thick. Beneath the loose sand of the covering pit, lies the undisturbed, laminated sediment of the backbeach facies, which contains the urn-shaped egg chamber (and its clutch of eggs) dug down into it as well as the neck of the egg chamber that has been backfilled with sand by the turtle. The backfilling sand has lost its internal textural integrity and will often appear as a marbled or *brecciated* texture with a strength approximating that of soft butter. The process of finding the clutch of eggs involves either carefully probing through the covering pit with a probe until the soft sand filling the neck of the egg chamber is found by the probe dropping into it, or, by care-

fully removing the loose sand of the covering pit until the neck of the egg chamber forms a textural bull’s-eye surrounded by the laminated sand of the backbeach, which appears as a contour-like pattern due to the nearly horizontal laminations of alternating light-colored quartz sand and dark-colored heavy minerals (fig. 15.1C, D). The clutch is validated by following the egg chamber neck downward until the ping-pong ball-sized eggs are encountered, which can be harvested or, in the St. Catherines Island Sea Turtle Program, relocated if necessary.

The search process (fig. 15.2) would involve: (1) locating crawlways onto the beach by walking along the beach; (2) determining if a nest was deposited by morphology of the covering pits; (3) reading of traces to identify the entrance crawlway; (4) following the midline of the turtle into the covering pit (defining the pathway the turtle crawled); (5) excavating through the loose, bioturbated sand of the covering pit along the midline from the edge of the covering pit into the covering pit until the mottled sand of the egg chamber discontinuity cutting through the surrounding laminated sand of the undisturbed backbeach is crossed; and (6) following the egg chamber neck downward until the clutch of eggs is found.

Once a probable nest is located by crawlways emerging from the ocean and an elliptical nesting area, the presence of eggs is substantiated by validation. Entrance and exit crawlway lengths, thrown sand, crosscutting relationships on crawlways, and covering pit geometry are currently used to determine the probable presence and location of the egg chamber beneath the stirred-up surface sand (Brannen and Bishop, 1993; Bishop and Marsh, 1994; Bishop et al., this volume, chap. 13). Most modern sea turtle programs locate egg chambers and the contained eggs using a blunt probe, such as a wooden dowel rod, systematically inserted into the soft, bioturbated sand of the covering pit delimiting the firm sand of the underlying, undisturbed backbeach facies. This process is effective, but potentially prone to pierce the eggs once the probe enters the soft sand of the egg chamber neck.

In the St. Catherines Island Sea Turtle Program we use a different search technique, semi-archaeological excavation of the bioturbated soft sand of the covering pit (but not constrained by orthogonal survey units). Nests are first read, identifying the entrance and exit crawlways by “opening forward” Vs made by front flipper

claws, by asymmetrical push marks made by the rear flippers (steep side forward), or by crosscutting relationships of the last crawlway made (the exit crawlway) crossing over the entrance crawlway (fig. 15.1A). Occasionally the exit crawlway of the covering pit may also be obvious. Normally, the egg chamber will be on the entrance crawlway midline about half the turtle length (50–60 cm) inside the rim of the covering pit. The surface sand above this “target” area is carefully removed centimeter by centimeter with a sharpened flat sand shovel until the firm, laminated sand of the backbeach is encountered beneath the covering pit. The horizontally layered, interlaminated sand presents as both a firm substrate (in contrast to the loose overlying soft sand of the covering pit) with an acoustic rasping sound as the shovel scrapes across it and with a strong visual signal of contourlike patterns produced as the laminated sand is shaved off. When the egg chamber neck is encountered, it presents as a circular to oblong “bull’s-eye” of marbled, bioturbated sand surrounded by the contourlike patterning of the backbeach facies (fig. 15.1D). These generalities may be contradicted when the nest is deposited in homogeneous sand, in heavy mineral sands, or in lightly laminated and steeply dipping festooned cross-bedded sand of dunes. Native American foragers would have gone through a similar process of nest reading and validation, prior to exploitation of the egg resource.

#### NEST SIZE AND EGG DEPTH

The covering activity significantly camouflages the position of the clutch of eggs. Data taken in 1994 documents the average size and shape of loggerhead nests on St. Catherines Island. Nests average 2.35 m long (usually parallel to the shoreline) and 1.99 m wide with a surface area that averages 3.72 m<sup>2</sup> in size, camouflaging the underlying egg chamber necks, which average 318.2 cm<sup>2</sup>, presenting a “predation target” of only 1.01% to numerous egg predators, that today include raccoons (*Procyon lotor*), feral hogs (*Sus scrofa*), ghost crabs (*Ocypode quadrata*), and fire ants (*Solenopsis invicta*). Covering behavior undoubtedly evolved to evade egg depredation by these predators, as well as the best egg predator of all, *Homo sapiens*. “In the U.S., killing of female loggerheads (for meat harvest) is infrequent. However, in a number of areas, egg poaching and clandestine markets for eggs are not uncommon. From 1983 to 1989, the Florida Marine Patrol,

DEP, made 29 arrests for illegal possession of turtle eggs” (Multi-Species Recovery Plan for South Florida). The only documented instance of human depredation on nests on St. Catherines Island was Nest 09–002 in 2009, which we believe was taken by humans.

#### EXPERIMENTAL EGG EXPLOITATION

Ancient egg gatherers would have had to dig eggs using either their bare hands or with found tools (fig. 15.3), natural items found near the beach, including shells, sticks, or fronds. It is thought that Native Americans, like us, would have found the effectiveness of tools to be a significant advantage, and would have used tools in their search for sea turtle eggs. Preferred shells would have been large, like those of the giant Atlantic cockle (*Dinocardium robustum* [Lightfoot, 1786] or one of the whelks, the knobbed whelk (*Busycon carica* [Gmelin, 1791]), lightning whelk (*Busycon perversum*), or the channeled whelk (*Busycotypus canaliculatus* [Linnaeus, 1758]). Shafts of the fronds of cabbage palm (*Sabal palmetto*) would have been used both as probes and scraping tools.

Exploitation of eggs was tested in 2004 and 2005 by using “found tools” to validate in situ loggerhead clutches on St. Catherines Island in order to replicate a cost/benefit analysis of energy in egg finding. We discovered that by combining reading the nest with excavation by found tools, the actual expenditure of energy was minimal, and the payback was large.

Tools of choice for digging were tested experimentally and include abundant shells of hand-sized local molluscs such as the knobbed whelk (*Busycon carica* [Gmelin, 1791]), channeled whelk (*Busycotypus canaliculatus* [Linnaeus, 1758]), and the giant Atlantic cockle (*Dinocardium robustum* [Lightfoot, 1786]), all found to be wanting in terms of manipulative potential and because they lack a straight, sharp edge. Broken tree branches and the stems of saw palmetto were tried and were successful, especially in locating egg chambers by probing.

The digging tool of choice, determined after two years of experimental “native” digging using various found tools, is the stem fronds of cabbage palm (*Sabal palmetto*), which has a broadly concave-convex stem with sharp keels on either edge (fig. 15.2E). When broken into short pieces the fronds form trowellike hand tools that easily move sand and also can be used to scrape the surface of

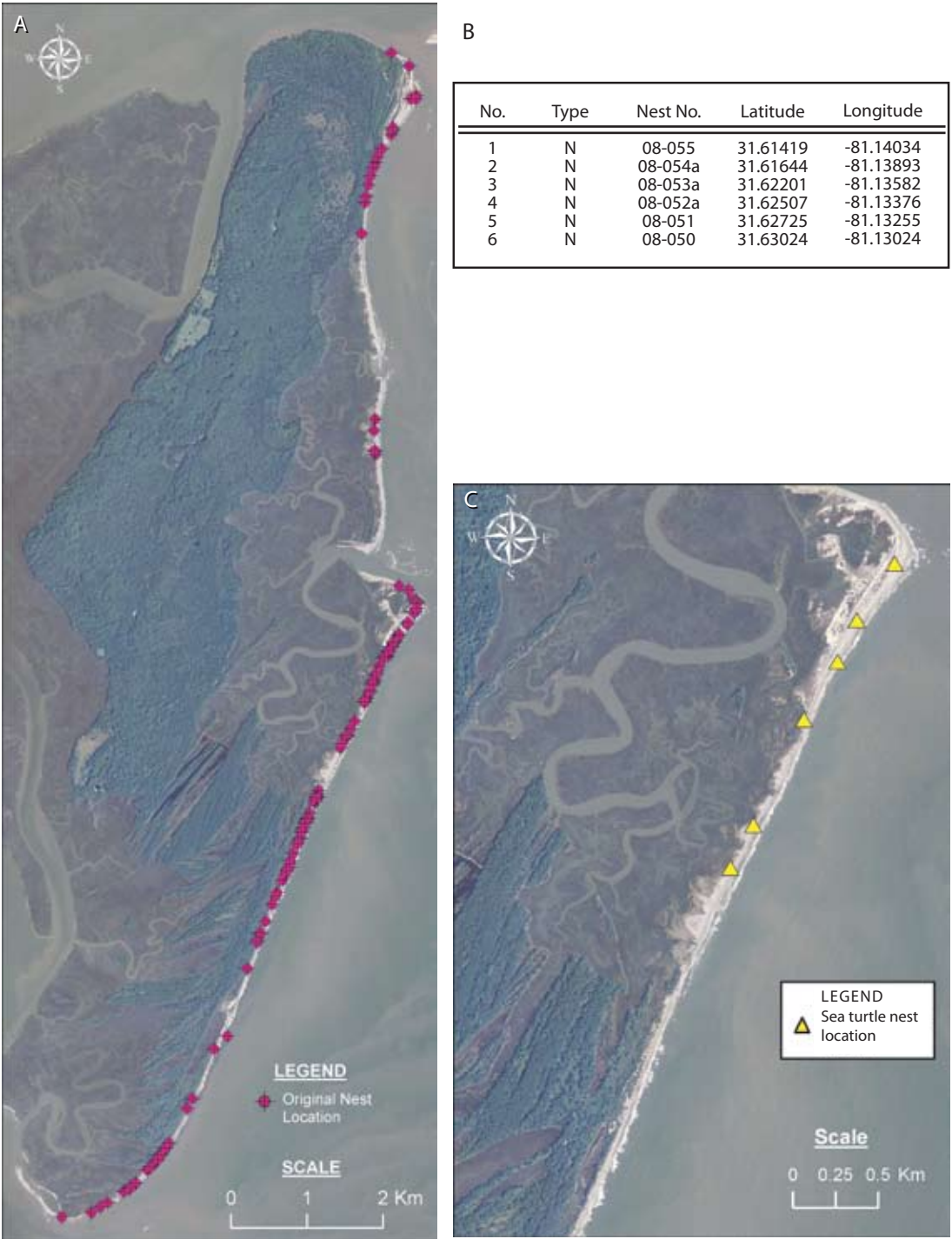


Fig. 15.4. Distribution of loggerhead sea turtle nests deposited on St. Catherines Island in 2008 showing **A**, distribution of all nests; **B**, a list of nests from South Beach Entrance to McQueen Inlet on June 19, 2008; and **C**, a map of their distribution.

TABLE 15.2  
Time It Takes to Locate and Validate a Clutch of Loggerhead Sea Turtle Eggs

	Nest	Species	Date	Latitude	Longitude	Dug by	Time (mm:ss)	Technique	# Eggs	Avg. wt/egg (g)	Cal/egg (200 kcal/200g)	Recovered calories (kcal)	Caloric cost (kcal)	Net benefit (kcal)
1	Leatherback 1	D. coriacia	5/8/2005	31.589	81.153	Archaeologists	180	shovel	0	—	—	—	—	—
2	05-090w	D. coriacia	5/9/2005	31.602	81.147	GAB	165	shovel	94(27)	—	—	—	—	—
3	05-056	C. caretta	7/1/2005	31.625	81.134	NAM	6	shovel	133	32.7	32.7	4349.1	450	3899
4	05-057a	C. caretta	7/1/2005	31.625	81.134	GAB	4	shovel	85	32.7	32.7	2779.5	450	2330
5	05-059	C. caretta	7/2/2005	31.609	81.143	Univ. So.-Ashley	19	shovel	116	32.7	32.7	3793.2	450	3343
6	05-060a	C. caretta	7/2/2005	31.567	81.164	GAB	5	shovel	117	32.7	32.7	3825.9	450	3376
7	05-061a	C. caretta	7/3/2005	31.686	81.135	NAM	1	shovel	151	32.7	32.7	4937.7	450	4488
8	05-062a	C. caretta	7/3/2009	31.571	81.161	—	3	shovel	150	32.7	32.7	4905.0	450	4455
9	05-063a	C. caretta	7/3/2005	31.599	81.148	GAB	12	shovel	100	32.7	32.7	3270.0	450	2820
10	05-064	C. caretta	7/3/2005	31.663	81.150	GAB	3	shovel	127	32.7	32.7	4152.9	450	3703
11	05-065a	C. caretta	7/4/2005	31.589	81.152	—	10	shovel	114	32.7	32.7	3727.8	450	3278
12	05-066a	C. caretta	7/4/-7/05	31.597	81.149	—	4	shovel	112	32.7	32.7	3662.4	450	3212
13	05-070a	D. coracia	7/6/2005	31.674	81.138	GAB	1	shovel	105	32.7	32.7	3433.5	450	2984
14	05-072a	C. caretta	7/7/2005	31.679	81.137	GAB	2	shovel	96	32.7	32.7	3139.2	450	2689
15	05-088	C. caretta	7/19/2005	31.631	81.130	RKV&LV; GAB&NAM	9	GPR	63	32.7	32.7	2060.1	450	1610
16	05-091a	C. caretta	7/21/2005	31.674	81.138	RKV	9:30	shovel	76	32.7	32.7	2485.2	450	2035
17	05-092a	C. caretta	7/21/2005	31.633	81.132	GAB	1:00	shovel	91	32.7	32.7	2975.7	450	2526
18	05-093a	C. caretta	7/21/2005	31.615	81.140	GAB	1:05	shovel	96	32.7	32.7	3139.2	450	2689
19	05-094a	C. caretta	7/22/2005	31.594	81.150	GAB	1:05	shovel	113	32.7	32.7	3695.1	450	3245
20	05-095	C. caretta	7/28/2005	31.630	81.130	CC	10:00	palmetto & whelk	washed out	32.7	32.7	—	—	—
21	05-097	C. caretta	7/30/2005	31.362	81.084	CC	15:00	palmetto & whelk	washed out	32.7	32.7	—	—	—
22	05-104	C. caretta	8/9/2005	31.590	81.152	KT, JT, MW, GB	21	palmetto & whelk	washed out	32.7	32.7	—	—	—
23	05-105	C. caretta	8/10/2005	31.629	81.131	GAB	0:44	shovel	76	32.7	32.7	2485.2	450	2035
24	05-114	C. caretta	8/19/2005	31.590	81.152	GAB	1:55	shovel	washed out	32.7	32.7	—	—	—
25	06-002a	C. caretta	5/20/2006	31.632	81.130	Kim Stewart	11	shovel	139	32.7	32.7	4545.3	450	4095
26	06-005	C. caretta	5/24/2006	31.606	81.145	GAB	3	palmetto, Dinocardium	132	32.7	32.7	4316.4	450	3866
27	06-006	C. caretta	5/26/2006	31.626	81.134	GAB	15	palmetto, knobbed whelk	in situ	32.7	32.7	—	—	—
28	06-008	C. caretta	5/27/2006	—	—	GAB	2	shovel	103	32.7	32.7	3368.1	450	2918

TABLE 15.2 — (Continued)

	Nest	Species	Date	Latitude	Longitude	Dug by	Time (mm:ss)	Technique	# Eggs	Avg. wt/egg (g)	Cal/egg (200 kcal/200g)	Recovered calories (kcal)	Caloric cost (kcal)	Net benefit (kcal)
1	06-039	C. caretta	6/14/2006	31.627	81.133	GAB	05:20.5	palmetto & shovel	43	32.7	32.7	1406.1	450	956
2	06-040	C. caretta	6/14/2006	31.680	81.137	GAB	09:08.7	palmetto, knobbed whelk	141	32.7	32.7	4610.7	450	4161
3	06-043	C. caretta	6/16/2006	31.619	81.137	GAB	00:35.4	palmetto, knobbed whelk	80	32.7	32.7	2616.0	450	2166
4	06-046	C. caretta	6/19/2006	31.626	81.134	GAB	00:54.2	shovel	116	32.7	32.7	3793.2	450	3343
5	06-047	C. caretta	6/19/2006	31.618	81.138	GAB	02:12.6	shovel, foot	106	32.7	32.7	3466.2	450	3016
6	06-048a	C. caretta	6/19/2006	31.586	81.154	GAB	02:00.8	palmetto, knobbed whelk 2	112	32.7	32.7	3662.4	450	3212
7	06-049	C. caretta	6/20/2006	31.612	81.142	GAB	07:03.4	palmetto, knobbed whelk 2	135	32.7	32.7	4414.5	450	3965
8	06-051	C. caretta	6/21/2006	31.626	81.134	GAB	07:08.5	shovel	93	32.7	32.7	3041.1	450	2591
9	06-053	C. caretta	6/22/2006	31.628	81.132	GAB	04:47.0	shovel	95	32.7	32.7	3106.5	450	2657
10	06-054a	C. caretta	6/22/2006	31.623	81.135	GAB	02:15.2	shovel	115	32.7	32.7	3760.5	450	3311
11	06-055a	C. caretta	6/22/2006	31.606	81.145	GAB	02:23.2	palmetto, knobbed whelk 3	130	32.7	32.7	4251.0	450	3801
12	06-056	C. caretta	6/23/2006	31.614	81.140	GAB	03:30.0	shovel	96	32.7	32.7	3139.2	450	2689
13	06-057	C. caretta	6/23/2006	31.601	81.147	GAB	06:09.1	palmetto, knobbed whelk 4	109	32.7	32.7	3564.3	450	3114
14	06-059a	C. caretta	6/26/2006	31.605	81.145	GAB	03:14.9	palmetto, whelk 4, "scraper"	128	32.7	32.7	4185.6	450	3736
15	06-060a	C. caretta	6/26/2006	31.562	81.170	GAB	03:39.2	"scraper" frond, whelk 4	118	32.7	32.7	3858.6	450	3409
16	06-061a	C. caretta	6/27/2006	31.666	81.136	GAB	02:15.4	"scraper" frond	108	32.7	32.7	3531.6	450	3082
17	06-062	C. caretta	6/29/2006	31.620	81.137	GAB	02:23.8	"scraper"	118	32.7	32.7	3858.6	450	3409
18	06-063a	C. caretta	6/30/2006	31.623	81.135	GAB	01:00.6	shovel, foot	129	32.7	32.7	4218.3	450	3768
19	06-064a	C. caretta	6/30/2006	31.625	81.134	GAB	00:55.9	"scraper"	114	32.7	32.7	3727.8	450	3278
20	06-066	C. caretta	6/30/2006	31.669	81.138	GAB	02:02.0	shovel	129	32.7	32.7	4218.3	450	3768
21	06-071a	C. caretta	7/1/2006	31.562	81.170	GAB	02:34.6	shovel	131	32.7	32.7	4283.7	450	3834

TABLE 15.2 — (Continued)

	Nest	Species	Date	Latitude	Longitude	Dug by	Time (mm:ss)	Technique	# Eggs	Avg. wt/egg (g)	Cal/egg (200 kcal/200g)	Recovered calories (kcal)	Caloric cost (kcal)	Net benefit
22	06-073a	C. caretta	7/2/2006	31.623	81.135	GAB	02:49.3	shovel	107	32.7	32.7	3498.9	450	3049
23	06-074	C. caretta	7/2/2006	31.596	81.150	GAB	02:58.1	“scraper” 2	131	32.7	32.7	4283.7	450	3834
24	06-076a	C. caretta	7/3/2006	31.683	81.136	GAB	03:16.1	Scraper 3	119	32.7	32.7	3891.3	450	3441
25	06-085a	C. caretta	7/5/2006	31.565	81.166	GAB	03:28.4	scraper 3	89	32.7	32.7	2910.3	450	2460
26	06-089a	C. caretta	7/9/2006	31.623	81.135	GAB	02:07.2	shovel	119	32.7	32.7	3891.3	450	3441
27	06-091a	C. caretta	7/9/2006	31.604	81.145	GAB	01:30.4	scraper 4	74	32.7	32.7	2419.8	450	1970
28	06-095	C. caretta	7/12/2006	31.608	81.144	LK-L	21:06.1	scraper 4	111	32.7	32.7	3629.7	450	3180
29	06-096	C. caretta	7/12/2006	31.604	81.146	LK-L, GAB	17:20.9	—	76	32.7	32.7	2485.2	450	2035
30	06-103	C. caretta	7/18/2006	31.627	81.133	Class	20:28.3	scrapers	69	32.7	32.7	2256.3	450	1806
31	06-105	C. caretta	7/20/2006	31.605	81.145	SS	07:16.2	scraper	103	32.7	32.7	3368.1	450	2918
32	06-108a	C. caretta	7/24/2006	31.676	81.137	ED, JB	28:11.2	shovel	114	32.7	32.7	3727.8	450	3278
33	06-109a	C. caretta	7/25/2006	31.562	81.169	GAB	02:31.2	shovel	71	32.7	32.7	2321.7	450	1872
34	06-111a	C. caretta	7/28/2006	31.624	81.135	GAB	02:51.1	shovel	107	32.7	32.7	3498.9	450	3049
35	06-114a	C. caretta	8/1/2006	31.604	81.146	GAB	01:39.6	shovel	64	32.7	32.7	2092.8	450	1643
36	06-116	C. caretta	8/6/2006	31.608	81.144	GAB	01:23.2	shovel	wo	32.7	32.7	—	—	—
37	06-117	C. caretta	8/6/2006	31.603	81.146	KAM	06:11.9	shovel	121	32.7	32.7	3956.7	450	3507
38	06-119	C. caretta	8/10/2006	31.625	81.134	GAB	10:46.5	shovel and scraper	80	32.7	32.7	2616.0	450	2166
					Digging with Shovel		33:09.6							
					Digging with Whelk Shell		27:20.5							
					Digging with a Fronde Scraper		12:32.10							
					overall average		18:23.5	average clutch size	105					

the undisturbed laminated beach sand beneath the covering pit, exposing the egg chamber neck as a bull's-eye contrasting with the contourlike patterns of the undisturbed backbeach sediment.

