CHAPTER 1

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

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The Fourth Caldwell Conference is all about geoarchaeology, as played out on St. Catherines 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. Catherines 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. Catherines 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.[1]

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 Rivenna 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.[2]

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^3 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

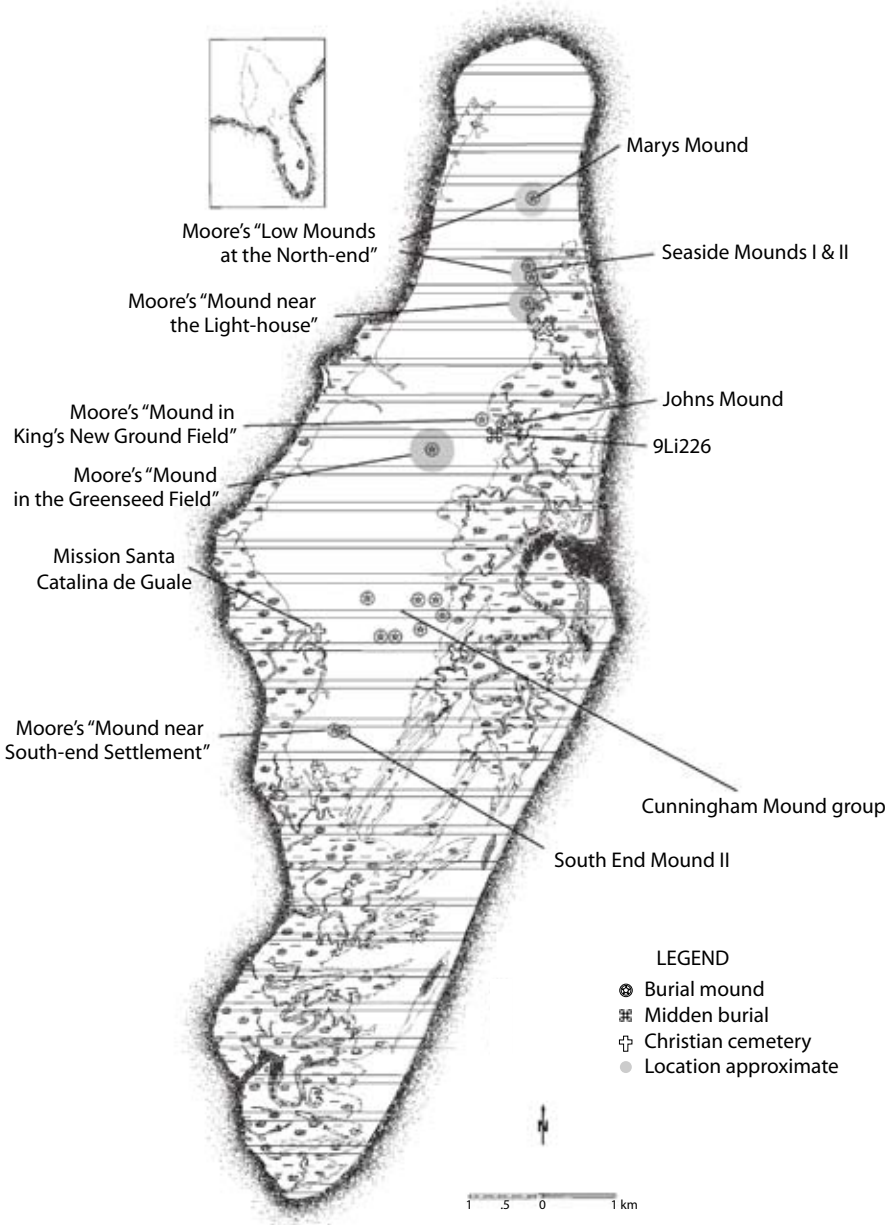


Fig. 1.2. The location of known aboriginal mortuary sites on St. Catherines Island (after Thomas, 2008: fig. 24.1). The horizontal lines demarcate the 100 m wide survey transects.

