CHAPTER 8
ROLE OF STORM EVENTS IN BEACH RIDGE FORMATION, ST. CATHERINES ISLAND

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There is obvious correlation between storm frequency and intensity, and rates of erosion and deposition along barrier islands, and there have been several demonstrations of how single storms can affect temporal patterns of erosion and deposition.[1] Sexton and Hayes (1983), for example, described downdrift beach accretion following repositioning of an inlet channel during Hurricane David in 1979. The sedimentary dynamics of ebb-dominated inlet systems along the southeastern United States have been investigated in some detail and models have been developed that are applicable to various temporal scales (Oertel, 1977; Kana, Hayter, and Work, 1999). In this chapter, we document how a single storm, Hurricane Hugo in 1989, helped to catalyze an ongoing depositional pattern and led to the formation of a set of three distinct beach ridges along the northeast end of St. Catherines Island over an interval of five years. This provides evidence that single storm events might trigger cascading deposition of beach ridges and we suggest that clusters of violent storm events might have long-term effects on the geomorphic configuration of barrier islands.

Causal links between individual beach ridges and storms have been assumed since the earliest work on beach ridges by Redman (1852, 1864) and by Johnson (1919). Storm events have most commonly been invoked for genesis of coarse clastic beach ridges, sometimes complemented by fair weather accumulation of sediment in the nearshore (Ting, 1936; Thom, 1964; Psuty, 1967). On the other hand, many models of beach ridge formation downplay the role of storm events, emphasizing instead various combinations of such processes as ocean swells, emergent bars, swash, berm construction, vegetational construction, and eolian activity (Taylor and Stone, 1996). In some cases, these processes have been assumed to operate in concert with sea level change (see discussion by Thomas, chap. 1). Some of these processes are thought to act gradualistically, slowly building individual beach ridges; others are considered to operate catastrophically in a manner similar to that of storm events. However, the construction of multiple beach ridges (beach ridge sets) has always, to our knowledge, been viewed as gradual, the product of fusion of individual ridges (by whatever process) over decades or even millennia.

ST. CATHERINES ISLAND

St. Catherines Island is one of a string of barrier islands (the Sea Islands) along the southeastern coast of the United States, stretching from Cape Fear in North Carolina along the Georgia Embayment to northern Florida (see fig. 1.1). Unlike the barred coasts farther north, or those along the Gulf of Mexico, many of the Sea Islands are complexes of older Pleistocene cores with aggraded sets and subsets of erosionally truncated Holocene beach ridges at their northern and southern ends. Individual Sea Islands are separated from one another by tidal inlets (sounds) from the mainland by vast expanses of coastal salt marsh (Leatherman, 1979; Frey and Howard, 1988; Bishop et al., 2007; among others).

Several of the Sea Islands are actually "double islands," consisting of Pleistocene cores with Holocene companions that accreted against the northeastern portions of the cores during Holocene stabilization of sea level some 4000–5000 years ago. Examples of this double configuration include Sapelo Island and its Holocene partner, Blackbeard Island, and St. Simons Island with its Holocene counterpart, Little St. Simons Island. Although St. Catherines Island retains no Holocene attachment, evidence of a former companion (named Guale Island) is provided by the presence of extensive sea-facing relict salt marsh muds along the eastern North and Middle beaches (Morris and Rollins, 1977; West, Rollins, and Busch, 1990; Rollins, West, and Busch, 1990; Linsley, 1993; Bishop et al., 2007; Thomas, Rollins, and DePratter, 2008). Following the erosional destruction of Guale Island there has been very rapid erosion of the eastern margin of the island core (Oertel and Chamberlain, 1975; Goodfriend and Rollins, 1998; Bishop et al., 2007. The greatest intensity of washover activity in the Georgia embayment occurs along this stretch of unprotected shoreline (Deery and Howard, 1977). Also, the absence of a Holocene companion has meant that the northern end of St. Catherines Island has received the brunt of unbuffered sedimentary impact associated with St. Catherines Sound, the inlet separating St. Catherines Island from Ossabaw Island to the north (but see Chowns et al., 2008 and Chowns, this volume, chap. 9, for alternative scenarios). Thus, it is not surprising that some of the best-developed beach ridge sets to be found along the southeastern coast of the United States occur at the northern end of St. Catherines Island (Oertel, 1975b; fig. 8.1).