Data on the time it takes to locate and validate a clutch of sea turtle eggs was collected in 2005 and 2006 on St. Catherines Island. Initial times in 2005 were kept using a wristwatch with a second hand, becoming more precise as the data collecting progressed. In 2006, a stopwatch was used to time the egg finding activity (table 15.2). Although a sample of variable precision, these data at least give an approximate measure of time to find eggs. The 2006 data increased the precision of the egg locating activity.

Various combinations of tools were used throughout the season (to compensate for experience across the year). The location of eggs in the loggerhead nests took an overall average of 18 minutes and 23.5 second to locate, with the shovel (modern) technique taking longest (33 min 09.6 sec), probing and digging with a whelk shell was slightly more efficient (27 min 20.5 sec), and digging with a frond scraper was significantly more efficient (12 min 33.0 sec). These data are certainly biased in the sense that more difficult nests would have been dug by shovel, the modern tool of choice, resulting in the longer digging time for shoveling (more complex nests). However, the same bias probably does not exist for nests dug with a scraper, as all "neo-native" nests were selected in the same way (they were not the complex, obstructed nests dug by shovel). This could be tested by random selection of nests to dig, if it were important enough to replicate.

Two aspects of egg gathering activity that are not timed are the time to locate a possible nest by walking along the shoreline and the time it takes to remove the eggs from the egg chamber once it is located by the digging activity. The time to return to the eating site and effort of transportation would also be added as part of the total cost of acquisition. Most timed nests were loggerhead sea turtle nests, however three leatherback nests were also deposited in 2005 on St. Catherines Island and a variety of experimental digging tools were used on different nests, including small, square-ended sand shovels that we usually use in the modern program.

#### ECONOMICS OF EGG GATHERING

Nest location can be estimated by assuming an adult would walk (4 mi/hour) along a beach

(fig. 15.5). By knowing that nests cluster along a beach (learned by experience), certain segments of beach to walk would be favored by Native American gatherers (fig. 15.5). For this exercise we might assume a group would walk from the present location of South Beach entrance northward to McQueen Inlet (fig. 15.5C), a distance of 5.5 km. and back (a total of 11 km; 15.6). Ainsworth has compiled a compendium of the effort for various human activities in terms of a metabolic equivalent (MET), "the ratio of the work metabolic rate to the resting metabolic rate." According to her calculations, "One MET is the rate at which adults burn kcal at rest, ... approximately 1 kcal per kilogram (kg) of body weight per hour (expressed as 1 kcal/kg/hr). The caloric cost of collecting a clutch of eggs by walking from South Beach entrance to McQueen Inlet by a 100-pound native person can be calculated using metabolic equivalents (Ainsworth, 2002).

During nesting season 2008 the number of nests deposited between South Beach entrance and McQueen Inlet ranged from 0 to a maximum of 7 nests/day. The likelihood of encountering a nest (or nests) would be high in this portion of the beach (fig. 15.5), especially during the height of the nesting season of loggerheads, around the summer solstice. Each nest dug using a palm frond tool would have taken an average of 12 minutes 33.0 seconds and (assuming a MET equivalent of 5.0; Ainsworth, 2002) would involve an expenditure in energy of  $3.833 \text{ kcal/min} \times 12.55 \text{ min} = 48.10 \text{ kcal}$ . Removing the eggs from the nest is estimated to take approximately 3 minutes and would cost  $(3 \text{ min} \times 3.833 \text{ kcal/min})$  approximately 11.50 kcal. Transporting the gathered eggs would be a relatively expensive proposition, estimated to be approximately  $818 \text{ eggs} \times 32.7 \text{ g/egg} = 26.747 \text{ kg}$  (58.7 pounds). This is added to the assumed 100 pound gatherer's weight = 158.7 pounds  $\times$  walking 5.5 km @ a moderate rate of 3.22 km/hr (2.0 mph) = 1.70 hr. This is equal to  $3.833 \text{ kcal/min} \times 51.24 \text{ min} = 133.68 \text{ kcal}$  (see table 15.3, *opposite*).

The cost/benefit ratio computed (adding the rapid walk, nest digging, unloading, and return carry would total 813 kcal). The return caloric content for an average clutch is 7940 kcal, producing a positive economic return of ~9.77:1 on energy expended, if only one clutch were collected, and a maximum bonanza (~68.4:1) if seven clutches were collected!

The possibility also exists that native forag-

TABLE 15.3  
Energy Expenditure for Nesting between South Beach and McQueen Inlet

1. Walking the beach.....	5.5 km @ 6.4 km/h @ 2.500 kcal/min	= 128.9 kcal
2. Digging a nest.....	12.55 min @ 3.833 kcal/min	= 48.10 kcal
3. Loading the eggs.....	3 min @ 3.833 kcal/min	= 11.50 kcal
4. Return walk (loaded with eggs).....	5.5 km @ 3.2 km/h @ 6.057 kcal/m	= 624.63 kcal
Total caloric cost/clutch		= 813.13 kcal

ers would occasionally come across nests with hatchlings emerging from the beach surface after the eggs hatch beneath the beach. It is possible that such an enticing food source might have been utilized by Native Americans, perhaps as a basis for a soup or stew, although no references have been seen alluding to this behavior, nor have any references to modern analogs of the eating of hatchling sea turtles. It should be noted, however, that the raccoon (*Procyon lotor*) and the feral hog (*Sus scrofa*) do not hesitate to eat hatchlings when they are caught emerging, and in fact, will follow the hatchlings back to their emergence crater and dig out the nest to eat the rest of the hatched clutch of eggs.

TRANSPORTING THE EGGS  
TO THE RESIDENTIAL BASE

Transportation from the beach to residential bases and/or temporary summer campsites was likely a problem (in the absence of cheap, plastic, five gallon pails!) because the number of round, ping-pong-sized eggs gathered from a single nest would number about 113; those dug from as few as 10 nests would amass an impressive 1130 eggs. Transportation to an eating site would probably entail skin bags, baskets woven of grasses (perhaps smooth cord grass *Spartina alterniflora*), or some other light carrying mechanism (maybe even transport in a canoe or raft).

Once transported to an eating site, the eggs would likely have been eaten raw with little preparation as their storage would be difficult and preparation by heating does not coagulate the albumin as in chickens' eggs. Because of the difficulty of preparation, sea turtle eggs may have formed the basis of a summer solstice feast or celebration, perhaps in conjunction with the dim beginnings of the concept of perceived aphrodisiac effects of sea turtle eggs at the summer solstice.

Archaeological evidence of egg harvesting and eating would rapidly disappear from the re-

cord as egg shells (the only preservable "hard" evidence) were trampled and decomposed in the area. Evidence of preservation of eggshells returned to nests and subsequently eroded out due to scarp retreat (fig. 15.6) indicates a residence time of at least a year in "old nests." An experiment will be designed to test the survivability of eggshells over time, and enhance our limited observational evidence.

Acid environments of coastal sand soils are not amenable to preservation of organic evidence (bone, shell, or grass fabric) of this seasonal sea turtle-based economy, therefore much of the nutritional story of sea turtle egg economics in indigenous societies of coastal Georgia will remain speculative. Just what sea turtle eggshells in middens might look like is a pertinent question here. The fragile, leathery shells rapidly dry to a brittle condition and would be easily destroyed by even moderate trampling, rapidly reducing the preserved egg remains to tiny fragments and carbonate dust. Again, an experiment ought to be designed to put eggshells into a midden environment and measure how long sea turtle eggshells survive.

HARVESTING SEA TURTLE MEAT:  
ST. CATHERINES ISLAND

Harvesting nesting females and harvesting sea turtle eggs were clearly differentiated by Thomas (2008: 156) from hunting activities that occurred offshore. Harvesting nesting female loggerheads would have easily been accomplished by patrolling the beach at night and, when a nesting female was encountered, simply tipping her onto her back, immobilizing her until she was either killed or bound and transported onto the island. As Thomas pointed out, two adults, or even youngsters, can tip a loggerhead sea turtle when she is nesting on a beach. An adult female averaging 68 kg (Larson, 1980) could be tipped and tied in 15 minutes and, as Thomas pointed out

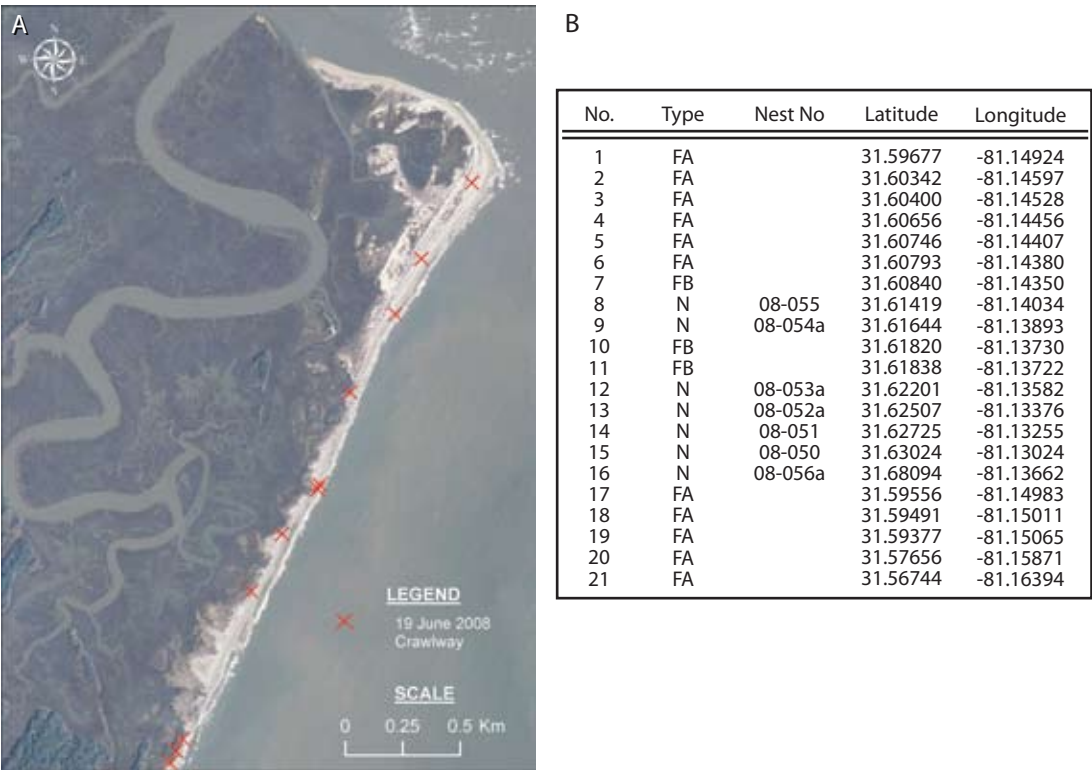


Fig. 15.5. Map of north end of South Beach with nonnesting and nesting crawlways encountered in monitoring nests on June 19, 2008. **A**, location of sea turtle event sites, both nesting and nonnesting crawlways that would have been encountered by native foragers; and **B**, a list of the sites encountered on one day near the summer solstice of 2008.

(2008: 159), would then have had to be butchered, taking an estimated two hours, yielding a return rate of 21,360 kcal. However, this activity would almost certainly have had to be performed in the dark of night, as that is when most loggerhead sea turtles nest. Without sharpened tools of steel, stone, or volcanic glass it would have been virtually impossible to butcher a fresh sea turtle, as their skin is extremely tough. We suggest here that the normal procedure for turtle preparation would more likely have involved cooking a turtle whole, using its carapace as a roasting container. Most of the turtles that were consumed locally in Tonga are cooked in the shell in an earthen oven (*Umu*), following which the shells were discarded (Havea and MacKay, 2009: 16). Regardless of preparation techniques, the pay-back for harvesting loggerhead sea turtles would

have been impressive.

Hunting or harvesting of loggerhead sea turtles for meat was a likely seasonal economy, as nesting loggerheads could be easily “tipped” after nesting, prepared on the beach by roasting using flotsam wood, and distributed to tribal members. It is also speculated that a canoe-based harpoon or spear fishery may have existed exploiting loggerhead sea turtles and migrating leatherback sea turtles (a very oily species and a likely source of cosmetic oils), an industry that would provide oil for the economy and prestige and status for the hunter during annual migrations of leatherbacks past St. Catherines Island (April and October). It is likely that cooking and butchering of sea turtles would have been done on or near the beach, leaving virtually no preserved record in seasonal habitation sites. There

are no data on the quality of meat from common sea turtles found in Georgia (loggerheads [*Caretta caretta*], green sea turtles [*Chelonia mydas*], leatherbacks [*Dermochelys coriacea*], and Kemp's Ridley [*Lepidochelys kempii*]), but the literature abounds with accounts of turtle ingestion. Even as late as the 19th century, the green turtle was once highly sought for its greenish colored body fat, or *calipee*, a key ingredient in the popular delicacy, "green turtle soup."

### THE OBSERVED ARCHAEOLOGICAL RECORD

To reiterate:

(1) The diet-breadth model predicts that (based

on postencounter return rates) every St. Catherines Island forager (seeking to maximize net energy) should harvest every single sea turtle encountered.

(2) Central place foraging theory addresses the trade-off between increasing the utility of a load (through field processing) and increasing the amount being harvested (which involves foraging and travel time). Terrestrial transport thresholds project that foragers should only "sometimes" field process the carcasses of male and female leatherback turtles before returning to the residential base. Similar computations for male and female loggerheads indicate that the carcasses would "almost never" be field butchered before returning to residential base.

(3) Actualistic experimentation on St. Cath-

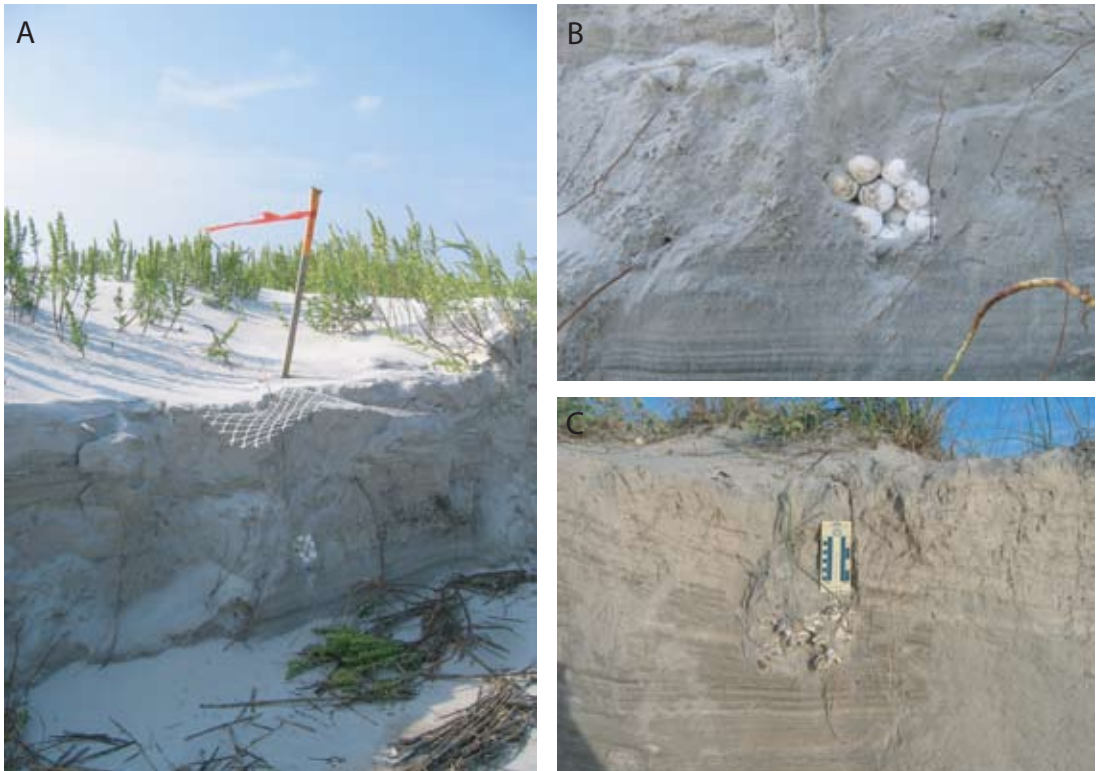


Fig. 15.6. Exposed old and new nests preserve eggshells that have a residence time of at least one year. **A**, naturally exposed clutch in scarp on McQueen Dune Field eroded during a nor'easter; **B**, close view of exposed clutch of loggerhead sea turtle eggs seen in A [Nest 06-119]; and **C**, naturally exposed clutch of hatched eggshells from a relocated nest [Nest 05-074a] deposited in a dune called the turtle bowl 3 m behind the scarp, eroded out during nor'easter a year later, and exposed to view, proving at least a one-year residence time in eggshells in dune sand.

erines Island demonstrates a very high cost-benefit ratio for harvesting sea turtle eggs, suggesting that the energy-efficient foragers should always take such eggs upon encounter.

In archaeological terms, then, human behavior ecology projects that nearly all loads of sea turtle meat would be transported in bulk for processing at the central base. If so, then, the discarded, inedible parts of sea turtles should be abundant in the middens associated with residential bases, and virtually absent elsewhere. We believe that all archaeological evidence of egg harvesting and eating would rapidly disappear from the archaeological record.

We will now see how well these theoretical projections fare against empirical archaeological evidence.

#### SEA TURTLE EXPLOITATION IN ANTIQUITY

Even the most cursory examination of the archaeological record demonstrates, beyond doubt, that humans have a long history of exploiting sea turtles (e.g., Frazier, 2003). In the Middle East, abundant green sea turtle remains are found in archaeological sites at as-Sabiya in Kuwait and Dalma Island in the United Arab Emirates (Frazier, 2003). Sea turtles were a common food item during the Bronze Age (6000–4000 <sup>14</sup>C yr B.P.) in the Persian Gulf (Mosseri-Marlio, 1998; Spotila, 2004: 64). Sea turtles were commonly captured for food in Greece ca. 2700 years ago and their shells were used as shelters. Smith et al. (2007) document the extensive exploitation of sea turtles along the Pacific coast of Mexico, where sea turtles are the most common reptilian remains in Late Archaic deposits (ca. 5500–4000 cal B.P.). Such hunting activity significantly reduced local availability during the next 3000 years, with sea turtle bones disappearing entirely in later deposit levels. Throughout the Caribbean basin, archaeological sites contain abundant marine turtle remains (e.g., Wing and Reitz, 1982; Frazier, 2003: 13–15).