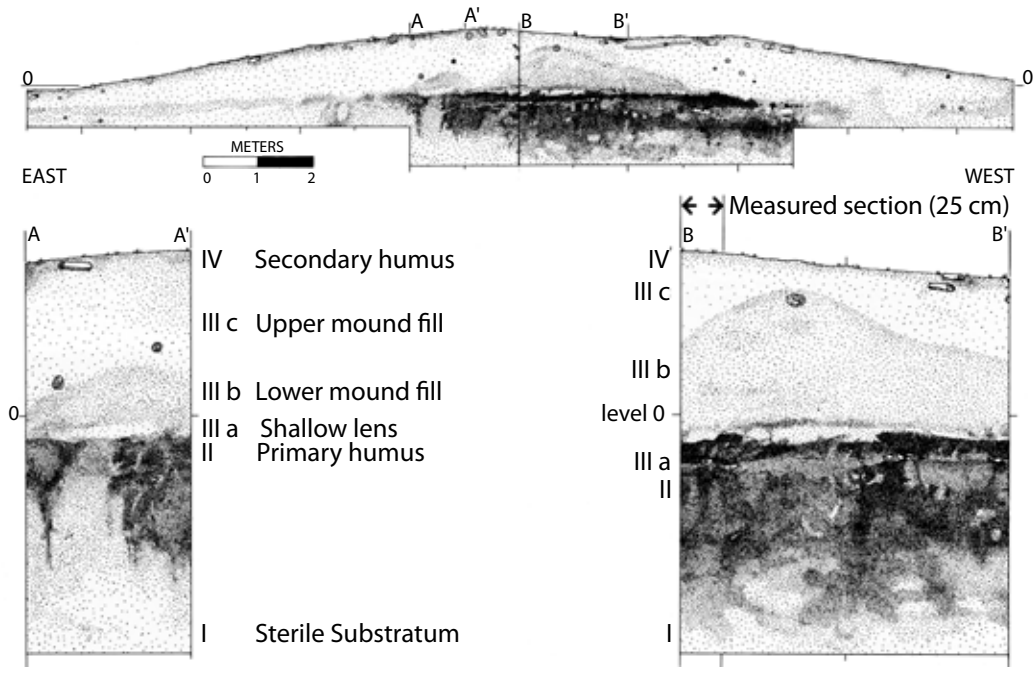


Fig. 1.3. Measured stratigraphic section of McLeod Mound, St. Catherines Island (after Thomas and Larsen, 1979: fig. 9).

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 horizontal stain across the McLeod profile, formed after the deposition of unit I, but prior to any human activity at the site. Two ^{14}C determinations processed on charcoal from this surface indicate ages of 3250 ± 60 cal B.P. (1680–1410 cal B.C., UCLA-1997E) and 2660 ± 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}C dates are available on the hard clams from the shell feature within this central tomb: 2760 ± 70 cal B.P. (850–460 B.C.; UGA-1554) and 2290 ± 80 cal B.P. (340 cal B.C.–cal A.D. 80; UGA-1555).[3] 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 ± 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 stratigraphic 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.

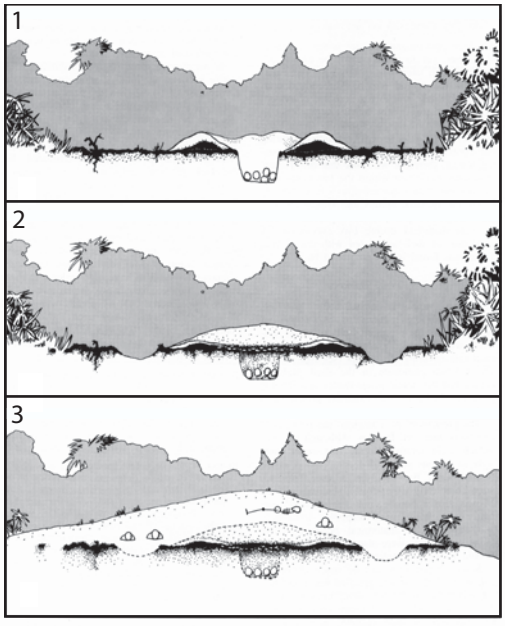


Fig. 1.4. Inferred stages of mound construction at McLeod Mound (after Thomas and Larsen, 1979: 10).