METHODOLOGY

Two approaches were used to assess the effects of Hurricane Hugo on the geomorphology of the northern end of St. Catherines Island: (1) analysis of aerial and ground-based photographs, and (2) detailed topographic mapping of the newly deposited beach ridges (fig. 8.2).

Panchromatic and natural color aerial photographs ranging in scale from 1:10,000 to 1:60,000 were analyzed. To minimize effects of differences in tidal cycles, the aerial photographs were standardized by locating the High Water Line (HWL) on each photograph. The HWL "appears as a tonal change on the beach face due to differences in the water content of the sand" (Smith and Zarillo, 1990: 29). This approach is not applicable for photographs taken in rainy conditions or during storms because there would be little contrast of brightness above and below the HWL (Shoshany and Degani, 1992). All aerial photographs used in this study clearly displayed the HWL.

The following enhancement strategies were applied to the aerial photographs for analysis and interpretation of features:

(1) Photographs were scanned using Adobe Photoshop and a flat bed scanner at 300 dots per inch resolution.

(2) The scanned photographs were imported to ENVI, an image processing software program.

(3) Removal of geometric distortion (except that due to topography) was accomplished by registration (warping) of an image to a base photograph. In ENVI, the images were warped using a polynomial transform and nearest-neighbor resampling method. Warping was accomplished by identifying and matching common points (ground control points) on the base photograph and the photograph selected to be warped. At least 12 ground control points were selected on each photograph. Some common features that made excellent ground control points were isolated trees, sand pits, tree/sand lines, swamps, sloughs, and dirt road intersections.

(4) Once the images were warped, they were enhanced to emphasize the targeted marginal ramp shoal features. Aerial photographs record the amount of sunlight reflected by the surface of the earth. In this case, beach sand tends to have the highest reflectivity (albedo). A gray-scale image is broken down into 255 shades, with category 255 being pure white and category 0 pure black. The range of values for beach sand is from 195 to about 255. A density slice was produced by selecting the values of beach sand and assigning a color to the range (in this case, green). This resulted in an almost three-dimensional image, allowing us to easily distinguish beach sand from the other island surface features.

During the fall of 1995 and late spring, 1996, detailed field mapping of beach ridges was conducted at two specific locations along preselected baselines: the beach ridge field at North Beach and the Picnic Point beach ridge set (fig. 8.3) (Pottinger, 1996). The North Beach site baseline was oriented north-south and base stations were selected by optimizing the overlap of splay transects. Picnic Point stations were spaced 100 ft apart and unsplayed transects orthogonal to