#### SEA TURTLE EXPLOITATION ALONG THE GEORGIA BIGHT

By contrast, it must be noted that marine turtle remains are virtually absent from the archaeological record of St. Catherines and the Georgia Bight.

Despite the projected high return rates, only five sea turtle bones were recovered during the islandwide survey on St. Catherines Island (Re-

itz, 2008). All of these came from Little Camel New Ground Field, site number 5 (9Li206; AMNH-466), a medium-sized Irene period site (with a secondary St. Catherines period component) located 10 m east of South Beach Road (in transect J-1; Thomas, 2008: 588). Test Pit I (0–10 cm) contained one costal, one carapace (upper shell) fragment, and two “peripherals,” fragments from the edge of the carapace (Elizabeth Reitz, personal commun.). Given the stratigraphic position of these finds, we suspect that the sea turtle bones from 9Li206 likely derive from an Irene period context, estimated to range from cal A.D. 1300 to A.D. 1580 in the St. Catherines Island chronology (Thomas, 2008: table 15.3).

Recent excavations at the McQueen Shell Ring, also on St. Catherines Island (Sanger and Thomas, 2010), recovered a single sea turtle bone. Preliminary analysis indicates that this bone is probably the right humerus of a small loggerhead turtle, with four distinct butchering marks (Carol Colaninno and Betsy Reitz, personal commun.).<sup>2</sup> Fifteen radiocarbon dates that are currently available from the McQueen Shell Ring have been derived from three different contexts: shell deposits that constitute the ring itself, features found within the interior of the ring, and later (post-Late Archaic) features encountered at the ring (Thomas and Sanger, 2010: table 3.1). We believe that the vast majority of the shell mound construction derives from either the initial construction stage, dating between 2300 and 2120 cal B.C. (4250–4070 cal B.P.) and a later phase about 2130–1950 cal B.C. (4080–3900 cal B.P.). At present, these are the best age estimates for the loggerhead bone found at the McQueen Shell Ring.

Sea turtle bones are likewise rare in archaeological sites elsewhere along the Georgia Bight. At the Sapelo Shell Ring, Waring and Larson (1968: table 25) report finding a sea turtle humerus and part of a carapace, probably *Caretta caretta*. A total of 19 sea turtle bones (of unknown species) were recovered at the North End site, Little St. Simons Island (Weinand, Andrus, and Crook, 2000). A single Atlantic green sea turtle bone is reported from Kenan Field, on Sapelo Island (Reitz, 1982: table 1; Crook, 1978, table 2). Milanich (1971, table 6) identified two sea turtle bones from house excavations on Cumberland Island. Excavations in a historic-era midden produced six loggerhead bones, one Kemp's Ridley turtle bone, and 42 additional unidentified sea

turtle bones (table 10 in Steinen, 1978).

Considering the large numbers of sea turtles that today nest along the Georgia coastline and the extensive archaeological excavations that have taken place here, the scarcity of marine turtle bones is striking indeed.

At least three hypotheses come to mind when considering this disparity:

(1) *Sea turtles were present along the Georgia Bight during the last five millennia, but foragers*

*did not harvest them.* This hypothesis suggests that the diet-breadth projections (based on high postencounter return rate estimates) are incorrect and foragers deliberately elected not to harvest marine sea turtles in great numbers.

(2) *Sea turtles were harvested, but butchered on the beach, with only edible portions returned to the residential base.* This hypothesis suggests that central place foraging projections (based on terrestrial transport thresholds) are incorrect and



Fig. 15.7. Skeletal remains of sea turtles on the beaches of St. Catherines Island. **A**, skeleton of loggerhead sea turtle buried in dune facing east, being eroded by beach retreat, South Beach; **B**, close view of another loggerhead sea turtle skeleton buried in the dunes near Sand Pit Road; **C**, scatter of disassociating skeletal elements of dead, stranded loggerhead sea turtle on South Beach; **D**, isolated carapace bone eroding out of North Beach after being buried for some time.

foragers routinely field-butchered sea turtles, which could explain the absence of marine turtle remains in residential sites.

(3) *Sea turtles were rare (or absent) from the Georgia Bight during the last 5000 years.*

The archaeological and paleobiological record of the Georgia Bight is currently inadequate to distinguish among these, or other, alternative hypotheses.

## FUTURE RESEARCH DIRECTIONS

The residence time of sea turtle bones in the beach, in terrestrial soils, and in shell middens needs to be documented in a series of experiments. Experiments have been run in the past preparing loggerhead sea turtle skeletons for osteological research and study, indicating that sea turtles buried in the backbeach dunes decompose almost to clean, bare bone within one year (15.7A, B). This work should be continued by burying dead, stranded sea turtles in dune fields and in middens, excavating them after succeeding intervals of time, perhaps six, nine, and 12 months after burial, to investigate the survivability of sea turtle bone in sandy, backbeach soils (fig. 15.7). The experiment ought to be replicated by observations of buried sea turtles in shell middens. A third experiment would test the residence time and measure recovery of sea turtle skeletal elements disassociated in the beach environment, partly addressed by Knell (2004) as described in Bishop et al. (2009).

Future research should reexamine all turtle elements in the St. Catherines archaeological collections (fig. 15.9) to attempt to identify and assign each skeletal element to a genus- or species-level taxon in order to document the presence/absence and condition of all turtle taxa in St. Catherines' shell middens. These remains should be compared with observed sea turtle bones from known taphonomic settings (fig. 15.7).

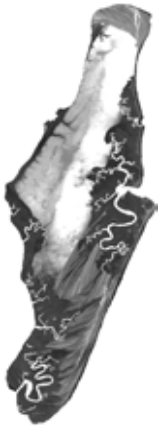
Experiments should be designed to determine the residence time of sea turtle bone and sea turtle eggshells in the sandy acid soils of the Pleistocene core and Holocene accretional terrains (see Bishop et al., this volume, chap. 3), in the beach, and in the basic soils associated with shell middens.

## NOTES

1. Many organizations have supported the research of the St. Catherines Island Sea Turtle Program over the last 19 years, including our major sponsors, the Georgia Higher Education Eisenhower/Improving Teacher Quality Program (~60% of funding) and the St. Catherines Island Foundation. Essential support of the teachers programs has also been received from Georgia Southern University, GeoTrec LLC of Fayette, Iowa, and the Georgia Department of Natural Resources (Non-Game Division). Grants have been received from the Edward John Noble Foundation (administered through the American Museum of Natural History), the St. Catherines Island Scientific Research Advisory Committee, the Turner Foundation, the JST Foundation, the M.K. Pentecost Ecology Fund, and the Partnership for Reform in Science and Mathematics (PRISM), an NSF-sponsored initiative designed to improve teachers' science and math content knowledge.

So many individuals have contributed to our program that we hesitate to name them for fear of leaving somebody out who deserves to be acknowledged, if we have done so, please accept our apology! We thank the St. Catherines Island staff for their day-to-day support for 18 years, especially Jeff Woods, Spyder Crews, Alan Dean, Richard Bew, Fred Harden, Lee Thompson, Ian Dutton, Kerry Peavler, Veronica Greco, Dr. Terry Norton, Jen Hilburn, and Mary-Margaret Pauley Macgill. Royce Hayes, Ed Davis (along with Doris Davis), Kelly Vance, Fred Rich, Brian Meyer, and Nancy Marsh provided service far above and beyond the line of duty in helping so many ways over so many years. Georgia Department of Natural Resources personnel who have helped with the Program include Charles Maley, Mike Harris, Brad Winn, Mark Dodd, and Adam Mackinnon. The Board Members of the St. Catherines Island Foundation, Inc. are collectively thanked for their continuing support of the St. Catherines Island Sea Turtle Program and its research programs.

2. No marine eggshells have been recovered from the archaeological sites on St. Catherines Island.



## CHAPTER 16

### GEOMORPHOLOGY, SEA LEVEL, AND MARINE RESOURCES: ST. CATHERINES ISLAND

HAROLD B. ROLLINS AND DAVID HURST THOMAS

The abundance, diversity, and accessibility of marine resources available to the prehistoric Native American populations of St. Catherines Island were certainly influenced by a myriad of interacting geomorphological, sedimentological, and ecological processes, played out within the context of sea level change.<sup>1</sup> Any discussion of prehistoric foraging strategies must be ultimately constrained by the accumulation of observational data. Several avenues of ongoing research now offer opportunities for some degree of discriminatory heuristic modeling of temporal changes in the St. Catherines Island marine resource base. This chapter discusses a largely empirical interactive integration of rate and magnitude of sea level change, tidal amplitude, sedimentary dynamics, and developmental evolution of bay and marsh habitats, and how these variables may have influenced the shellfish resources on St. Catherines Island.

#### OVERVIEW OF LATE PLEISTOCENE SEA LEVEL CHANGE ALONG THE GEORGIA COAST

The shallow Georgia embayment currently extends eastward over 100 km into the Atlantic. There is general agreement that St. Catherines Island and the other Georgia Sea Islands were constructed during the Silver Bluff submergence when sea level rose to 1–3 m above present-day level; these data have been summarized elsewhere (Thomas, 2008: chap. 4; see also chap 1, this volume). The age of the Silver Bluff transgression remains elusive. Although conventional opinion places the last Pleistocene sea level high-

stand at about 125 <sup>14</sup>C ka B.P., numerous radiocarbon dates along the eastern U.S. coast have come in at between 25 and 40 <sup>14</sup>C ka B.P. Attempts to explain these younger than expected dates in terms of contamination by “young” carbon have not been successful, as the distribution of these dates shows a consistently tight pattern and not the expected array of varying degrees of contamination. Moreover, the number of finite dates zeroing in on 25 to 40 <sup>14</sup>C ka B.P. would be less than the number of infinite dates, if contamination were the sole explanation. Either these dates are valid, or explainable in terms of local tectonism, or perhaps, as suggested by Dockal (1995) the rate of past <sup>14</sup>C production has not been constant and was influenced by an increase of cosmic ray flux at about 60 <sup>14</sup>C ka B.P.

Vibracores completed on St. Catherines Island, along North Beach, Cracker Tom, and at the St. Catherines Shell Ring have likewise produced a number of dates in the range of 25–40 <sup>14</sup>C ka B.P. (Linsley, 1993; Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008). Vento and Stahlman (2008; see also chap. 4, this volume) dated the A horizon of a basal paleosol exposed at Yellow Bluff along North Beach at about 22,820 years <sup>14</sup>C yr B.P. Fiddler crab burrows in that soil horizon provide evidence of a washover deposit more or less penecontemporaneous with a shell lag date of 22,600 <sup>14</sup>C yr B.P. from a vibracore taken along North Beach transect A–A' (Linsley, 1993) and confirm its proximity to the paleoshore at that date (Martin and Rindsberg, 2008; see also Martin and Rindsberg, this volume, chap. 5).

There is also general agreement that 18,000 <sup>14</sup>C years ago much of this was subaerially ex-

posed as sea level was about 100 m lower than at present. Pilkey et al. (1981) reported the results of two vibrocore transects, extending into the embayment, one located just opposite the present-day Savannah River. These cores, although widely spaced, penetrated the very thin (about 4 m thick) offshore sedimentary veneer and demonstrated that the initial Holocene transgression following the Wisconsinan sea level lowstand involved an extensive westward movement of barrier island facies. The cores, however, were too widely spaced to permit detailed reconstruction of that migration of the barrier island facies tract, but did provide clear evidence that barrier islands tracked sea level rise, and were not constructed only following achievement of present sea level stability about 5–7  $^{14}\text{C}$  ka B.P. A few vibracores described in the Pilkey et al. (1981) report, completed in their northern transect off Cape Romain, penetrated the earlier Pleistocene and contained some in situ oyster shells that were radiocarbon dated at 22,590  $^{14}\text{C}$  yr B.P. and 25,070  $^{14}\text{C}$  yr B.P., again nicely within the range of the Silver Bluff chronology.

The relative rate of sea level rise following the Wisconsinan regression, on average, must have been slow enough to permit barrier island construction as backbarrier lagoonal deposits and fauna, including the oyster *Crassostrea*, occur in many of the cores. Core spacing was too coarse, however, to determine whether sea level rose gradually or episodically, and whether the barrier island/lagoon facies track moved seamlessly or in a stepwise manner characterized by short-term stability followed by “spurts” of rapid rise. In any case, by between 5  $^{14}\text{C}$  ka B.P. and 3  $^{14}\text{C}$  ka B.P. sea level hovered within a few meters of its present position and the transgressive barrier island/lagoon facies tract lodged against the relict Silver Bluff escarpment. The Silver Bluff escarpment, by this time, was likely erosionally diminished in comparison to its earlier stature. Paleosol 5A on Yellow Bluff, dated at 22,820  $^{14}\text{C}$  yr B.P. (Vento and Stahlman, this volume, chap. 4) is penecontemporaneous with the 22,600  $^{14}\text{C}$  yr B.P. date reported by Linsley (1993) on a cojacent subtidal marine shell lag in core 3, transect A–A' (Linsley, 1993; Linsley, Bishop, and Rollins, 2008). The paleosol represents an interval of extensive temporal stability and its vertical separation from the shell lag approximates 8 m, providing a crude estimation of the relief of the Silver Bluff escarpment in this area at that time.

Moreover, such a steep gradient suggests that this area of the coast at that time was possibly wave dominated, not tidally dominated. What was earlier a labile facies tract marching (albeit, perhaps, in episodic spurts) over a low relief coastal plain was transformed, by “fusion” to an anchored river-dissected relict shoreline, into a sedimentary regime characterized by imposition of ebb tidal dominance and a type of stability leading to lagoonal/marsh infilling.

### OVERVIEW OF HOLOCENE GEOMORPHOLOGY AND SEA LEVEL CHANGE

Thomas (2008: chap. 4; see also chaps. 1, 8, and 9, this volume) summarizes the previous work on Holocene sea level change along the Georgia coast, and details a scenario for concomitant geomorphologic modification, Native American occupation, and resource exploitation on St. Catherines Island, in particular. Highlights of this pattern include:

(1) About 18  $^{14}\text{C}$  ka B.P. the shoreline that fronts present-day St. Catherines Island was around 100 km eastward of its present position and sea level was about 100 m below present MSL.

(2) A relatively rapid early Holocene sea level rise of 1 cm/yr, slowing to about 3 mm/yr occurred by about 7  $^{14}\text{C}$  ka B.P. (7900 cal B.P.).

(3) According to Crusoe and DePratter (1976), extensive oyster beds only developed behind the Sea Islands when sea level flooded freshwater lagoons (5000–4000  $^{14}\text{C}$  yr B.P.; 3780–2530 cal B.C. [5730–4480 cal B.P.]) and the earliest recognizable shorelines (associated with St. Simons artifacts and Late Archaic shell rings) date to this time interval and represent occupation on both sides of the Sea Islands (DePratter and Howard, 1980). Sea level was, at this time, 1–2 m below present level, evidenced by observations of the shell ring basal strata below present marsh surface (DePratter and Howard, 1980; Thomas, 2008; see this volume: fig. 1.5). Zooarchaeological evidence from several shell rings along the Georgia and Florida coasts demonstrates a fully developed estuarine environment during this period (e.g., Marrinan, 1975, 1976, 2010; Russo, 1998, 2002; Quitmyer and Jones, 2000; Russo and Heide, 2001, 2002; Russo, Heide, and Rolland, 2003; Sanger and Thomas, 2010).

(4) This was accompanied by reduction in stream gradients, wetter climate, bay filling, in-

let straightening, narrowing, and deepening, and the development of an extensive salt marsh tidal prism with tidal creeks and estuaries. In addition, this may mark an initial transition from a wave-dominated to tidal-dominated coast similar to, but predating, the scenario postulated by Chowns et al. (2008) accompanying the ~2600 B.P. lowstand and subsequent ~2500 B.P. transgression that resulted in formation of the modern Sapelo, St. Catherines, and Ossabaw inlets.

(5) Present-day sea level was attained in this area by about 3000 cal B.P. (1050 cal B.C.) when shoreward transgression of an early- to mid-Holocene barrier island facies tract anchored against the older (Pleistocene) Silver Bluff shoreline. DePratter and Howard (1981) provided additional evidence of this sea level highstand and Thomas (2008) emphasized its role in expansion of intertidal resources, such as oyster patches. Brooks et al. (1989) reported that, in the South Carolina area, shell middens extensively occur more inland between 3000 cal B.P. and 800 cal B.P. (1050–1150 cal B.C.) due to estuarine expansion (Thomas, 2008; see also chap. 1, this volume). More recent research at middens at Litchfield Beach estuary (just south of Murrells Inlet) produced dates ranging from about 2100 to 600 cal B.C. (Irby Quitmyer and Chester DePratter, personal commun.).

(6) An interval of sea level lowering and shoreline regression occurred in the late Holocene. DePratter and Howard (1980) indicated that this event occurred about 2500  $^{14}\text{C}$  yr B.P. (550 cal B.C.) and involved a 4 m drop below modern MSL. Transgressions correlate with the breaching of inlets. Thus the original inlets (Blackbeard and Guale) probably date from the highstand prior to 3000 B.P. (?5000–4000 B.P., items 3 and 5 above), the spits date to the lowstand (~2600 B.P.), and the modern inlets (Sapelo, St. Catherines, Ossabaw) date to resumed transgression (~2500 B.P. onward; item 9 below). From the available dates these three breaches all fall between middle Refuge and late Wilmington (Chowns, personal commun.). This postulated regression was also supported by Brooks et al. (1989), who indicated that sea level in the South Carolina area was 3 m to 4 m below present MSL about 3000 cal B.P. (1050 cal B.C.), but rose again between 2400 cal B.P. and 1700 cal B.P. (450 cal B.C. to cal A.D. 250; Thomas, 2008: 44–47). According to DePratter (1977a), this resulted in a significant hiatus in shellfishing, between 3000  $^{14}\text{C}$  yr B.P. and 2700

$^{14}\text{C}$  yr B.P. (1260–820 cal B.C.; 3210–2770 cal B.P.). By 2600  $^{14}\text{C}$  yr B.P. (800 cal B.C.; 2750 cal B.P.), sea level again rose and extensive oyster beds reformed (Crusoe and DePratter, 1976).

(7) Detailed studies in Murrells Inlet, South Carolina, by Gayes et al. (1992) and Scott, Gayes, and Collins (1995) focus on a late Holocene sea level highstand between 5300 cal B.P. and 4300 cal B.P. (3350–2350 cal B.C.), followed by a 2 m fall between 4300 cal B.P. and 3600 cal B.P. (2350–1650 cal B.C.). Gayes et al. (1992) also suggest, if their Santee Delta data are included, that the lowstand might actually date somewhat later, roughly 2600 cal B.P. (650 cal B.C.). The highstand reached about 1.5 m below present day MSL indicating that sea level 2650  $^{14}\text{C}$  yr B.P. (700 cal B.C.) was a bit more than 3 m below present level. Relative sea level rise (RSLR) was about 50 cm per century during this event, but slowed to about 10 cm per century after 3600  $^{14}\text{C}$  yr B.P. (1650 cal B.C.) until present (i.e., less than the global average of 18 cm per century; Scott, Gayes, and Collins, 1995: 616).

(8) Thomas (2008: 45) stressed that “high-ranking marine patches” would be negatively impacted during this late Holocene regression, and any midden material would likely be either “eroded away” or “buried beneath 2 m of more recently deposited salt marsh sediments.” Over an interval of only seven centuries, salt marsh would have been eliminated from the western side of St. Catherines Island. Oceanward, however, formation of a new barrier island (Guale Island) afforded an eastern source of interisland marsh resources (Thomas, 2008: chaps. 32, 34).

(9) The 10 cm per century rise in sea level following the late Holocene regression led to overtopping and erosion of Guale Island and an eventual renaissance of more westerly estuarine marshland resources. This led Thomas (2008: chap. 4) to predict the existence of few Late Archaic and Refuge-Deptford sites on the northeast side of St. Catherines Island (see also chap. 1, this volume).

We can expect that the aforementioned scenario of change would lead to significant perturbations in the abundance, distribution, and exploitation potential of the St. Catherines Island shellfish resources over time. But we hasten to add that these observations have yet to be tested against comprehensive zooarchaeological analysis of the vertebrate and invertebrate remains from these sites (although considerable

research in this direction is currently ongoing). Further, the nuances that are associated with relative rates of sea level change, wave versus tidal dominance, temporal span of causality, and sedimentological and biological responses have yet to be fully analyzed.