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-

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.[4]

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 ^{14}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}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 2σ cal A.D./B.C. and cal B.P. estimates, accompanied by their raw radiocarbon ages (expressed in ^{14}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}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[a]	—	A.D. 1700[b]
Altamaha			
	A.D. 1580	—	A.D. 1580[b]
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.

[a]Beginning and ending age estimates for the Altamaha period in the northern Georgia coast chronology are based on historical documentation, not ^{14}C dating.

[b]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.[5]

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 ^{14}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 Guale—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}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}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}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

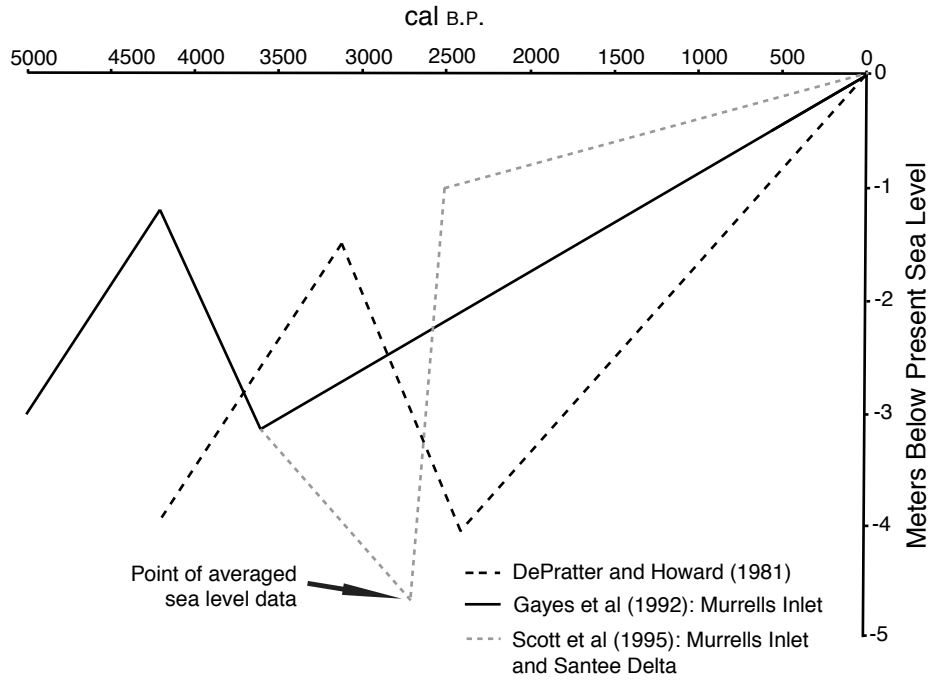


Fig. 1.5. Sea level curves for the Georgia Bight, adopted from Colquohoun and Brooks (1986), DePratter and Howard (1981), and Gayes et al. (1992; after Thompson and Turck, 2009: fig. 9).

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

Holocene Sea Level Change: Fallacies of Misplaced Concreteness?[6]

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 ^{14}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