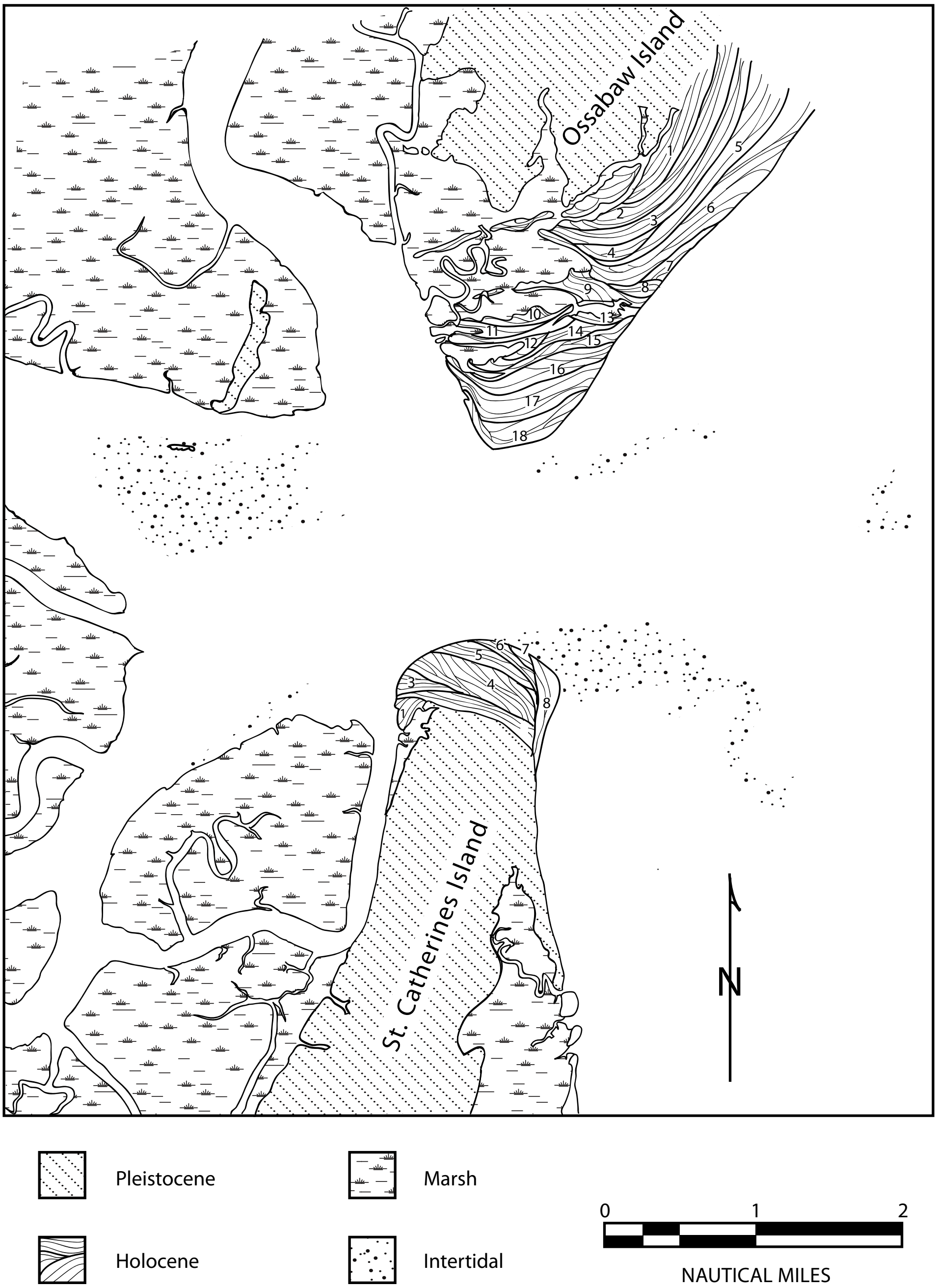


Fig. 8.1. Pattern of truncated Holocene beach ridge sets (numbered) at north end of St. Catherines Island (after Oertel, 1975).

Fig. 8.2. Location of Picnic Point and North Beach study areas. Google Earth™ image, 2010.

the baseline were used to provide detailed mapping of the beach ridges. The northernmost base station was tied into a Coast and Geodetic Survey benchmark located at the north point of the island. Mapping was carried out with the use of a Total Station Theodolite.

BEACH RIDGE CONSTRUCTION FOLLOWING HURRICANE HUGO

In the fall of 1989, Hurricane Hugo, a Category 5 hurricane, reached landfall off Charleston, South Carolina. Significant amounts of sediment flushed through St. Catherines Sound as a result of inland rainfall. The ebb-tidal delta oceanward of St. Catherines Sound is asymmetrically enlarged downdrift to the south. Export of surplus sediment through St. Catherines Sound following Hugo led to increased enlargement and detachment of this southern ramp-margin shoal and it quickly moved shoreward blocking the southward transport of ebb-tidal sediment through normally deeper spillover channels. This converted the largely subaqueous marginal shoal to a shallow and extensively emergent wave-dominated bar. In effect, this acted, metaphorically, to create a shield-trapping sediment moving northward on the flood tide before it could enter the main ebb channel to be flushed seaward and swept away by dominant ebb flow. The trapped sediment was subsequently moved southward by wave action and longshore drift to become engaged in beach ridge construction (a phenomenon known as "shoal bypassing") (Sexton and Hayes, 1983). This was accomplished without significant modification of the main tidal inlet channel (fig. 8.4).