Historically, the availability and utilization of marine shellfish resources along the Sea Islands of Georgia have depended upon the dynamic interaction of several factors. At the risk of oversimplification, this interaction can be categorized.

#### ECOLOGICAL DIMENSIONS AND CONSTRAINTS OF THE RESOURCES

Shellfish taxa exhibit habitat specificity. This is rather obvious in a comparison of major near-shore between-habitat biotopes, such as shoreface, marsh, and estuarine environments, but it is also applicable to proximal within-habitat situations, such as intramash oyster patches, tidal creek clam beds, and higher marsh streamside mussel clumps. The proximity of salt marsh resources to those of the terrestrial hinterland greatly influenced Native American foraging strategies along coastal Georgia, and has become a focus of the analysis of resource exploitation on St. Catherines Island (Thomas, 2008: chap. 10).

#### GEOMORPHOLOGICAL DIMENSIONS ENGENDERING RESOURCE CHANGE AND AVAILABILITY

Several factors regulate maintenance of salt marsh ecosystems and useful discussions and reviews can be found in Frey and Basan (1985), Fletcher et al. (1993), Jennings, Carter, and Orford (1995), Donnelly and Bertress (2001), Torres et al. (2006), Ward et al. (2008), among others. The most important controls are considered to be those that allow the dominant marsh macrophytes (e.g., *Spartina alterniflora*) to retain their elevational habitat, usually a rather restricted portion of the intertidal range. Specifically, the long-term controls on this dynamic equilibrium involve interactions among sea level, substrate elevation, primary productivity, and sedimentary accretion rate. Geomorphological influence on this equilibrium includes change in tidal amplitude and wave intensity and lateral (along strike) variation in sediment supply and antecedent topography. In the sediment-rich salt marsh estuaries of the southeastern United States, the critical rate of sea level rise, beyond which the *Spartina* growth will be

inhibited, is thought to be about 1.2 cm/yr—more than 3.5 times the current long-term rate of sea level rise (Morris et al., 2002). Kirwan and Temmerman (2009) note, however, that the position of a marsh in the tidal frame and the range of tidal amplitude may determine whether a given relative rate of sea level change leads to marsh deterioration or survival. The interplay of controls on marsh growth and survival can perhaps be best viewed in those areas, such as coastal Louisiana and certain other sites along the northern Gulf of Mexico, where the impact of sea level rise is exacerbated by land subsidence, due to tectonic downwarping, sediment compaction, and human impact (Shirley and Battaglia, 2006).

There is a tendency to think about coastal retreat and advance simplistically, in terms of rate and amplitude of sea level change but, in fact, these may not be the primary drivers of change along many shorelines. For example, relative availability of fluvial sediment due to proximal riverine estuaries, along mesotidal to macrotidal low gradient coasts, may determine whether a shoreline exhibits progradation or retrogradation.

#### ECOLOGICAL DIMENSIONS OF SHELLFISH RESOURCES

For the past three years, zooarchaeologist Nicole Cannarozzi (working with Irvy Quitmyer, Florida Museum of Natural History) has been analyzing column samples from the Late Archaic shell rings on St. Catherines Island (Sanger and Thomas, 2010). Similarly, Sarah Bergh (working with Elizabeth Reitz, University of Georgia) has been studying shellfish frequencies in the late prehistoric middens of St. Catherines Island. But in both cases, this research is ongoing and the results remain preliminary.

Lacking these empirical results based on zooarchaeological data, we have (for present purposes) selected five shellfish known to occur in the St. Catherines Island middens: the quahog *Mercenaria mercenaria*, the eastern oyster *Crassostrea virginica*, the Atlantic ribbed mussel, *Geukensia demissa*, the periwinkle *Littoraria irrorata*, and the knobbed whelk *Busycon carica* (and other busyconine species). All of these (and others such as the stout tagelus, *Tagelus plebius*, and possibly the eastern mudsnail, *Ilyanassa obsoleta*, have been harvested as food resources by Native Americans on St. Catherines Island

(Thomas, 2008: esp. chap. 7).

*MERCENARIA MERCENARIA* (QUAHOG)

The northern quahog *M. mercenaria* ranges today from Canada to the Gulf of Mexico and archaeological evidence suggests that this latitudinal distribution has existed for millennia. To the south it is replaced by *Mercenaria campechensis*, the more offshore, subtidal southern quahog. *M. mercenaria* exhibits a notable cross-latitude change in habitat preference. From North Carolina to Canada it generally occurs intertidally and subtidally in open embayments, whereas to the south (South Carolina to Florida) it prefers shallow subtidal to intertidal portions of salt marsh tidal creeks and oyster patches. This pattern correlates strongly with the change from a wave-dominated coastline north of Cape Fear, North Carolina to one of tidal domination along the southeast U.S. Atlantic coast. Moreover, this has led to extensive commercial harvesting of this resource to the north, where its occurrence is more predictable and subject to mechanical harvesting but, to the south along the Georgia coast, it is subject to the vagaries of hydrodynamic tidal flow associated with salt marsh creeks; it is thus a less predictable resource, exploitable only by hand-picking or raking (Rollins, Prezant, and Toll, 2008), even though densities may reach more than 100 individuals per square meter (Walker, 1987).

Quahogs exhibit variation in growth rate associated with habitat (Jones et al., 1990; Quitmyer and Jones, 2000) and, in general, larger individuals are found in the more subtidal populations. They are shallow infaunal organisms, burrowing into shell, sand, silt, or mud, but can also occur clustered around *Spartina* rhizomes or nestled among oyster valves. Life spans can approach 40 years but *M. mercenaria* can reach harvestable size in the southeastern United States in only two to three years.

A multiyear study of *M. mercenaria* at Engineers Point, St. Catherines Island, demonstrated the “top-down” environmental forcing mentioned above on populations of this species in such tide-dominated regimes (Prezant, Rollins, and Toll, this volume, chap. 12). In this study, three intertidal clam stations exhibiting varying substrate conditions were repeatedly sampled over a three-year period. All clams were harvested from all sites, and they were replaced after marking and measuring. Even though only marked clams were replaced after each defaunation, by the time

of the next harvest, all of the sites contained a mix of both marked and unmarked clams. The sampled clam populations were repopulated by recruits, due to hydrodynamic movement of adult clams and not by larval settlement. The greatest rate of clam movement in this mesotidal regime occurred at the site experiencing the greatest amount of hydrodynamic change (determined by laser level measurement of substrate change). Only a few years after this study, recruitment at this site ceased apparently due to hurricane-induced change. A similar experiment, at the same time, was performed in a tidal creek on the eastern side of St. Catherines Island. In that situation, a point-bar population of quahogs subjected to even stronger tidal flow (up to 1.1 m/sec) was selected for mark and recapture. In such ebb tidal environments the “downstream” side of point bars typically harbor flanking lower energy runnels sandwiched between the point bar and marsh and this serves as a catchment for dislodged clams. Marked clams were only lost from the point bar, not from the runnel, demonstrating again the prevalence of top-down hydrodynamic winnowing and adult recruitment in this regime. These processes could be expected to result in a paucity of multisized cohorts and relatively uniform sized valves in shell middens; this might easily be incorrectly attributed to selective harvesting of this resource. Description of the methodologies and more detailed results of these studies are presented in chapter 12 (Prezant, Rollins, and Toll, this volume).

Based on this study, Rollins, Prezant, and Toll (2008: 27) ventured the following a priori expectations: (1) “Shell middens in the coastal southeastern U.S. should often lack a significant quahog component, and display a temporal variation in quahog abundance, a result of the more stochastic distribution of southern quahog populations,” (2) “Shell middens in the coastal southeastern U.S. should often exhibit stratigraphic zones with very high densities of quahog shells, reflecting extensive but intermittent exploitation of very localized high density populations,” (3) “The more predictable northern populations of quahogs should have been more vulnerable to over-exploitation by humans (as they are today). One might expect a pattern of quahog distribution in shell middens that displays a dwindling of average valve size, perhaps followed by complete disappearance of the species from the record—the result of either extirpation of the resource or

abandonment of harvesting due to small return for investment of time,” (4) “On the other hand, the more southerly quahog populations had a built-in resistance to over-exploitation ... unpredictably distributed by hydrodynamic control and ... protected by refugia,” (5) “The relative lower stability of the southern quahog resource base might have led to lessened utilization of that species by Amerind populations of the southeastern U.S. and to intervals of greater dependence on other resources, either marine or terrestrial,” and, finally, (6) “Analysis of size/age data of quahogs found in shell middens provides very little information about abundance of the food resource because there is a strong habitat control on size and growth rate. Thus, different sizes may not reflect age or abundance of quahogs but rather a change in harvested habitat....”

*CRASSOSTREA VIRGINICA* (EASTERN OYSTER)

Over four decades, archaeologists have systematically sampled aboriginal shell middens from all time periods on St. Catherines Island (Thomas, 2008: chap. 20), and considerable additional research is currently being undertaken by Irv Quitmyer, Nicole Cannarozzi, and Sarah Bergh. It is abundantly clear that oyster valves are the most common bivalves in these midden deposits. Beyond all doubt, this marine resource was heavily exploited by human populations over the past 5000 years (e.g., Marrinan, 1975, 2010; Quitmyer, 1985; Quitmyer, Hale, and Jones, 1985; Quitmyer, Jones, and Arnold, 1997; Reitz and Quitmyer, 1988; Russo, 1998, 2002; Quitmyer and Jones, 2000; Russo and Heide, 2002; Reitz, 2004; Quitmyer and Reitz, 2006). More recently there may have been a significant decline in the areal extent of oyster beds in coastal Georgia. Drake (1891) estimated an areal extent of 8.9 ha of oysters in the Duplin River (along the southwestern margin of Sapelo Island), whereas a more recent survey by Walker and Cotton (1981) reported only 4.4 ha of oyster beds. This loss is attributed to disease, lowered freshwater aquifers, and overfishing. But Walker and Cotton (1981) also suspect that Drake's estimation of oyster abundance may have been “unrealistically high.”

Recent extirpation of oyster resources has occurred both north and south of coastal Georgia, as well. Oyster bar acreage in the Maryland portion of Chesapeake Bay apparently decreased more than 50% between 1907 and 1982, possibly due to the use of mechanical harvesters (instead

of hand tongs) that destroy oyster reefs, although other factors, such as overfishing, increased susceptibility to pathogens, and environmental degradation may be involved. Independent lines of evidence indicate that oyster density in that region is now about 4% of what it was in 1884 (Rothschild et al., 1994). Harding, Mann, and Southworth (2008) noted, in addition, that oysters were dominant in Chesapeake Bay before European colonization, but “four centuries of harvest pressure, habitat degradation, ... and disease activity...” have taken their toll. Moreover, in the Chesapeake James River region, “historic oysters had significantly faster growth rates than modern oyster populations” (Harding, Mann, and Southworth, 2008). Similarly, Gunter (1938) noted midden evidence that precolonial oysters harvested from coastal South Carolina were significantly larger (61% longer and 43% wider) than modern ones (cited in Thomas, 2008: 98). To the south, in the Canaveral National Seashore, Florida, a 57-year study record (1943–2000) identified about 60 oyster reefs with dead margins in proximity to navigation channels, an increase of 16.4% over this time interval (Grizzle, Adams, and Walters, 2002). Although water movement is essential to healthy oyster reefs, wave action can strongly affect the vertical growth and morphology of intertidal reefs; this interaction has apparently received very little study to date. Grizzle, Adams, and Walters (2002: 12) summarized the theoretical impediments posed to intertidal oyster reef development by excessive water movement, listing “vertical accretion of the reef surface to an elevation too high in the intertidal caused by waves, smothering and substrate instability caused by excessive sediment transport, and inhibited larval settlement caused by sediment (‘grit’) movement.” They also indicated that a reef “can be physically moved by wave energies, resulting in a range of responses from slow migration to total destruction, much in the fashion that barrier islands migrate shoreward ... under increased wave energies.” In contrast to the dead margin phenomenon, the central areas of intertidal oyster reefs often exhibit dead oyster valves surrounded by living individuals (the so-called “senescent” stage of an oyster reef; Bahr and Lanier, 1981; Grizzle, Adams, and Walters, 2002).

Although environmental degradation and disease have likely affected the demography of recent oyster beds along the Atlantic coast, it is more difficult to accurately assess the sig-

nificance of historic changes in the size of individual oysters. The challenge for archaeologists investigating such patterns of historic change in size of oysters (and other molluscs, for that matter) has been whether to attribute the midden record of size change to the stress imposed by overexploitation, or to the harvesting of diverse habitats containing oysters exhibiting disparate growth rates.

Eastern oysters are, indeed, found today in diverse habitats, ranging from isolated patches in intertidal marsh muds to the firm substrates of more extensive subtidal reefs. From North Carolina to east-central Florida, intertidal oyster reefs predominate. In general, subtidal oyster shells are larger and rounder than the elongate shells growing in intertidal muds (Kent, 1992). Dame (1972) indicated that subtidal oysters contain about 40% more meat, by weight, than intertidal oysters of comparable size (cited in Thomas, 2008: 96). Growth rate in oysters positively correlates with salinity and larger shells afford allometrically increased surface area that effectively translates into a positive feedback where, in subtidal habitats, the larger oyster valves provide increased settlement area which, in turn, leads to larger patch size (increased resource potential; Kraeuter et al., 2009; Harding, Mann, and Southworth, 2008). A comparison of oyster "condition index" in five beds in Sapelo Island and Doboy Sound (Georgia) found that oysters living in rivers and sounds had significantly higher meat quality compared with those occupying sites with lower nutrient flux and width (i.e., tidal creeks; Mercado-Silva, 2005).

In coastal Georgia, oyster patch demography is affected by season of the year. Individual oyster beds typically experience rather stable numbers of living oysters during the winter months, with an increase in spring due to increased spat fall. But, in the fall, number of individuals decreases as the oyster disease *Perkinsus marinus* increases (Walker and Cotton, 2001). Lower intertidal and subtidal oysters are more vulnerable to predation (e.g., by whelks, pea crabs, etc.) and disease because many of these vectors of oyster mortality are ecologically excluded from the higher intertidal marshes and tidal creeks.

Oysters in coastal Georgia occur in diverse microhabitats. Crook (1992) described four types of oyster occurrence in Georgia marshes: "Singles" are small patches housing from two to six individual oysters found in mud substrate "with-

in the lower portion of the intertidal zone along small tidal creeks." "Clusters" are clumps of from 10 to 30 individuals attached to firmer substrates along tidal creek channels, or in mud on tidal flats. "Banks," he noted, consist of clusters of 30 or more attached oysters found along larger tidal creek levee margins forming "linear aggregations ... from 2-4 metres wide" and "50 m or more in length." Finally, "reefs" are "very dense and closely spaced clusters of 30 or more oysters each, also located along larger tidal streams." Reefs are wider than banks, up to 20 m long, with more densely spaced individual oysters. Crook (1992) further noted that oyster shell morphology varied with intertidal microhabitat. He stated that single oysters occupying hard substrates tend to exhibit rounder shells but cluster, bank, and reef inhabitants tend to be "long and slender." Frey, Basan, and Smith (1987) had also mentioned that oyster individuals "dwelling on the salt marsh surface are diminutive and sparse relative to those along creek banks, and tend to be more rounded in shape." Crook (1992) sampled, as well, oysters from archaeological sites on Sapelo Island, and was able to statistically demonstrate that the microhabitat oyster growth forms were identifiable from shell middens (see also Kent, 1992).

Frey, Basan, and Smith (1987) present a more detailed description of oyster morphology and habitat in Georgia salt marshes, noting that the species can be found mainly in the lower portion of the intertidal zone up to about one-half tide level but isolated clumps are found higher in the ponded marsh areas. They indicated that "oysters form small to large beds along Georgia tidal creek banks ... and estuary margins ... they also form small beds on small point bars ... or within shallow creek channels..., and small isolated clusters in ponded water marshes (Frey, Basan, and Smith, 1987: 3). Subtidal oysters are, in their words, "riddled" with *Cliona* (sponge) borings and much more prone to predation by other organisms than are intertidal oysters. These observations provide the paleoecologist and archaeologist with a potential tool for identification of tidal depth of origin in both the fossil record and in midden materials (Wiedemann, 1972; Frey, Basan, and Smith, 1987). Detailed analyses of epibionts (such as *Cliona*) that inhabited harvested oyster and clam shells found in middens remains a potentially powerful tool for identification of exploited habitats—one that has, thus far, been barely utilized. By

the same token, some macropredators of shellfish (especially shell-boring gastropods) only attack subtidal to lower intertidal prey and rarely invade the more back-barrier marshland habitats. Shellfish valves often display a record of unsuccessful predation by these gastropods and evidence of unsuccessful (aborted) attacks are often visible on the shells in the form of incomplete boreholes caused by naticids and muricids, or the chip marks from apertural wedging by whelks. In the low intertidal to subtidal portions of larger St. Catherine's Island tidal creeks, the boring pholad clam *Diplothyra smithii* can frequently be found clustered along the siphonal margins of large quahog shells. This infestation is visible today in the upper reaches of Seaside Inlet and similar occurrences on large quahog valves exhumed from the relict muds of the former Guale Marsh at North Beach provides additional evidence for the former existence of major tidal creeks in that area of the island. Clearly, detailed examination of shell midden material might provide significant clues to sites of shellfish harvesting.

*Crassostrea virginica* is a protandric hermaphrodite (that is, some older males become females) and the larger (shell length) individuals tend to be females. Under intense harvesting pressure, where larger individuals are preferentially taken, a populational decrease in the number of females occurs, with a concomitant decrease in average shell length (Kennedy, 1983; Rothschild et al., 1994).

Recruitment of oysters in the southeastern United States is highest in the intertidal zone (O'Beirn, Walker, and Heffernan, 1996). Recruitment of oysters in coastal Georgia is extended, lasting for six months (May through October), peaking between July and September (O'Beirn, Walker, and Heffernan, 1995). The distribution of oysters, whether intertidal or subtidal, is generally more predictable than that of clams especially in strong hydrodynamic regimes such as coastal Georgia. Unlike clams or many other species in the midden, oyster spat preferentially affix to the hard substrata afforded by other oyster valves, and oyster patches and reefs represent a long-term multigenerational resource. Oyster settlement is enhanced by water-soluble chemicals that are effective in strong hydrodynamic flow as well as in still water (Turner et al., 1994). Even so, there are notable differences between the resource potential of a small marsh mud cluster of oysters and

the larger reefoid patches of open embayments.

#### *GEUKENSIA DEMISSA* (ATLANTIC RIBBED MUSSEL)

The Atlantic ribbed mussel is a major component of the salt marsh fauna of the eastern coast of the United States, ranging from Maine to northern Florida. In the Georgia Sea Islands this species is typically found in transitional and low-marsh back levee habitats where it is found attached by bysall threads in moundlike aggregations (Kuenzler, 1961; Smith and Frey, 1985; Frey, Basan, and Smith, 1987). *Geukensia* mounds, up to 15 cm high and 1 m in diameter, comprise as much as 7.8% of the area of back-levee ponded marsh environments, and the feces and pseudofeces of this species make up a large proportion of Georgia salt marsh mud deposits (Smith and Frey, 1985). Frey, Basan, and Smith (1987: 4) note that the vertical range of *Geukensia demissa* extends up to mean high water, and that it occurs only sparsely in the lower intertidal and subtidal areas, apparently due to increased predation pressures.

As is the case with many sessile marsh molluscs, the size, growth rate, and settlement of *Geukensia* decreases with increasing tidal height. On the other hand, predation intensity decreases with increased tidal height, and the moundlike aggregations afford additional protection (Bertness and Grosholtz, 1985). The semiendobenthic habit of this species protects it from desiccation and temperature shock, and permits it to inhabit a higher intertidal range than most mollusc species (Frey, Basan, and Smith, 1987: 12).