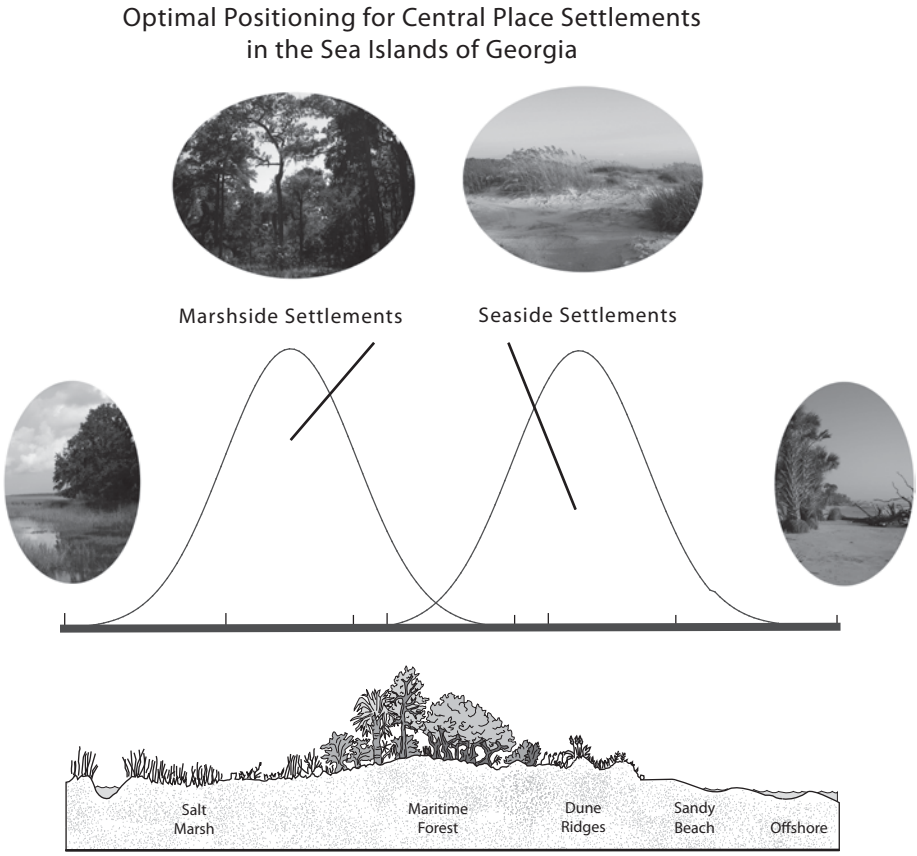


Fig. 1.6. Probabilistic distribution of optimal central places in the Sea Islands off coastal Georgia (after Thomas, 2008: fig. 11.10).

> 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).[7]

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).[8]

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 ^{14}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

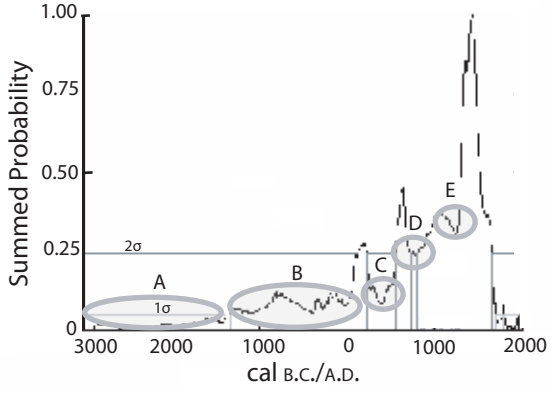


Fig. 1.7. The probability distribution of "cultural" radiocarbon dates ($N = 116$) available from St. Catherines Island processed before January 1, 2005 (after Thomas, 2008b: fig. 16.11). Multiple dates have been run since this in the attempt to fill the obvious "gaps" (indicated by gray ellipses) evident 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 preexisting 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 Peltier (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 similarities 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}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}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}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 "unequivocably" 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 ^{14}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 perceive 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}C B.P. then falling at 1500 ^{14}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 semiparallel 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}C yr B.P., with later ridge sets (D, E, F, and G) formed between 3000 and 1000 ^{14}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 ± 790 and 3950 ± 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 ± 404 and 2859 ± 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 siphoniny (the transfer of ocean water to offshore collapsing forebulge areas) … or hydro-isostacy (a result of the transfer of vicious 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, 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. Employing 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 "unequivocably" 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}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}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}C of the ocean surface from that of atmospheric CO_2. Regional patterns of ΔR 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. ΔR 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}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}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 ΔR value for the Carolina–Florida subsample (106 ± 26 years) compares favorably with the other available regional average ΔR values (available from the online Marine Reservoir Correction Database) for the Bahamas and Florida (36 ± 14 years), Long Island Sound, New York (165 ± 78), and the Gulf of Maine (38 ± 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 ± 10 years.