The sequence of events outlined above closely follows the scenario of inlet-related mixed energy dynamics described by Hayes (1975), Oertel (1975b, 1977), and Kana, Hayter, and Work (1999). For at least two decades prior to 1989, the exposed portion of the shoal at the south end of St. Catherines Sound had been diminished in overall size and was semidetached. Picnic Point, an erosional scarp cut into the Pleistocene core about 0.75 mi south of the northern end of the island, had been actively wave-cut until the 1980s when the southern ramp-margin shoal became more emergent and created what Oertel (1977) termed a "shield" confining tidal flow to the main axis of the inlet channel. This pattern was enhanced by Hurricane Hugo, in 1989, and by 1990 the first of three nascent beach ridges had begun to form in front of Picnic Point bluff. A progression of beach ridge development can be seen over the subsequent multiyear evolution of this beach ridge subset, and is reflected in a seaward to landward transect over the beach ridges. The development of the beach ridges followed the morphogenetic pattern outlined by Frey and Howard (1988). Straw dunes (small isolated dunes that formed by the entrapment of windblown sand around wracks of beach-drifted marsh grass (*Spartina alterniflora*) accumulated in the upper backshore and evolved into sparsely vegetated foredunes and eventually coalesced into highly vegetated primary dune ridges (fig. 8.5). Over just a few years three dune ridges formed and the more landward ridge became heavily vegetated with dense bushes and small trees. The topographic maps (figs. 8.6 and 8.7) depict the three beach ridges, oriented north-south, ranging in elevation from 0.1 ft to 1.25 ft above the high water line (HWL) (in 1996), and extending the entire length of the Picnic Point mapping site.

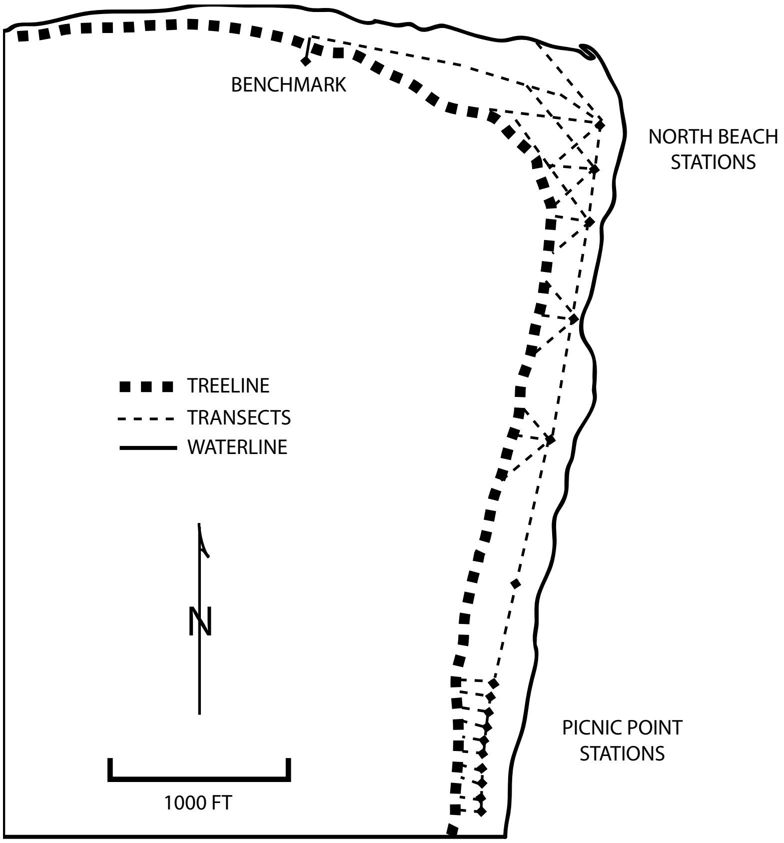


Fig. 8.3. Distribution of Picnic Point and North Beach mapping stations.