Although *Geukensia demissa* shells commonly occur in shell middens of coastal Georgia, there is very little available ethnohistoric information regarding exploitation of this resource by southeastern Indian populations (Thomas, 2008: 101). As is the case with many estuarine shellfish species, this species exhibits annual changes in soft tissue weight, independent (uncoupled) from shell growth. This is most common in older individuals and is often correlated with onset of the spawning cycle (e.g., oysters). Borrero and Hilbish (1988) noted that, for *Geukensia demissa* in coastal South Carolina, this uncoupled growth is more pronounced than it is for that species in other locations at higher latitudes. They attributed this to an extended growing season in South Carolina, and this would likely apply as well to coastal Georgia. This aspect of growth in some exploitable shellfish species has obvious archaeological implications for interpretation of caloric

intake as recorded in shell middens, but appears to be largely attributable to seasonal change and not longer life spans. However, Franz (1993) noted that *Geukensia demissa*, at a site in Jamaica Bay National Wildlife Refuge, N.Y., exhibited a “decrease in both shell and biomass with increasing shore level,” but “shell metrics (length, height, width, weight) did not differ between shore levels.” Thus, these patterns of growth may or may not be significant for the analyses of midden material over extended temporal spans. *Geukensia demissa* also has a very thin aragonitic shell, and that likely would lead to a significant taphonomic overprinting affecting its recordable fidelity in shell middens. Shell dissolution in acidic marsh mud would therefore be more pronounced in this species than would be the case with calcitic-shelled mollusc species.

#### *LITTORARIA IRRORATA* (MARSH PERIWINKLE)

Marsh periwinkles are commonly found in Georgia Sea Island shell middens and there appears to be little doubt that they were a foraged dietary item in the southeastern U.S. Native American smorgasbord (see Thomas, 2008: 107, and references therein). *Littoraria irrorata* is a conspicuous inhabitant of marsh cordgrass (*Spartina*), where it voraciously grazes on fungi coating the wounds on stalks and leaves induced by its radular scraping (Silliman and Bertness, 2002). Periwinkles occupy both short and tall *Spartina*, and dense accumulations (about 1200 individuals per square meter) of *Littoraria irrorata* have been indicted as significant destroyers of marsh cordgrass canopy, especially the nitrogen-rich tall *Spartina* zones where they can totally destroy the cordgrass within eight months, converting it to a barren mudflat. Silliman and Bertness (2002) noted that *L. irrorata* density, in turn, is predator-controlled (largely terrapins, blue crabs, and mud crabs) and fluctuations in top-down predation leads through trophic cascading to observed patterns of growth and destruction of marsh cordgrass (for a contrasting interpretation, see Kiehn and Morris, 2009). Marsh periwinkles, in coastal Georgia, are most abundant in areas of high marsh, whereas recruitment occurs more commonly in relatively quiescent low marsh areas, in closer proximity to the edges of tidal creeks and presumably the source and a mechanism for dynamic delivery of periwinkle larva (Silliman and Bertness, 2002).

Fierstien and Rollins (1987) described the

morphometric variation and demography of several high marsh populations of *L. irrorata* on St. Catherines Island, and compared these modern populations with one subrecent but undated (fossil) sample ( $N = 89$ ) collected from relict marsh mud exposed on Middle Beach between McQueen and Seaside inlets. They noted that present-day average adult size was expressed by the fossil individuals in fewer whorls, indicating more rapid average growth in the fossil population. Thomas (2008: chap. 20) presented preliminary data from the St. Catherines Shell Ring (9Li231), a Late Archaic midden accumulation that contained a number of larger than average (compared with modern) specimens of *L. irrorata* (see also Sanger and Thomas, 2010). This, in combination with the demographics of the fossil population (Fierstien and Rollins, 1987), suggests a temporal change in growth dynamics of this species, perhaps connected with environmental modification or predation intensity.

#### *BUSYCON CARICA*, *BUSYCOTYPUS CANALICULATUS*, AND *BUSYCON CONTRARIUM* (WHELKS)

Whelks occur frequently in shell middens of the southeastern United States, and were exploited by Native Americans for food and as a toolstone source for construction of beads and implements (Thomas, 2008: 111; Blair, Pendleton, and Francis, 2009). They were also widely traded throughout the American Southeast and were particularly important in the Black Drink ritual practiced there (Hudson, 1979). Prezant et al. (2002), in their survey of the modern macroinvertebrate fauna of St. Catherines Island, listed several species of whelk: the knobbed whelk, *Busycon carica*, the channeled whelk, *Busycotypus canaliculatus*, the lightning whelk *Busyccon contrarium*, and the diminutive Kiener's whelk *Busycon carica eliceans*. Knobbed and channeled whelks range from Cape Cod, Massachusetts to Cape Canaveral, Florida and, in 1978, a fishery harvesting these species was initiated by shrimpers along South Carolina barrier islands and it quickly became the largest subtidal fishery in the United States. Since 1980 a whelk fishery, harvesting these species, has existed in coastal Georgia. However, in both states production of whelks peaked in the 1980s and has since declined, following overfishing due to poor shrimping years (Eversole, Anderson, and Isely, 2008).

The knobbed whelk is more abundant than the

other large whelk species in the coastal waters of the southeast United States; consequently more is known about its natural history (Walker, 1988). During spring and fall months both the knobbed whelk and (to a lesser degree) the channeled whelk can be readily collected alive along the lower intertidal shoreface and on oyster patches along salt marsh tidal creeks, as they prey on bivalves, wedging and breaking the shells of their prey using their outer apertural lips. During their "hunt," knobbed whelks often occur partially buried in sand, leaving a characteristic trace impression on the sand surface (Thomas, 2008: 113). Hunting is often carried out by "herds" of whelks, and they can easily be harvested by human foragers during these activities. Knobbed whelks are long-lived (average age of over 16 years) and sexually dimorphic, with adult females much larger than adult males (Power et al., 2002). Commercial hauls routinely display more females than males, contributing to the short life of this shellfishery along the South Carolina and Georgia coasts (Eversole, Anderson, and Isely, 2008). The vulnerability of this resource is pronounced today, and may have been also when it was manually foraged by Native American populations. Large numbers of living whelks have been observed lethargic and exposed on the intertidal shoreface during short-term anoxia events induced by natural or anthropogenic disruption of normal wave patterns and circulation. One such anoxia event was anecdotally noted along North Beach, St. Catherines Island, in October 1990 during an unusually large spring tide (range of 9.3 m; Prezant et al., 2002: 22). Therefore, as a manually foraged dietary marine resource, whelks would probably have been preferentially exploited by aboriginal populations during summer months while in predatory swarms and/or opportunistically during anoxia events.

The knobbed whelk and the lightning whelk exhibit very similar trophic positions and prey choices and are typically not found together, perhaps due to competitive exclusion. The channeled whelk is an occasional nocturnal feeder and unlike *B. carica* and *B. contrarium*, is commonly attracted to dead bait in crab traps (Walker, 1988; Edwards, 1988). Edwards and Harasewych (1988) noted that "busyconine species are distributed across most of their collective ranges in pairs, containing one *Busycon* species and one *Busycotypus* species." Such differences, although

small-scale, might nevertheless affect resource distribution and be discernible in the shell midden record.

### GEOMORPHOLOGICAL DIMENSIONS OF SHELLFISH RESOURCES

The aforementioned ecological constraints on shellfish distribution along coastal Georgia have been determined by time-static study of recent populations of these species. Although this transferred ecology approach provides invaluable insight into "deeper"-time paleoecology and archaeology, it inevitably suffers from a lack of input that might be provided by scenarios of change that were uniquely played out over the vast expanse of the Holocene. For St. Catherines Island these deep-time scenarios are the subjects of diverse and ongoing research, providing a rich, but continually evolving, hypothetical framework with myriad geomorphological dimensions. The following discussion represents a largely heuristic approach to exploration of these temporal geomorphological interactions and to retrodiction of their influences on marine shellfish habitats and resources.

#### WAVE VERSUS TIDAL DOMINANCE

The Georgia Sea Islands experience ebb-dominant tides with a mean amplitude of 2.4 m and ebb flow velocity that can approach 130 cm/second (Frey and Howard, 1988). This type of tide-dominated coast is quite unlike that to the north where wave dominance is the rule. Has ebb tidal dominance always characterized the St. Catherines Island shoreline? Chowns et al. (2008; see also Chowns, this volume, chap. 9) suggested that high sea level stands led to a tidal dominated coast whereas low stands resulted in wave dominance. Moreover, he postulates that during highstands of sea level some of the major inlets between the sea islands of Georgia straightened, effectively pirating former salt marsh estuarine river systems. The Ogeechee River, he suggests, switched from the Seaside/McQueen area to St. Catherines Sound, and later to Ossabaw Sound. The Newport River migrated from the present-day St. Catherines Island South Beach area southward to between Blackbeard Island and Sapelo Island, and then northward again to the modern Sapelo Sound.

Other sedimentary wrinkles accompany Chowns' model, and implications for the distri-

bution of shellfish resources could prove to be significant. On a regional scale along the southeastern United States and over extended time, the northern and southern interfaces between a wave-dominated coast and a tide-dominated coast may have changed with fluctuations in sea level (Chowns, 2008) and this might have correlated with major changes in the overall availability of shellfish to Native American populations—perhaps evidenced by noticeable shifts in dietary preferences. Chowns (2008) hints at such a correlation by suggesting that the 3 m regression between 4300 and 3600 cal B.P., noted by DePratter and Howard (1981), Gayes et al. (1992), Colquhoun, Brooks, and Stone (1995), and Scott, Gayes, and Collins (1995), may have led to a wave-dominated system and major ecosystem change. Chowns notes that “Archaeologists identify this still stand as a time of major change in the coastal ecosystem that apparently disrupted the St. Simons cultural phase (4350–3000) and led to replacement by the younger Deptford, Swift Creek, Wilmington, and Savannah phases (2400–450 B.P.)” (Chowns, 2008: 157).

A reasonable heuristic approach to analysis of the potential marine resource effects accompanying changes in wave and tidal dominance along the Georgia coast might involve examination of comparable low-gradient coastlines elsewhere. The microtidal, wave-dominated Gulf Coast along the Florida Panhandle has received intense geological scrutiny for decades, and provides some such insight (see later discussion of “Ecosystem Changes”).

#### PROXIMITY TO HINTERLAND: FORAGING AND THE DEGREE OF RESOURCE SEPARATION

The interface of marine and terrestrial resources was highlighted by Thomas (2008: esp. chaps. 10 and 11) in his discussion of optimal foraging on St. Catherines Island, particularly with respect to the central place foraging model describing various field processing and transport strategies. Thomas (and other researchers) has noted that the rise and fall of sea level could dramatically change the exploitation potentials of marine and terrestrial resources, and that these changes might be in evidence upon analyses of coastal archaeological sites (Bailey and Flemming, 2008). Even a moderately rapid 2 m drop in sea level along the Georgia Bight, under present conditions of a very low onshore/offshore bathymetric gradient, in addition to imposition of a wave-dominated

system (as discussed above) would likely expose a vast expanse of barren coastal margin, and it would probably be millennia, even under optimal climatic conditions, before mature forest cover and other aspects of hinterland diversity could be established. An elevated sea level would compress this interface, juxtaposing marine and older terrestrial resource bases, rendering both available to foraging.

If a Native American population existed close to the carrying capacity of the environment and exploited both marine and terrestrial resources, under conditions of sea level lowering along a broad shallow shelf, the degree of separation could be expected to more quickly become an impediment to joint exploitation of these resources than it might along a narrow, steep shelf. As the land/sea interface widens, during sea level lowering, the more inland archaeological sites might be expected to display evidence of dwindling marine resources. Perhaps there would be a gradual overall decrease of such evidence (as well as major change in harvested species due to habitat modifications), and examples of resource overexploitation culminating in sudden absence, when isolation (separation from marine resource base) reached a “tipping” point. Bailey and Craighead (2003) point out that it is generally assumed that a distance of 10 km represents a maximum for daily subsistence trips.

Thomas (2008: 265–271) constructed a case in support of the central place foraging model for the foraging populations on St. Catherines Island over the past five millennia. Central place foraging focuses upon exploitation of diverse resources engendered by long-term residential stability at optimal locations. Thomas points out that residential proximity to hinterland resources would be critical, even for populations exploiting predominantly marine resources. Under such conditions, shoreline position becomes exceedingly significant and even a relatively slight lowering of sea level played out over a century scale along the Georgia Bight might be reflected in the archaeological record by first a decrease and then absence of marine shell material.

Before the degree of separation became critical in this scenario, one might expect to see other nuances in the St. Catherines Island archaeological marine shellfish record. For example, marsh shellfish “targets” should be impacted early on as marshland becomes increasingly restricted (Reitz and Quitmyer, 1988; Reitz, Quitmyer, and

Marrinan, 2009). Shoreface resources, such as whelks, and nearshore resources, including fish, turtles, etc., might remain in the record after the disappearance of marsh species. This projected pattern would be quite unlike that expected in a steeper coastal intertidal setting, especially a rocky coast.

#### LATERAL VARIABILITY

Lateral, or along-shore, variability in the resource base would change with sea level rise and fall. St. Catherines Island currently displays not only diverse proximal marine and terrestrial resources, but habitats of resource species exhibit great lateral variation as a result of relative temporal stability and low rate of sea level change. The inherited stability of the Silver Bluff island core combined with a few millimeters per year of sea level rise permit simultaneous growth and development of marshland along portions of the island while marsh loss, erosion, and ebb delta and inlet modifications occur at other island sites. In other words, lateral habitat diversity correlates with relative sea level stability and contiguous presence of an "inherited" mature hinterland. Such would not have been the case during sea level lowering.

#### ONSHORE/OFFSHORE VARIABILITY

Onshore and offshore variability in the resource base would also radically change with sea level rise and fall. There would be not only, as mentioned previously, an increase in the degree of separation of hinterland and marine resources during a prograding shoreline, but one would also expect rapid habitat change in marine environment and overall decrease in marine resource diversity. On the other hand, a high local rate of relative sea level rise might have occurred along the Georgia Bight due to various combinations of tectonic activity, inlet switching and change of sediment supply, and episodic change in eustatic sea level. This rise would have had rather predictable effects on the transitional states of coastal vegetation (and their respective resources), such as coastal gradations between marsh and more landward shrub- and forest-dominated states. Under such conditions of more rapid sea level rise, physical loss of marshland occurs primarily along the seaward edges and marsh species (again, with attendant resources) migrate landward, replacing shrub and forest species (Brinson, Christian, and Blum, 1995; Shirley

and Battaglia, 2006; see figs. 16.1, 16.2).

The subtleties of ecosystem changes in coastal wetlands accompanying sea level rise have been, in general, little studied. However, Brinson, Christian, and Blum (1995) presented, for the Virginia Coast Reserve, detailed scenarios of change that might provide a theoretical base applicable to the Holocene geomorphic evolution of St. Catherines Island (fig. 16.2). Defining "state" changes as "transformations from one ecosystem class to another" they recognized four "patterns" that would likely accompany combinations of dynamic interactions both at the marsh-estuarine margin (prograding versus eroding) and at the terrestrial-marsh margin (migrating landward versus stalling). With only slight modification, each of their scenarios might apply to potential geomorphic change on St. Catherines Island under conditions of varying rate of sea level rise (episodic fast versus slow gradual), variation in slope gradient (low plain versus escarpment), variation in sediment supply ("jumping inlet" model of Chowens et al., 2008; see also Chowens, this volume, chap. 9), and tidal intensity (wave versus tidal dominance). The following geomorphic conceptualization, Brinson, Christian, and Blum (1995) noted, omits an important component of resource development—i.e., the more or less internal ecosystem dynamics, both biotic and abiotic, that take place at a fixed site as these transitional states interact. Moreover, add to all of this the variables associated with Native American foraging strategies and the situation becomes complex indeed (Thomas, 2008: esp. chap. 35).

**OVERLAND MIGRATION AND MARSHLAND PROGRADATION:** This is the classic condition of a prograding salt marsh estuary under abundant sediment supply, and one that has been applied to the evolutionary development of the expansive modern salt marsh estuaries along the Georgia coast (Frey and Basan, 1985). The combination of sediment abundance, enlarged tidal amplitude, and decreased wave intensity converts subtidal estuary into intertidal marshland. Degree and rate of overland migration of transitional marsh vegetation depends upon the gradient of the landward slope (fig. 16.2A). To the extent that it results in overall expansion of clam- and oyster-rich intertidal marsh, this scenario affords optimization of marsh resources.

**OVERLAND MIGRATION AND MARSHLAND EROSION:** Conditions of sediment starvation in the face of relatively fast-rising sea level leads to

seaward erosion of marshland and, depending on the rate of low-marsh flooding, this loss can occur over the marsh interior as well as at the seaward edge (fig. 16.2B). Sediment starvation can occur following changes in coastal riverine source, inlet switching, climate, or wave/tidal dynamics. As in the first condition (above), the degree of overland migration depends on the coastal gradient.

**STATIONARY LANDWARD, PROGRADING MARSHLAND:** Under conditions of a steep shoreward gradient, marshland encroachment might be abruptly halted. If there is adequate sediment supply and the rate of sea level rise is slow to moderate, the seaward marsh edge would prograde (fig. 16.2C). Some of the fringing marshes that abut the steeper Silver Bluff escarpments of St. Catherines Island fall into this category.

**STATIONARY LANDWARD, ERODING MARSHLAND:** The tug of war (fig. 16.2D) between marsh progradation and erosion is visible today in many of St. Catherines Island fringing marshes, especially along the eastern margin of the island (e.g., North Beach) where ebb tidal sediment supply is constantly changing.

### ECOSYSTEM CHANGES

The four geomorphic categories of Brinson, Christian, and Blum (1995) were developed under the constraint of slow gradual sea level rise. They recognized that ecosystem dynamics (espe-

cially the biotic factors) complicate the resultant patterns of marsh development and distribution. Understanding the effects on shellfish resources demands the integration of biotic (organismal) and abiotic (geomorphic) influences. With slow sea level rise, ecosystem states would be expected to change over time from a forest to a subtidal benthic system (Brinson, Christian, and Blum, 1995). On St. Catherines Island, upland forested bluffs (live oak, longleaf pine, hickory) would change to organic-rich high marsh (shrubland, *Juncus*, *Salicornia*, *Distichlis*, etc.), then sequentially to a predominantly sediment-rich intertidal low marsh (*Spartina*) and mud flat, shallow subtidal autotrophic benthic system (benthic algae) and, finally, a deeper subtidal heterotrophic benthic system (embayment or lagoon; Coile and Jones, 1988; Howard and Frey, 1985).

Although quantitative zooarchaeological studies are ongoing, it seems clear that oysters are the shellfish resources most commonly exploited by Native American populations on St. Catherines Island; hard clams occur in most middens, although their relative frequencies vary considerably. These two taxa, as stressed earlier, were ecologically optimal in various intertidal low marsh and tidal creek habitats (herein termed the zone of optimal shellfish harvesting, or ZOOSH). The rate of sea level rise may control the developmental expression of the gradual transitions described above, and individual stages may be

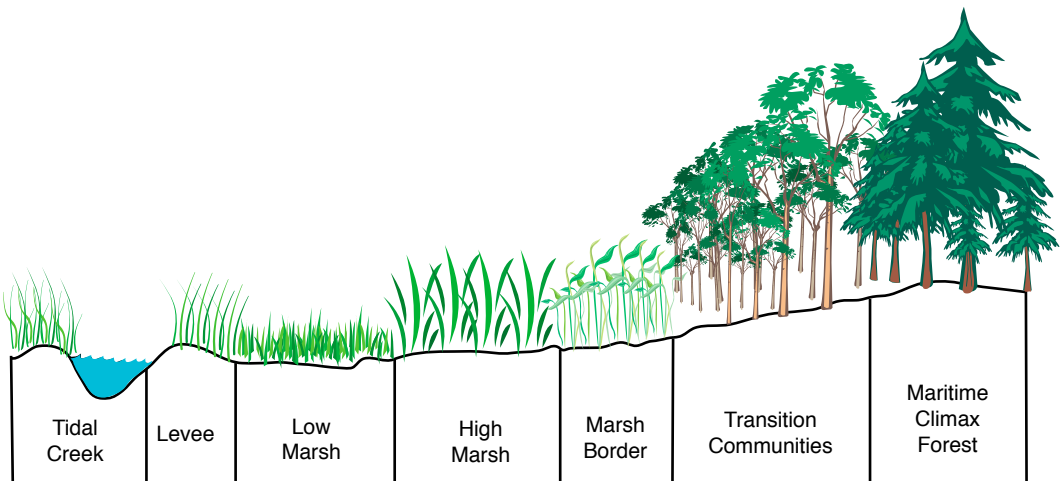


Fig. 16.1. Schematic illustration of transitional states from marsh to maritime forest.

overstepped by rapid rates of sea level rise. Examples of such rapid rates of sea level rise along modern coasts are generally found in areas experiencing strong anthropogenic alteration and land loss due to subsidence, such as coastal Louisiana. Shirley and Battaglia (2006: 1058) noted that relative sea level rise (RSLR) “far exceeds accretion in the Mississippi Delta” whereas, “conversely, the Coastal Plain has a positive net accretion in selected sites along the Gulf Coast,” and that “in the Delta, we expect migration to be unable to keep pace with RSLR, causing vegetation to be replaced by open water.” The RSLR necessary for overstepping is largely unknown, and likely to vary from one coastal situation to another. For the southeastern United States, where sediment loading is rather high, it has been suggested that a RSLR of 1.2 cm/yr would provide the limiting threshold whereby *Spartina* growth could not keep pace with sea level rise (Morris et al., 2002). It is difficult to accurately assess whether Holocene RSLRs ever approached this threshold. The published temporal resolutions of sea level change can typically only be averaged over centuries to millennia and tell us little of marsh response to decadal to centuries variation that might

accompany, for example, local cessation of accretion due to tidal inlet switching and/or inherited antecedent topography, and how this might have affected the availability of shellfish resources in specific marshes on a barrier island such as St. Catherines. Some of the temporally averaged Holocene rates appear sufficient for overstepping, if viewed in concert with other factors of sediment loading and inherited topography. Anderson et al. (2008), in a study of Gulf Coast estuaries, reported landward shifts of bayhead deltas from flooding events in the early Holocene at RSLRs averaging 40 cm/100 yr. They noted that even the decreased rates of RSLR during late Holocene flooding events reached 15 cm/100 yr.