We processed numerous ^{14}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 ΔR value of -134 ± 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}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 ΔR 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 ± 138 ^{14}C yr B.P. (N = 8), whereas the corresponding mean age differential for clam shell–charcoal pairs is 430 ± 26 ^{14}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 ΔR 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 distributary 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 ΔR. 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 ΔR 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 ΔR Remain Constant Through Time? As a practical matter, we initially assumed that ΔR, the global reservoir ^{14}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 ΔR values have fluctuated through time, due primarily to changing patterns of ocean circulation or regional upwelling in which deeper, older water may cause ΔR 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}C ages were older than 2000 ^{14}C yr B.P. (Thomas, 2008: table 13.1). To test the proposition that ΔR 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[9]: 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 be 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).

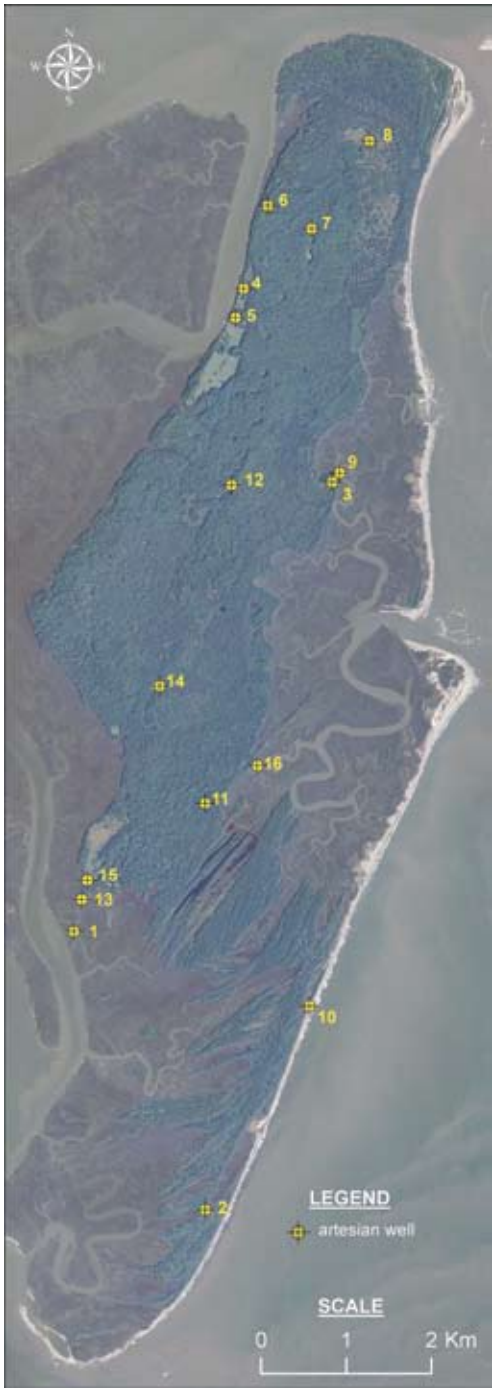
The Central Depression is clearly evident on the 1867 map of St. Catherines Sound, produced by the U.S. Coastal Survey. This long, nearly linear zone of freshwater swamp extends from present-day Wamassee Pond northward to the depression immediately to the east of the present animal enclosures (but for 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.[10]

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



No.	Name/Location	Date
1	South End Boiler Well	Drilled in 1898
2	Flag Pond Well	Drilled before 1900
3	1st King New Ground Well	Drilled before 1900
4	Button Gwinnet House Well	Drilled before 1905
5	Bradford Hall/Power House Well	Drilled around 1930
6	Sawmill Well	Drilled in 1939
7	Windmill Well	Drilled in 1946
8	North Pasture Well	Drilled in 1946
9	2nd King New Ground Well	Drilled 1946
10	Beach Pond Well	Drilled in 1946
11	Well	Drilled in 1946
12	Greenseed Pond Well	Drilled in 1963
13	South End Dock Well	Drilled in 1967
14	Wamassee Pond Well	Drilled in 1968
15	South-West Well	Drilled 1968
16	Back Creek Well	Unknown

Fig. 1.8. The location and age of known artesian wells on St. Catherines 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}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}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}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}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 timescale 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:[11]

(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}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").[12]

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 ^{14}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 ^{14}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 ^{14}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 ^{14}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 ^{14}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}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 approximately1600 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}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}C determinations cited in this chapter have been calibrated at the 2σ 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 Nels 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 ^{14}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.