This may be a moot question in terms of late Holocene shellfish resources exploitable by St. Catherines Island foragers as the long-term Holocene RSLR rates would mostly bear upon the question of whether or not intertidal marshland facies would have marched landward as integral transgressive facies tracts during the early to mid-Holocene. Once “docking” of the Holocene barrier (Guale Island) against the Silver Bluff escarpment occurred, the waxing and waning of intertidal marsh resources would appear to be

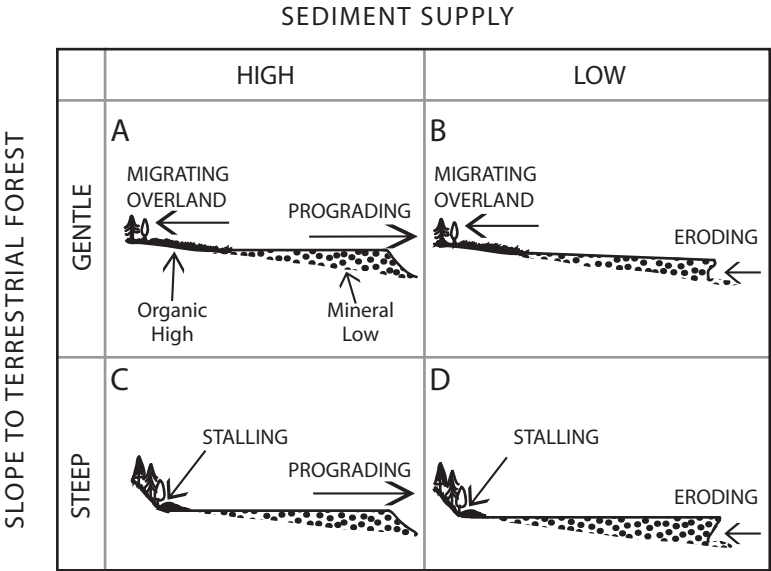


Fig. 16.2. Transitional states at Virginia Coastal Reserve (after Brinson, Christian, and Blum, 1995). The scenarios depicted in A–D are discussed in the text.

mostly controlled by local variation in sediment supply, inherited topography, and (possibly) climate change, and not by RSLR (unless late Holocene to recent episodic flooding events can be documented along coastal Georgia).

There is evidence for episodic flooding events rather than gradual eustatic early Holocene sea level rise but there is growing consensus that mid-to late Holocene eustatic sea level “overshoots” (i.e., higher than present levels), described in the northern Gulf Coast region (Morton, Paine, and Blum, 2000; Blum et al., 2001; Stapor and Stone, 2004) are not real but rather explainable in terms of local variation in antecedent topography and sediment supply (Otvos, 2005; Wright et al., 2005; Anderson et al., 2008; Milliken, Anderson, and Rodriguez, 2008; Rodriguez et al., 2008). Goodbred, Wright, and Hine (1998) described an 1800 <sup>14</sup>C yr B.P. flooding event that affected the Waccasassa Bay area of west Florida and ascribed it to a small sea level fluctuation of 10–20 cm over an interval of perhaps as little as 100 years. For some 2000 years prior to this incursion, relative stability had prevailed under conditions of slow sea level rise, permitting the extensive development of oyster reefs that “arguably required a considerable time to grow (hundreds of years)” (Goodbred, Wright, and Hine, 1998: 250). These large reefs were abandoned under conditions of shoreline retreat estimated at 10–20 m/yr, an order of magnitude greater than the retreat rate both before and after the flooding event. Whether this flooding event is attributable to regional sea level rise or to local shoreline dynamics is irrelevant for our purposes, for it does apparently demonstrate a late Holocene situation leading to a large-scale reduction of oyster resources (albeit subtidal oyster reefs) by transgressive overstepping—which could easily have played out in coastal Georgia, given similar conditions. However, in a study of early Holocene barrier-lagoon systems in the Adriatic shelf, Storms et al. (2008) suggested that the probability of barrier island overstepping may be inversely proportional to the tidal amplitude. The enlarged mesotidal ZOOSH of the Georgia coast may be more insulated from major habitat transgressive overstepping than the microtidal coast of the Adriatic, or Florida (for that matter); but, of course, these suggestions must be tested against the zooarchaeological record from Native American sites of the Georgia Bight.

It is interesting to speculate about controls upon the vertical amplitude of the ZOOSH.

For example, Chowns et al. (2008) and Oertel (1975a) have discussed the dynamics that have led to tide- versus wave-dominated sedimentary systems along the Georgia coast. Chowns (2008: 157) noted that “marine transgression tends to favor the tidal system,” increasing sediment accommodation space by increasing the volume and velocity of tidally entrained water in the back-barrier area. This enhances back-barrier sediment entrapment and tends to destabilize the inlets between barriers, encouraging straightening. Given this relationship, the amplitude of the ZOOSH should be maximized by rapid sea level transgression, especially episodic flooding events, leading to an expansion of shellfish resources. Very rapid transgression might lead to (at least short-term) subtidal expansion of the ZOOSH as flooding of marshland transitions to lagoonal embayment. Filling of back-barrier accommodation space under stability or low RSLR would constrict the ZOOSH. Regression, to the extent that it might engender wave dominance, would likely further restrict the ZOOSH by greatly reducing the tidal prism that nourishes the salt marsh ecosystem.

The relevance of the central place foraging model to St. Catherines Island archaeology is conditioned, in large measure, by the relative modest size of the island, permitting diverse resources to be exploited with minimal foraging distance over shorter intervals of time (Thomas, 2008: esp. chaps. 10 and 11). The short-term (microscale, i.e., few centuries or less) stochasticity of intertidal marine shellfish resources becomes, under this model, relatively insignificant, as depletion of one shellfish source might be easily supplanted by exploitation of another—as long as the optimal intertidal shellfish zone is maintained along significant portions of the island by slow gradual sea level change and/or the vagaries of lateral sedimentary dynamics (see previous discussion). Furthermore, even over broader (mesoscale, i.e., few centuries to a millennium) time spans during which purported episodic flooding events might occur, the existence of the Silver Bluff escarpment might virtually ensure that these conditions would indeed persist along portions of the island by reducing the likelihood of shoreline retreat or transgressive overstepping of the optimal zone of intertidal shellfish productivity. On a macroscale time span (millennium or more) only evidence of a Holocene sea level highstand in excess of present-day

level would, it seems, lead to a major habitat disruption of intertidal marine resources.

The microscale stochasticity of the ZOOSH resources deserves further discussion. Coastal Georgia, South Carolina, Louisiana, and many areas in New England have experienced, in recent years, events involving what has been termed acute salt marsh "dieback." Dieback affects both *Spartina* and *Juncus* and is characterized by vegetational thinning and browning, leading eventually to bare mud and rhizomal stubble. In situations of dieback, plant death occurs within months—distinguishing it from the state changes discussed previously that typically play out over decades (Alber et al., 2008). Causes of marsh dieback remain speculative, ranging from overfishing to change in freshwater flow to airborne dust to ecosystem disruption catalyzed by trophic cascades (Silliman and Bertness, 2002). Although it may not be appropriately termed "dieback," even decadal-scale marsh destruction can be considered as microscale impact on the ZOOSH. In this regard the relationship between submergence and reducing conditions is especially germane to salt marsh viability. As little as a 20 cm change in marsh surface elevation can spell the difference between marsh life and death. Increased submergence time leads to reducing conditions, high sulfide concentrations, and death of marsh grasses, especially in the low-lying interior portions of a marsh. Such changes can readily occur locally with tidal creek meanders and cutoffs, and shifts of tidal deltas and inlets.

Climatic perturbations cannot be ruled out as microscale causation of marsh dieback events. Alber et al. (2008: 6) note that, in coastal Georgia, the years 1999 to 2001 were the "driest 3-year period on record." Moreover, climate can affect the ZOOSH in more indirect ways. Oyster production, for example, is apparently quite sensitive to salinity variation that might accompany the change in the freshwater budget. Buzan et al. (2009) analyzed over 20 years of eastern oyster production in Galveston Bay, Texas, noting that increased freshwater inflow and decreased salinity correlated with increased abundance of market-sized oysters. Apparently, oyster production simply benefits from avoidance of predation pressure, disease, and parasites that accompany normal marine salinity. On the other hand, another study conducted in Galveston Bay (Turner, 2004) indicated that oysters suffer mass mortality under conditions of excessive freshwater inflow

and extended periods of low salinity.

In addition, climate change can affect the frequency, intensity, and distributional pattern of hurricanes and tropical storms, although details of coupling of these processes remain somewhat elusive. Hurricanes are known to modify community structure and function, however, and "may be the most environmentally significant force in coastal tropical and subtropical ecosystems" (Michener et al., 1997: 775). Temporal changes in hurricane frequency might have impacted the ZOOSH of St. Catherines Island in several ways, including modification of salinity regimes and freshwater supply (e.g., local recharging of water table, freshwater flooding, low-elevational soil saturation, dramatic increase in surface sediment and nutrient supply to the marsh). Increased nutrient supply could have facilitated estuarine and bay anoxia events (storm-induced litterfall that occurs prior to normal litterfall is much richer in nitrogen [Blood et al., 1991]). Storm surges from hurricanes transport saltwater sediment inland, elevating salinity of freshwater marshes and soils, and possibly triggering long-term changes in successional gradients within marsh and hinterland (Hook, Buford, and Williams, 1991). Increased overwash activity from hurricane-induced storm surges salinizes lower elevations, leading to replacement of terrestrial forest species by high marsh vegetation. Increases in sediment supply from storm surges may enhance overall marsh growth and certain ZOOSH resources. Extended climate-induced intervals of increased frequency and intensity of hurricanes might have disproportionately affected the mesotidal ZOOSH of coastal Georgia where, as discussed previously, some resource species are more highly adapted to conditions of abiotic stress and the opportunism of the hydrodynamic regime than to the biotic interactions associated with competition, predation, etc. Might extended intervals of increased hurricane activity have led, in the past, to increased stochasticity of shellfish resources and, perhaps, a culling of species less adapted to abiotic stress? Would quahogs fare better than oysters under such conditions, and might this be discernible in the midden record? In this context of possible selective winnowing of more stenotopic taxa under abiotic stress, and also perhaps relevant to the broader spectrum of St. Catherines Island resources, Hurricane Hugo destroyed about 25% of the unhatched logger-

head turtle nests in South Carolina and also greatly reduced white-tailed deer and squirrel populations in selected areas (Cely, 1991; Michener et al., 1997; see also Thomas, this volume, chap. 1).

Any of these factors, as well as anthropogenic ones, may have influenced the accessibility of the ZOOSH resources for late Holocene foragers and farmers on St. Catherines Island. One might suspect that central place foraging (and farming) may have imposed some peripheral impact on the ZOOSH. For example, if grid-ditching (ditches dug to channel water) or impoundment were employed in agricultural practice it may have influenced the ZOOSH by changing salinity, sediment supply, and/or submergence. Artificial impoundments in coastal Georgia have led to depositional rates of 1 cm/month (Edwards and Frey, 1977; Kennish, 2001), especially in the streamside-levee marshes, thus choking off the residence time of tidal flooding (and sediment delivery for vertical accretion) of the shellfish-productive lower marsh habitats. Inhibition of marsh accretion could lead to marsh death by submergence. Similarly, the possibility of oyster farming (see Thomas, 2008: 82–85), perhaps undertaken to stabilize the stochasticity of marine resources on the island, may have affected the natural ZOOSH. Ironically, as far as marine resources of the ZOOSH are concerned, what might not have worked for Native Americans would have been any activity that interfered with the natural stochasticity of the Georgia salt marsh system and demanded harvesting of a specific intertidal site.

#### RIISING VERSUS FALLING SEA LEVEL: RESOURCE ASYMMETRY?

There appears to be a paucity of research on the ecological effects of sea level fall, perhaps because we live in a time of rising, not falling, sea level in most parts of the world. There is empirical justification for not viewing the effects of rise and fall as mirror images. In terms of applying central place foraging models to the archaeological record of St. Catherines Island, it seems clear that the degree of isolation of food resource patches should increase, over longer spans of time, with lowered sea level as the ZOOSH becomes more separated from the higher elevation forested hinterland by an intervening low-gradient coastal plain. If Chowns' mod-

el of sedimentary dynamics is correct, we could also expect that the very nature of the ZOOSH would change as a more wave-dominated coastline led to destruction of back-barrier marshland and greater focus on eastern shoreface intertidal and subtidal resources.

However, over micro- to mesoscale intervals of time, more subtle differences exist in resource pattern change during sea level rise and fall. As Brinson, Christian, and Blum (1995: 657) noted, "resistance to change in state is an important property that regulates the pace of landward migration." On barrier islands such as St. Catherines, during sea level rise, transitions from forest to high marsh (e.g., as seen along edges of the Silver Bluff escarpment) are influenced by shore-parallel (longitudinal, *sensu* Thomas, 2008) nuances, such as the inherited gradient of the landward surface, presence of forest canopies (preventing marsh invasion into shaded areas—some dominant high marsh grasses possess C-4 photosynthetic pathways hindering competition in the shade; Brinson, Christian, and Blum, 1995), the amount of freshwater runoff and groundwater discharge (retards transition to high marsh by flushing out saltwater intrusion and precipitation of potentially toxic sulfide minerals—often evidenced by iron-rich "beach rock" along marsh margins), and the frequency of fire or a variety of human activities, such as agriculture or cattle grazing (all of which may destroy forested areas). High marsh may either prograde by organic accretion or erode and be replaced by intertidal marsh. These patterns can coexist along shore under sea level rise. Aggressive colonization by intertidal plant species, such as *S. alterniflora*, *Salicornia* sp., and *Distichlis spicula*, occurs in areas where high marsh plants, such as *Juncus* sp. and *S. patens*, die or are smothered by blankets of wrack. All of these transitional patterns can be currently observed along the eastern North Beach margin of St. Catherines Island between Yellow Bank Scarp (Picnic Point) and Seaside Inlet.

Many of the aforementioned nuances would be lacking under conditions of sea level fall. For example, the progradational "push" of an accreting marsh in a Georgia mesotidal salt marsh estuarine setting is unique to a stable or slowly rising sea level and would not exist during lowering when a low gradient with surplus sediment prevails, leading perhaps to a microtidal wave-dominant coast, reduction of marshland, migration of inlets, and extension of spits by avulsion

and longshore transport of sediment previously trapped in the tidal prism (Chowns et al., 2008).

### CONCLUSIONS

It may be instructive to consider the aforementioned nuances in the context of the putative late Holocene -2 m regressive event that occurred along coastal South Carolina and Georgia, and to hypothesize how the ZOOSH resources might have been affected along the eastern margin of St. Catherines Island. The following scenario relies heavily upon geomorphic and archaeological data and syntheses taken from Chowns et al. (2008), Thomas (2008), Bishop et al. (2007), Linsley (1993), Gayes et al. (1992), and DePratter and Howard (1981); see also chapter 1, this volume.<sup>2</sup> The presentation follows the format of Thomas (2008: chap. 4).

#### 5300–4300 CAL B.P.

Following the Holocene transgression, Guale Island formed off St. Catherines Island, adjacent to the eastern margin of the Pleistocene Silver Bluff shoreline. Jones, Quitmyer, and Andrus (2004, 2005) report isotopic evidence of 3.5°C higher seawater temperature from northeastern Florida during this time period. Guale Island was separated from St. Catherines Island first by short-lived lagoonal embayment and then by an extensive interisland marsh (Guale Marsh) that developed as the rate of sea level rise slowed, about 1 m below the present level. Although Guale Island has been lost to erosion, remnants of such Sea Island doublets can still be seen along the coast (e.g., Sapelo-Blackbeard). As the mesotidal prism was sandwiched against the Silver Bluff escarpment, saltmarsh progradation filled in the lagoonal embayment (transitional state change) and the precursor of the modern Ogeechee River coursed through Guale Marsh, debouching in the vicinity of present-day Seaside Inlet. Over an interval of a few centuries to a few millennia the ZOOSH changed from a predominantly shoreface context to one of open lagoon, and then to intertidal marsh with bountiful oyster and clam resources (exploited by Native American foragers from marsh habitats on both the eastern and western margins of St. Catherines Island). The ZOOSH changed accordingly from less bountiful albeit more predictable lagoonal marine target areas to the very abundant, but unpredictable (stochastic), resources afforded by the hydrodynamism of the

mesotidal regime. The relict marshland preserved along North Beach from Yellow Bank Scarp to Middle Beach preserves abundant evidence of the formerly expansive Guale Marsh tidal creeks and resources (Rollins, West, and Busch, 1990; West, Rollins, and Busch, 1990). Perhaps the most relevant modern analog for Guale Marsh is provided by the Letzsch and Frey's (1980b) two-year study of Blackbeard Creek, similarly sandwiched between a Pleistocene core island (Sapelo) and its Holocene doublet island (Blackbeard). They established six monitoring stations along Blackbeard Creek and its tributaries and noted very active erosion (as much as 7.2 m/yr with a mean of 1.9 m/yr) due to slumping of unstable tidal creek banks and intense bioerosion by decapods. Such a high rate of lateral erosion demonstrates the downward control on the ZOOSH of such compressed marsh environments. The geographic compression of maritime forest and marsh resources (then and now) enabled operation of the central place foraging strategy (Thomas, 2008: chaps. 34–35), even under conditions of an unpredictable ZOOSH. Thomas (2008: 1084) estimates that, overall, "more than 80 percent of the maritime forest edge on St. Catherines Island fronts directly on the margin of a significant salt marsh—effectively doubling the number of optimally positioned central places." Shoreline-parallel (i.e., longitudinal, *sensu* Thomas, 2008) habitats are many and closely spaced, offering a maximum array of marine and terrestrial resources within a short foraging radius of centrally placed residential settlement loci, e.g., both the St. Catherines Shell Ring (9Li231) and the McQueen Shell Ring (9Li1648), the two oldest-known sites on the island (Thomas, 2008: chap. 20; Sanger and Thomas, 2010).

#### 4300–3600 CAL B.P.

A relatively rapid 2 m drop in sea level occurs (about 3 m below present MSL). Marshland to the west and east of St. Catherines Island is destroyed as the tidal exchange disappears, wave-dominance supplants tidal dominance, the Ogeechee River incises, and a surplus of sediment avulses to be transported by longshore currents and deposited by spit building as St. Catherines Island becomes elongated southward of the Zapala Scarp (Chowns, 2008). Guale Island is reduced by erosion. The rich marshland ZOOSH is significantly degraded or disappears, and the remaining shoreface ZOOSH becomes so isolat-

ed from human settlements that the central place foraging strategy is no longer operational. The ZOOSH collapses first along the island's western margin, extending soon thereafter to the eastern area of Guale Marsh. Major centrally placed St. Simons period sites (including both shell rings) are abandoned (Thomas, 2008: chap. 30; Sanger and Thomas, 2010). Greater emphasis is placed upon terrestrial resources, both freshwater and forest, and the midden record is conspicuously depleted in estuarine resources in general. Increasing numbers of Late Archaic settlements are sited along the island's eastern margin and around interior ponds and swamps (Thomas, 2008: chaps. 20 and 30).

#### 3600 CAL B.P. TO RECENT

Sea level slowly rises to present-day level. Transgression proceeds over a low gradient, oversteps the remnant of Guale Island, and embays the Ogeechee. The tidal prism is reestablished; Ogeechee Inlet is straightened and dis-

placed northward to the present-day St. Catherine's Sound and later moves more northerly to Ossabaw Sound (Chowns, 2008). Stripped of active tidal estuarine activity and less protected due to a diminished presence of Guale Island, the inherited former Guale Marsh surface becomes partially reactivated but is quickly threatened by increased overwashing of abundant sand now made available by the displaced inlet. The Guale Marsh ZOOSH never achieves its former stature and does not play a prominent role as a source of marine resources in post-St. Simon cultures.

#### NOTES

1. We gratefully acknowledge the assistance of Irvy Quitmyer, who provided extraordinarily useful feedback on an earlier draft of this paper.

2. We do note the significant lack of zooarchaeological data in this scenario, and we are presently trying to generate relevant empirical evidence on the shellfish proportions found in the archaeological record.



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# APPENDICES

## APPENDIX 1 Noncultural Radiocarbon Dates from St. Catherines Island<sup>a</sup>

Lab no.	Location	Material	Contexts	<sup>14</sup> C age B.P. ( $\pm 1\sigma$ )	<sup>13</sup> C / <sup>12</sup> C	<sup>13</sup> C adjusted age B.P.	Radiocarbon age calibrated ( $\pm 2\sigma$ )	Ref- erence <sup>b</sup>
Pitt-831	Core 3 (783–799 cm)	Shell	Subtidal marine	22,600 $\pm$ 310	*	—	—	1
Pitt-685	Core 5 (15–35 cm)	Organics	Marsh peat	Modern	—	—	—	1
Pitt-686	Core 5 (68–83 cm)	Organics	Low marsh <i>Spartina</i>	1600 $\pm$ 40	—	—	A.D. 380–560	1
Pitt-687	Core 5 (489–508 cm)	Organics	<i>Spartina</i> in mud clast	2590 $\pm$ 40	—	—	830–550 B.C.	1
Pitt-733	Core 6 (133–151 cm)	Organics	Marsh, point bar	1720 $\pm$ 50	—	—	A.D. 170–430	1
Pitt-734	Core 6 (480–516 cm)	Organics	<i>Spartina</i> in mud clast	4290 $\pm$ 80	—	—	3270–2620 B.C.	1
Pitt-735	Core 6 (653–689 cm)	Shell	Subtidal marine	24,220 $\pm$ 500	*	—	27890–25780 B.C.	1
Pitt-736	Core 8 (317–334 cm)	Organics	<i>Spartina</i> in mud clast	3100 $\pm$ 50	—	—	1490–1220 B.C.	1
Unknown	Core 13 (494–500 cm)	Organics	Disseminated carbon	4370 $\pm$ 120	—	—	3370–2670 B.C.	1
GX-16792	Core 14 (275–285 cm)	Organics	Disseminated in mud	14,090 $\pm$ 640	—	—	166500–13220 B.C.	1
Pitt-926	Core 17 (494–508 cm)	Organics	Marine lag deposit	4450 $\pm$ 50	—	—	3340–2930 B.C.	1
Pitt-926a	Core 17 (494–508 cm)	Shell	Mixed marine shell bed	7870 $\pm$ 90	***	8280 $\pm$ 90	7340–6760 B.C.	1
Pitt-927	Core 20 (27 cm from bottom)	Shell	—	4370 $\pm$ 120	***	4780 $\pm$ 120	3570–2930 B.C.	—
GX-16791	Core 20 (72–84 cm)	Organics	North side of McQueen	2450 $\pm$ 150	—	—	900–200 B.C.	—
GX-16708	Core 20 (34–38 cm)	Shell	North side of McQueen	550 $\pm$ 120	***	340 $\pm$ 120	A.D. 1620–1950	—
GX-13966	Eroding tidal scar	Wood	2 in. below peat surface	730 $\pm$ 80	—	—	A.D. 1060–1410	—
UGA-6267	Core 9005051 (502–512 cm)	Organics	Freshwater peat	28,370 $\pm$ 340	*	—	31640–29610 B.C.	1
Pitt-925	Core 9005051 (502–512 cm)	Organics	Freshwater peat	33,510 $\pm$ 530	*	—	37580–34800 B.C.	1
Pitt-645	Station 26 (surface)	Organics	Relict <i>Spartina</i>	840 $\pm$ 50	–0.10	1080 $\pm$ 50	A.D. 820–1030	1
Pitt-645A	Station 26 (surface)	Shell	<i>Geukensia</i>	1570 $\pm$ 60	0	1980 $\pm$ 60	360 B.C.–A.D. 10	1
Pitt-646	(surface)	Organics	Disseminated in mud	1060 $\pm$ 60	0.1	1300 $\pm$ 60	A.D. 640–880	1
GX-13966	(surface)	Wood	Palmetto in mud	730 $\pm$ 80	—	—	A.D. 1060–1410	1
UGA-6160	South of line 43 south	Wood	In relict mud	470 $\pm$ 90	–27.52	430 $\pm$ 100	A.D. 1300–1660	2
UGA-6161	South of line 43 south	<i>Ostrea</i>	In relict mud	100 $\pm$ 80	–0.63	500 $\pm$ 80	A.D. 1500–1890	2

## APPENDIX 1 — (Continued)

Lab no.	Location	Material	Contexts	$^{14}\text{C}$ age B.P. ( $\pm 1\sigma$ )	$^{13}\text{C} / ^{12}\text{C}$	$^{13}\text{C}$ adjusted age B.P.	Radiocarbon age calibrated ( $\pm 2\sigma$ )	Ref- erence <sup>b</sup>
UGA-6162	South of line 43 south	<i>Mercenaria</i>	In relict mud	290 $\pm$ 90	-1.90	670 $\pm$ 90	A.D. 1350-1690	2
UGA-6163	South of line 43 south	<i>Geukensia</i>	In relict mud	190 $\pm$ 90	-1.13	580 $\pm$ 90	A.D. 1440-1810	2
Unknown	(surface)	Organics	<i>Spartina</i> in relict mud	480 $\pm$ **	—	—	A.D. 1310-1620	3
Unknown	(surface)	Organics	<i>Spartina</i> in relict mud	1830 $\pm$ **	—	—	A.D. 60-340	3
Unknown	(surface)	<i>Crassostrea</i>	In relict mud	1040 $\pm$ **	—	—	A.D. 1070-1330	4
UGA-6442	Cracker Tom Hammock	<i>Crassostrea</i>	Zone C	3200 $\pm$ 70	-1.51	3590 $\pm$ 50	1870-1540 B.C.	5, 6
USGS #WW-1197	Cracker Tom Bridge	Peat	Zone A	47,620 $\pm$ 2500	*	—	—	5, 6
USGS #WW-1262	Cracker Tom Bridge	Shell	Zone B	4060 $\pm$ 50	***	4450 $\pm$ 50	3000-2670 B.C.	5, 6
USGS #WW-1198	Cracker Tom Bridge	Charcoal	Zone B	6020 $\pm$ 50	—	—	5040-4790 B.C.	5, 7
Beta-115910	Beach Pond (214 cm)	Wood	Zone B	1210 $\pm$ 40	—	—	A.D. 690-940	5
Beta-217245	South Beach	<i>Mercenaria</i>	Relic marsh	780 $\pm$ 50	-1.4	1170 $\pm$ 50	A.D. 990-1230	8
Beta-217246	South Beach	<i>Crassostrea</i>	Relic marsh	620 $\pm$ 50	-1.7	1010 $\pm$ 50	A.D. 1120-1350	8
Beta-217823	St. Catherines Shell Ring	Composite shell	Vibracore #3, 3.5 m below surface	—	-0.6	>44,800	—	8
Beta-217824	St. Catherines Shell Ring	Peat sample	Vibracore #2, 4.1 m below surface	39,130 $\pm$ 660	-26.2	39,110 $\pm$ 660	42420-40400 B.C.	8, 9
Beta-217825	St. Catherines Shell Ring	Peat sample	Vibracore #2, 4.1 m below surface	29,440 $\pm$ 260	-26.2	29,410 $\pm$ 260	32710-31410 B.C.	8, 9
Beta-223509	St. Catherines Shell Ring	Composite shell	Vibracore	—	-2.0	>38,290	—	8, 9
Beta-223511	St. Catherines Shell Ring	Composite shell	Vibracore	—	-2.0	>44,840	—	8, 9
Beta-244621	North Beach	Organic sediment	—	13,650 $\pm$ 40	-27.5	13,610 $\pm$ 40	15000-14630 B.C.	10
Beta-244622	North Beach	Organic sediment	—	22,800 $\pm$ 130	-23.8	22,820 $\pm$ 130	26080-24980 B.C.	10
Beta-260790	King New Ground Marsh	<i>Crassostrea virginica</i>	Modern sample	110.2 $\pm$ 0.4 pMC <sup>c</sup>	-2.6	105.3 $\pm$ 0.4 pMC <sup>c</sup>	—	—
Beta-260791	King New Ground Marsh	<i>Mercenaria</i>	Modern sample	117.1 $\pm$ 0.4 pMC <sup>c</sup>	-2.2	111.8 $\pm$ 0.4 pMC <sup>c</sup>	—	—
Beta-261655	Crane Yard Pond 2A	Organic sediment	—	15030 $\pm$ 60	-24.5	15040 $\pm$ 60	16600-16070	—
Beta-263588	St. Catherines Island	Peat sample	2009F 4.6	1900 $\pm$ 40	-26.4	1800 $\pm$ 40	A.D. 130-340	11
Beta-262151	St. Catherines Island	Wood	2009H 4.5	1720 $\pm$ 50	-25.4	1720 $\pm$ 50	A.D. 170-430	11
Beta-262150	St. Catherines Island	Wood	2009F 12.1	NA	-24.8	>43000	—	11
Beta-261351	St. Catherines Island	Organics	2009H 6.3	6320 $\pm$ 60	-24.2	6330 $\pm$ 60	5470-5210 B.C.	11

APPENDIX 1 — (Continued)

Lab no.	Location	Material	Contexts	<sup>14</sup> C age B.P. (± 1σ)	<sup>13</sup> C / <sup>12</sup> C	<sup>13</sup> C adjusted age B.P.	Radiocarbon age calibrated (± 2σ)	Ref- erence <sup>b</sup>
Beta-259900	St. Catherines Island	Wood	2009H 14.1	20550 ± 110	-24.8	20550 ± 110	23010–22260 B.C.	11
Beta-253537	Jekyll Island	Wood	2008C JEKYLL	3300 ± 40	-25.6	3290 ± 40	1680–1460 B.C.	11
Beta-230798	—	Organics	2007A 13-6	31850 ± 320	-27.9	31800 ± 320	34910–33310 B.C.	11
Beta-230797	—	Organics	2007A 5-2	1790 ± 40	-15.1	1950 ± 40	40 B.C.–A.D. 130	11
Beta-220145	Jekyll Island	Wood	JEKYLL 2003C	45680 ± 3300	-16.5	45820 ± 3300	48050–41930 B.C.	11
Beta-220144	Jekyll Island	Shell	JEKYLL 2002D	870 ± 40	-0.7	1270 ± 40	A.D. 890–1120	11
Beta-220143	Jekyll Island	Shell	JEKYLL 2002B	1080 ± 40	-0.5	1480 ± 40	A.D. 680–890	11
Beta-255650	—	Organic sediment	STCAT3A2A	10780 ± 60	-24.3	10790 ± 60	10900–10620 B.C.	12
Beta-255651	—	Organic sediment	STCAT2A2A	6440 ± 40	-24.8	6440 ± 40	5480–5330 B.C.	12
Beta-255652	—	Charred material	F44B HORSTCAT	6260 ± 40	-24.5	6270 ± 40	5320–5080 B.C.	12

<sup>a</sup>All marine dates corrected for reservoir effect, per Thomas, 2008, chap. 13; “cal” omitted throughout.

<sup>b</sup>References: (1) Linsley (1993: appendix), (2) Bishop and Rich (1990), (3) Pemberton and Frey (1985), (4) Fierstein and Rollins (1987), (5) Booth (1998), (6) Booth et al. (1999a), (7) Booth and Rich (1999), (8) Thomas (2008), (9) Booth et al. (1999b), (10) Vento and Stahlman (2008), (11) Chowns (chap. 9), (12) Vento and Stahlman (chap. 4).

<sup>c</sup>In radiocarbon reports, the terms “%Modern,” or “pMC” are used interchangeably to denote the absolute “percent modern carbon” (with the term “modern” meaning 1950).

\* Beyond the currently available calibration curve.

\*\*Estimate of variability unavailable; for calibration purposes will assume ± 60 radiocarbon years.

\*\*\*Fractionation estimate (<sup>13</sup>C ratio) unavailable; for calibration purposes will add 390 years (per Thomas, 2008, chap. 13).



## APPENDIX 2

**Vibracores and Artesian Wells Located on St. Catherines Island, Georgia**

Most locations accurate within  $\pm 3$  m (approximate locations enclosed in parentheses); older sites are approximated by using latitudes or longitudes from Google Earth™; well sites without casings are shown in brackets.

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
North Beach Transects (Linsley [1993], with H.B. Rollins), University of Pittsburgh Transect A-A', cores 1, 4, 2, and 3 (described in Linsley, 1993; Linsley et al., 2008; fig. 3.5; Thomas et al., 2008).					
Post-Hugo core 1: North Beach; Yellow Banks Bluff, September (21), 1989	In relict mud near south end of Yellow Banks Bluff; 2.5 m east of bluff, 37 m south of station 1, high tide swash zone of modern beach, (Morris and Rollins, 1979), elev. about 2.1 m above MLT.	(31.67562) (81.13687)	2.1 m	Spuded in relict marsh mud.	N. Hamilton H. Rollins G. Bishop D. Linsley
Post-Hugo core 2: North Beach; Yellow Banks Bluff, September (21), 1989	In relict marsh mud, modern beach, 22 m E of core 1; 37 m south of station 1, 7 m E of sand/mud contact; 0.4 m above MLT.	(31.67567) (81.13668)	5.3 m	Spuded in relict marsh mud.	N. Hamilton H. Rollins G. Bishop D. Linsley
Post-Hugo core 3: North Beach; Yellow Banks Bluff, September (21), 1989	Approximately 13 m east of core 2; spuded in relict mud; elev. ~0.9 m	(31.67569) (81.13652)	8.4 m	Dated intervals: shell bed at 783–799 cm depth in core, mixed subtidal marine ( <i>Anadara</i> , <i>Mulinia</i> , <i>Donax</i> ) and marsh shell ( <i>Ilyanassa</i> , <i>Tagelus</i> , <i>Crassostrea</i> ) assemblage dated at $22,600 \pm 310$ yr B.P. (Pitt 831).	N. Hamilton H. Rollins G. Bishop D. Linsley
Post-Hugo core 4: North Beach; Yellow Banks Bluff, September (21), 1989	Modern beach swash zone, 14 m east of core 1, elev. 1.5 m above MLT, between core 1 & 2; 2 m west of sand/mud contact.	(31.67562) (81.13700)	4.0 m	—	N. Hamilton H. Rollins G. Bishop D. Linsley
North Beach Transects (Linsley [1993], with H. B. Rollins), University of Pittsburgh Transect B-B', cores 5, 6, 7, and 8 (described in Linsley, 1993; Linsley et al., 2008, fig. 3.7; Thomas et al. 2008). [GPS location by estimation on Feb. 3, 1993, aerial photography and map in Linsley et al., 2008]					
Post-Hugo core 5: North Beach; Seaside Marsh meadow: September (21+), 1989	Modern beach, surface elev. of 1.2 m above MLT, immediately seaward of high tide wrack line; ~25 m S of station 20 and ~30 m E of baseline; 10 m N20°W from Hydra Tree; in sandy <i>Spartina</i> elev.	(31.67163) (81.13669) Transect B	5.2 m	Dated intervals: stacked lag deposits with a gradational fining-upward sequence of tidal creek channel point bar deposits and consisting of coarse to very coarse sands, and containing cm-size mud clasts with organics were dated at 15–35 cm deep (Pitt 685), organics (marsh peat) dated as modern; 68–83 cm deep (Pitt 686), organics (low marsh) dated at $1595 \pm 40$ yr B.P.; 489–508 cm deep (Pitt 687), organics ( <i>Spartina</i> in mud clast) dated at $2585 \pm 40$ yr B.P. (stated as $2590 \pm 40$ yr B.P. in Thomas, 2008: table 29.1).	N. Hamilton H. Rollins G. Bishop D. Linsley
Post-Hugo core 6: North Beach; Seaside Marsh meadow: September (21), 1989	On top of washover sands (15 cm thick), landward from core 5 behind vegetated beach dune ridge. 105 m N12°W from core 5, in barren overwash fan 22 m; elev. 1.3 m.	(31.67143) (81.13777) Transect B	7.9 m	Dated intervals: 133–151 cm depth (Pitt 723), organics, marsh point bar deposit, dated at $1720 \pm 45$ yr B.P. 480–516 cm depth (Pitt 734), organics, <i>Spartina</i> in mud clast dated at $4285 \pm 80$ yr B.P. 653–689 cm depth (Pitt 735), organics (Linsley, 1993: appendix 1) or shell (Thomas, 2008: table 29.1)? Subtidal marine, dated at $24,220 \pm 500$ yr B.P. N.B. Linsley et al., 2008: fig.3.7, p.34 (in Thomas, 2008, v. 1) erroneously states that core 6 contains a date of $22,600 \pm 310$ yr B.P. That date is actually $4285 \pm 80$ yr B.P. (see above). The incorrect date was apparently inadvertently transposed from the figure depicting core 3, transect A-A'.	N. Hamilton H. Rollins G. Bishop D. Linsley

## APPENDIX 2 — (Continued)

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
Post-Hugo core 7: North Beach, Seaside Marsh meadow; September 21, 1989	Sited on a low elev. (2.1–2.8 m above MLT) “marsh” ham- mock (veneer over marsh sediments, as opposed to an ero- sional remnant ham- mock), vegetated with longleaf pine and pal- metto. 125 m N35°W from core 6 on N side of palm tree, west side of North Beach ham- mock.	(31.67210) (81.13838) Transect B	5.0 m	Dated intervals: none.	N. Hamilton H. Rollins G. Bishop D. Linsley
Post-Hugo core 8: North Beach; Seaside Marsh meadow; September 21, 1989	Marsh behind and northwest of core 7, adjacent to a promon- tory of island core. 109 m N15°W from core 7; 30 m from island core; elev. 1.2–1.3 m. Near core 7.	(31.67335) (81.13875) Transect B	6.7 m	Dated intervals: 317–334 cm depth (Pitt 736), <i>Spartina</i> in mud clast, dated at 3100 ± 50 yr B.P.	N. Hamilton H. Rollins G. Bishop D. Linsley
North Beach Transects ( Linsley [1993], with H.B. Rollins), University of Pittsburgh Transect D–D', cores 9004211, 13, 9003231, 16, 15, 14, 22. Described in Linsley (1993), Linsley et al. (2008), and Thomas et al. (2008)					
Core 9004211 April 21, 1990	Beach Pond core, eastern side of island in low elev. area between beach dune ridges. Easternmost core of transect D–D', surface elev. approx. 1.5 m above MLT, within 200 m of mod- ern beach. Base (depth of approx 370 cm) of core contains abundant marine shells ( <i>Donax</i> and <i>Mulinia</i> ).	(31.59947) (81.14896)	—	(see Booth et al., 1999b)	G. Bishop
Core 13, August 1990	South Beach Road, high marsh tidal flat between two beach ridges. Elev. of top of core: ~1.45 m core taken 410 m NW of core 9004211 on modern high marsh in a wide area of salt marsh separating two areas of beach ridge complexes.	—	—	Dated intervals: 494–500 cm depth (lab no. unknown?), organics, disseminated carbon, full marine shells dated at 4370 ± 120 yr B.P. (shells from lag bed at 3.45 m below MLT). Shells dominantly <i>Mulinia</i> , <i>Donax</i> , <i>Tellina</i> , and <i>Anadara</i> . Marine base directly overlain by 1.5 m of marshlike deposits.	D. Linsley H. Rollins R. Busch R. West C. Maples B. Cecil
Core 9003231	South Beach Road in a swale between two dune ridges 800 m SW of core 13; surface elev. approx. 1.6 m above MLT.	—	—	Well-defined marine interval at base of core.	G. Bishop F. Rich
Core 16, August 1990	South Beach Road, on beach ridge dune crest. Elev. top of core 3.7 m above MLT on a vegetated surface with live oak and palmetto, 675 m NW of core 9003231.	—	—	—	D. Linsley H. Rollins R. Busch R. West C. Maples B. Cecil

APPENDIX 2 — (Continued)

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
Core 15, August 7, 1990	“First” (northernmost) causeway on South Beach Road; cored in a 50 m wide slough between beach ridges. Surface vegetation of short <i>Spartina</i> . Elev. of top at 1.50 m above MLT; core sited 260 m NW of core 16.	—	—	—	D. Linsley H. Rollins R. Busch R. West C. Maples B. Cecil
Core 14, August 7, 1990	Elev. 1.45 m above MLT; high marsh <i>Spartina</i> immediately adjacent to Pleistocene island core, 990 m west of core 15 (100 m east of old house owned by John Toby Woods, acc. to Linsley core log description).	—	—	—	D. Linsley H. Rollins R. Busch R. West C. Maples B. Cecil
Core 22	Westernmost end of transect D–D’; elev. 1.35 m above MLT; high marsh on the cut bank of a tidal creek levee, 35 m from the island core and 260 m SW of core 14. Johnson Creek situated 400 m to the west of core 22. Core 22 reached depth of 5.64 m below MLT, as such is one of deeper cores recovered by Linsley project.	—	5.64 m	The lower portion of core 22 preserved a series of lag deposits similar to core 17, interpreted to be a progradational sequence adjacent to a tidal estuary (Linsley, 1993, p. 118).	D. Linsley H. Rollins R. Busch R. West C. Maples B. Cecil
Georgia Southern University Early Probing with UGA Okefenokee Rig—G.A. Bishop, F.J. Rich, and Royce Hayes.					
Terrain 6; Zapala Sound margin core 3/23/90	So. of large live oak in east-west salt swale	31.59936 81.16061	4.97 m	Also known as core 4. (See Bishop et al., fig. 10.4, this volume).	G.A. Bishop R.H. Hayes
State Road Pond core 6.08/99	On edge of freshwater pond.	31.63800 81.15375A	4.15 m	Also known as core 5 Laminated heavy mineral sand (HMS) at –2.5 m. (See Bishop et al., fig. 10.5, this volume).	G.A. Bishop R.H. Hayes
Island Ecology Program; North Beach, North Oxbow core 16.2 6/06/95	On east edge of North Oxbow along line of GAB stand pipes.	(31.68551) (81.13601)	4.81 m	Also known as Core 3 9506061. Peat date: shell lag at –4.66 m. (See Bishop et al., fig 10.3, this volume).	B. Potter T. Keith- Lucas IEP students
Cracker Tom Transect Described in Booth et al., 1999: fig. 4; Bishop et al., 2007: fig. 36; Linsley et al. 2008: figs. 3-4 and 3-9.					
Cracker Tom Island core	—	(31.61821) (81.16097)	—	—	—
Cracker Tom Scarp core 6/08/99	—	(31.61705) (81.16021)	5.0 m	Ghost shrimp at 3.3 m.	G. Bishop R. Petkewich R. Hayes
Cracker Tom Hammock core	—	(31.616111) (81.15878)	5.52 m	Dated interval: oyster bed at 194–225 cm; 3200 ± 50 B.P.	G. Bishop R. Petkewich R. Hayes
Cracker Tom Bridge core	—	(31.61483) (81.15626)	5.03 m	Dated intervals: 487–503 cm shells at 4060 ± 50 B.P. and charcoal 6020 ± 50 B.P.; Pollen/spore assemblages described; dense Pteridophyte peat at 500–502 cm.	G. Bishop R. Petkewich R. Hayes

## APPENDIX 2 — (Continued)

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
Cracker Tom Rosetta core	—	(31.61491) (81.15644)	—	—	R. Boothe F. Rich
Island Ecology program core 6/23/00	—		4.95 m	—	B. Potter T. Keith- Lucas IEP students
St. Catherines Shell Ring Cores					
Island Ecology Program – Long Field 2 SCSR-1	Northernmost core of St. Catherines Shell Ring transect; 30 ft N and ~5 ft east of AMNH station VB-001	31.65545 81.16959	4.13 m	(See Bishop et al., figs. 6 and 8, this volume).	B. Potter T. Keith- Lucas IEP students
Island Ecology Program – Long Field 1 SCSR-2	Second northern core of St. Catherines Shell Ring transect; ~30 ft south and 3 ft W of AMNH station VB-001.	31.65533 81.16960	3.68 m	Do	B. Potter T. Keith- Lucas IEP students
Island Ecology Program – Long Field 3 SCSR 3	Third core along transect; ~22 ft north and on grid line of AMNH station VB-001.	31.65525 81.16592	3.60 m	Do	B. Potter T. Keith- Lucas IEP students
AMNH & SCISTP Aka: 20061102-1 SCSR-4	Fourth core of St. Catherines Shell Ring transect.	31.65526 81.16959	4.75 m	Do	G. Bishop M. Sanger A. Semon G. Mahar
AMNH & SCISTP SCSR-5	Fifth core in St. Catherines Shell Ring transect; in shell ring.	31.65497 81.16952	—	Do	G. Bishop M. Sanger A. Semon G. Mahar
AMNH & SCISTP SCSR-6	Sixth core of St. Catherines Shell Ring transect; inside shell ring.	31.65475 81.16959	—	Do	G. Bishop M. Sanger A. Semon G. Mahar
<p>Georgia Southern University Central Depression Research Group</p> <p>The topographic low near road jct. 61 trends N35–40°E and coincides with a synformal subsurface feature. The topographic “trough” spreads out into Gator Pond marsh to the NE and into marshy area around the crane yard to the SW as this drainage bends into an E-W trend approaching the crane yard wetlands. Circular depressions were observed along the margin of the trough on the NE and SW side of the road near jct. 61. Site 3 sits in one of these.</p> <p>*Coordinates taken with Garmin e-trex unit. Values shown here include a 1.3 sec correction (based on road junction coordinates on map) added to each latitude. Longitudes generally good except core 9, which appeared to be off by 1.3 sec.</p>					
Georgia Southern University (GSU) core 1 2008-05-27/31	Located in drainage adjacent to road jct. 61, northeast side of the road between jct. 61 and jct. 60 coin- cides with synformal subsurface feature in road area. Original upper meter may have been removed by pond and road excavation at this site.	31.684639 81.145806	—	See Bishop et al., chap. 10: “Gator Pond,” this volume, for log summary of GSU cores 1–9 and palynological analysis.	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wiclaw
GSU core 2 2008-05-27/31	In Gator Pond marsh, ~ 7 m from SW margin of marsh	31.685528 81.145806	—	—	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wiclaw

## APPENDIX 2 — (Continued)

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
GSU core 3 2008-05-27/31	In depression on NE side of road that runs from jct. 61 to jct. 60. (From jct. 61, the site is 55.5 m NW of jct. 61 along the road, then 12.8 m into depression in woods on NE side of road.) Site 3a and 3b ~2 ft apart.	31.684861 81.146028	—	Circular depressions were observed along the margin of the trough on the NE and SW side of the road near jct. 61. Site 3 sits in one of these. Site within or on the margin of the synformal feature shown on the GPR profile	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wieclaw
GSU core 4 2008-05-27/31	Located on SE side of road jct. 61. The site is 19 m east of jct. 61 measured along road from jct. 61 toward jct. 10, then 6.9 m on the south side of the road in a small clearing in the trees and palmetto. This site is on the higher ground on the SE side of the topographic low containing the gator ponds.	31.684389 81.145556	—	—	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wieclaw
GSU core 5 2008-05-27/31	Location is ~25.3 m SE (along road) of jct. 61 and approximately 11.3 m on W side of road between jct. 61 to and the Windmill Pond Road intersection. This site is on the high ground on the SE side of the drainage.	31.684139 81.145889	—	—	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wieclaw
GSU core 6 2008-05-27/31	Located near road on high ground on the NE side of road between jct. 61 and jct. 60.	31.685250 81.146917	—	—	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wieclaw
GSU core 7 2008-05-27/31	New pond site in crane yard area — measured ~1 m sect in pond walls, then set up vibracore at ~1.3 m below ground surface in the bottom of the pond below the hardest part of the humate “hardpan.”	31.683167 81.151806	—	—	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wieclaw
GSU core 8	On SE side of road jct. 10, ~14.5 m W of current jct. 10 and 12.8 m S of the E–W road.	31.685694 81.145806	—	—	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wieclaw
GSU core 9	SE of road jct. 60, ~24 m on SW side of road between jct. 60 and 61.	31.686028 81.148806	—	—	R.K. Vance G. Bishop S. Ferguson J. DeLaMater N. Wieclaw
Georgia Southern University Kim Hargett Northern Terrain Thesis Cores 6/05 and 6/06/2010 A series of cores drilled off the Island Core in the northern accretionary terrains north of Engineers Scarp.					
GSU Kim Hargett core 1	Not recovered	31.6956 81.1469	—	—	K. Vance B. Meyer B. Nelson K. Hargett

## APPENDIX 2 — (Continued)

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
GSU KH core 2	Road jct. in Holocene swale. Same swale as core 5.	31.6956 81.1469	1.72 m	Organic-rich soil and fine to medium sand to 0.42 m, fine sand with HMS to 4%–5% in laminated zones from 0.42–0.9 m. Very fine laminated sand with 8–15% HMS from 0.89–0.93 m. Fine to very fine sands with HMS to 4% in laminated zones, interlayered with poorly sorted fine sand to granules from 0.93–1.72 m. Mica present below 0.9 m. Laminated sands at 1.72–2.11 m contain minor clay. (See core 5.)	K. Vance B. Meyer B. Nelson K. Hargett
GSU KH core 3	At toe of Engineers Scarp, west side of Engineers Rd.	31.6922 81.1470	2.76 m	Gray topsoil and light gray fine to very fine sand to 0.34 m with accessory mica and HMS. Fine to very fine sand with 1%–2% HMS to 1.84 m. Strong goethite pigmentation in mottled zone at 0.65–0.87 m. Sharp contact at 1.84 m with fine to very fine poorly laminated sands with pale green tint, 1%–2% HMS and traces of clay.	K. Vance B. Meyer B. Nelson K. Hargett
GSU KH core 4	Engineers Rd. (north of jct.) in broad Holocene swale.	31.6979 81.1435	2.29 m	Organic-rich soil and fine sand to .77 m, fine to very fine sand with 1–2% HMS and accessory mica from 0.77–1.7 m. Laminated sands with 2%–5% HMS and accessory mica from 1.7–2.29 m. Minor clay in dark laminations near base.	K. Vance B. Meyer B. Nelson K. Hargett
GSU KH core 5	Holocene swale west of jct. on Engineers Rd. (same swale as core 2)	31.6957 81.1470	1.81 m	Organic-rich soil and medium to fine sand to .28 m, fine sand with 2–4% HMS at .28–.56 m; well sorted fine to very fine sand with 4–5% HMS interlayered with poorly sorted fine sand to granules at .56–1.8 m. Muscovite abundant at 1.3 m in coarse zones. Minor clay in fine, laminated sands at 1.8 m.	K. Vance B. Meyer K. Hargett F. Rich
Island Ecology Program Gardner Peninsula Cores 6/06/2010 Taken on the eastern and western sides of Gardner Peninsula					
IEP GP core 1	In marsh east of Gardner Peninsula; over site of hypothesized hammock. In (stranded) marsh west of Gardner Peninsula; behind Gardner Peninsula.	31.6232 81.1553	4.62 m	Well-stratified; horiz. lam. 1.1–1.8 m; disconformity at 2.25 m on top dark brown mottled sand.; hm lam 3.9–4.62 m. Mottled sandy mud 2–2.35 m (? disconformity); 4–5 cm indurated ss at 4.10–4.15 m; coarse sand 4.15–4.62 m.	B. Potter T. Keith-Lucas IEP Students
IEP GP core 2	Holocene Marsh and Beach Ridge, terrain XI. In marsh east of Gardner Peninsula; over site of hypothesized hammock.	31.6232 81.1553	4.62 m	Well-stratified; horiz. lam. 1.1–1.8 m; disconformity at 2.25 m on top dark brown mottled sand.; hm lam 3.9–4.62 m.	B. Potter T. Keith-Lucas IEP Students
West Georgia College Tim Chown's Projects					
2007 B	St. Catherines Spit Holocene marsh and beach ridge, Terrain XI	31.57710 81.16164	3.4 m	Progradational sequence from beach into marsh.	T. Chown's Sanders Stogner
2009 G Zapala Scarp	Slough within Cracker Tom Terrain III	31.60088 81.16451	4.63 m	Holocene beach facies resting on Pleistocene (Chown's, chap. 9).	T. Chown's G. Bishop
2009 H Zapala Scarp	Long Marsh south of South Beach Road	31.59996 81.16465	5.09 m	Holocene marsh and beach facies (1720±50) resting on Pleistocene (20,550±110) (Chown's, chap. 9).	T. Chown's G. Bishop
2010 A	Long Marsh 20 m south of 2009 H	31.59977 81.16469	5.61 m	Holocene washovers and beach sands resting on Pleistocene.	T. Chown's Kath
2010 B	South Beach Road 34 m north of 2009 H	31.60021 81.16459	5.67 m	Holocene beach ridge resting on Pleistocene.	Madden Albright

APPENDIX 2 — (Continued)

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
2010 G St. Catherines Scarp	Engineers Scarp (aka St. Catherines Scarp), east of Engineers Road	31.69171 81.14570	3.11 m	Pleistocene sand.	T. Chowns Kath
2010 H	Engineers Scarp (aka St. Catherines Scarp), east of Engineers Road	31.69200 81.14566	5.63 m	Holocene inlet fill.	Madden Albright
SCS 1 Shelby Cores Beach Ridge Terrain VI	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.59892 81.15864	—	Heavy mineral sand; unsuitable for dating (Chowns, chap. 9).	T. Chowns Sanders Stogner
SCS 2 Shelby Cores Beach Ridge Terrain V	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.59946 81.15850	2.4 m	osl 1.3 ± 0.5 ka	T. Chowns Sanders Stogner
SCS 3 Shelby Cores Beach Ridge Terrain XII	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.59947 81.15079	2.1 m	osl 1.5 ± 0.3 ka	T. Chowns Sanders Stogner
SCS 4 Shelby Cores Beach Ridge Terrain XII	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.59891 81.15185	2.1 m	osl 1.2 ± 0.3 ka	T. Chowns Sanders Stogner
SCS 5 Shelby Cores Beach Ridge Terrain VI	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.58327 81.15784	2.1 m	osl 1.2 ± 0.1 ka	T. Chowns Sanders Stogner
SCS 6 Shelby Cores Beach Ridge Terrain XII	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.57685 81.16172	2.1 m	osl 0.9 ± 0.1 ka	T. Chowns Sanders Stogner
SCS 7 Shelby Cores Beach Ridge Terrain XII	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.57391 81.16314	2.1 m	osl 0.3 ± 0.1 ka	T. Chowns Sanders Stogner
SCS 8 Shelby Cores Beach Ridge Terrain XII	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.58947 81.15580	2.1 m	osl 0.5 ± 0.1 ka	T. Chowns Sanders Stogner
SCS 9 Shelby Cores Beach Ridge Terrain XVII	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.56000 81.17280	1.5 m	osl 0.5 ± 0.3 ka	T. Chowns Sanders Stogner
SCS 10 Shelby Cores Beach Ridge Terrain XV	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.56429 81.16690	1.5 m	osl 1.0 ± 0.1 ka	T. Chowns Sanders Stogner
SCS 11 Shelby Cores Beach Ridge Terrain XIV	Southern Accre- tional Terrains (aka St. Catherines Spit of Chowns), dune and beach sands	31.57264 81.16246	1.8 m	osl 0.7 ± 0.1 ka	T. Chowns Sanders Stogner

APPENDIX 2 — (Continued)

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
Georgia Southern University South Pasture Disconformity Project Two cores were drilled to test the presence of the GPR disconformity discovered by R.K. Vance (see Vance et al., chap. 11).					
South Pasture 2 Control Core GPR Disconformity	West side of road to South Plantation ~ 700 m south of junction of State Road and South Beach Road.	31.61447 81.17341	1.9 m	(See Vance et al., chap. 11: fig. 11.7, this volume). Structureless, tan, fine- to medi- um-grained sand (~1% HMS) to 1.8 m, fine to very fine sand with 4–5% HMS at 1.8 to 1.9 m. Charcoal fragments (2–3 mm) noted to depths of ~1 m in both cores.	R.K. Vance
South Pasture 1 Ground Truth Core GPR Disconformity	West side of road to South Plantation ~ 1500 m south of junction of State Road and South Beach Road.	31.61372 81.17422	2.4 m	Structureless, tan to white, fine- to medium- grained sand (~1% HMS) to 1.94 m, gray, fine to very fine sand with 3%–5% HMS to 2.2 m. Contact with waxy blue-gray clay at 2.2 m marks the disconformity. Fe-oxide mottling in and above clay. (See Vance et al., chap. 11: fig. 11.7, this volume).	R.K. Vance
The Artesian and Deep Wells of St. Catherines Island, Georgia Royce Hayes, Jack Waters, and Brock Nelson visited all known artesian well sites on St. Catherines Island on June 16 and recorded GPS coordinates and documented each site. An Oral History of <i>Artesian Wells on St. Catherines</i> , from John Toby Woods was consulted during this expedition (by Brock R. Nelson; Royce H. Hayes, Jr., and Jack Waters). (See Thomas, chap. 1: fig. 1.8, this volume for map of well distribution).					
South End boiler well	Located near boiler on the point.	— —	—	—	R. Hayes J. Waters B. Nelson
Flag Pond well	Located on south end of pond near cattle gate.	— —	—	Drilled before 1900	R. Hayes J. Waters B. Nelson
1st King New Ground well	—	31.65283 81.14578	—	Drilled before 1900	R. Hayes J. Waters B. Nelson
Button Gwinnet house well	Located just off south porch under oak tree. Supplied house and pool with water.	31.67237 81.15868	—	Drilled before 1905	R. Hayes J. Waters B. Nelson
Power House/ Bradford Hall well	Located in-between and just north of the two structures	31.66931 81.15868	—	Drilled around 1930—8 in. pipe	R. Hayes J. Waters B. Nelson
Sawmill well	Exact location not known but location is within 100 m of the old mill site and actual well site.	31.68119 81.15474	—	Drilled in 1939	R. Hayes J. Waters B. Nelson
Windmill well	Located directly below the windmill on Windmill Rd.	— —	—	Drilled in 1946	R. Hayes J. Waters B. Nelson
North Pasture well	Approximate location due to missing well pipe.	31.68806 81.14218	—	4 in. well drilled in 1946	R. Hayes J. Waters B. Nelson
Second King New Ground well	Located near the old goat cabin.	31.65188 81.14671	—	Drilled in 1946	R. Hayes J. Waters B. Nelson
Beach Pond well	Located just off South Beach Ramp.	31.59628 81.14946	—	Drilled in 1946	R. Hayes J. Waters B. Nelson
Well	Located east of Back Creek Road.	31.61777 81.16234	—	Drilled in 1946	R. Hayes J. Waters B. Nelson
Greenseed Pond well	Located east of Back Creek Road.	31.65154 81.15917	—	Drilled in 1963	R. Hayes J. Waters B. Nelson

APPENDIX 2 — (Continued)

Vibracore	Location	Longitude W Latitude N	Total depth	Geology	Researchers
South End Dock well	Flowed freely only during high tide.	31.60756 81.17761	—	Drilled in 1967	R. Hayes J. Waters B. Nelson
Wamassee Pond well	—	31.63021 81.16800	—	Drilled in 1968	R. Hayes J. Waters B. Nelson
South-West well	Located west of the old slave quarters, used for cattle and water.	31.60958 81.17689	—	Drilled in 1968	R. Hayes J. Waters B. Nelson
Back Creek well	Last free flowing well on the island.	31.62179 81.15593	—	—	R. Hayes J. Waters B. Nelson