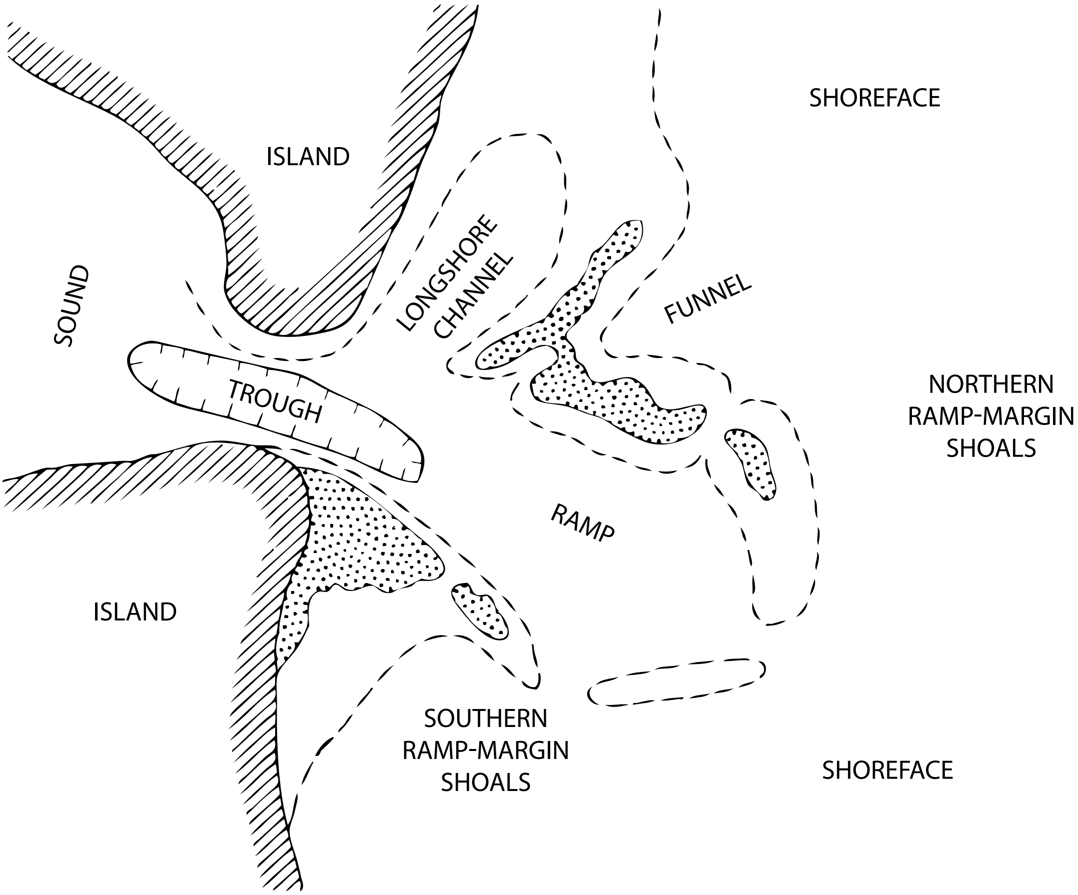


Fig. 8.4. Geomorphic features associated with a Georgia inlet shoal system (after Frey and Howard, 1988).

DISCUSSION

It appears that, in the context of models proposed by Oertel (1975b, 1977) and Kana, Hayter, and Work (1999), Hurricane Hugo likely initiated a bypassing event along the northeastern margin of St. Catherines Island by isolating the downdrift shoal from the inlet ramp and moving it shoreward. The shoreward proximity of this extensively emergent and shallow shoal sealed off much of the southward ebb flow normally coursing through shallow spillover channels. As stated by Oertel (1977: 1127), “When shoals are attached to the shore they function as shields which confine flow to the main axis of the channel.” “However, in the lee of a marginal shoal, the tidal circulation is restricted and forms a slack zone that is only effected by refracted waves.” In the ebb-dominant tidal systems of the Georgia coast, wave currents are nevertheless important during major storms and, as noted by several workers (Oertel, 1975b; Chowns et al., 2008), sediment transport along this coast tends to exhibit seasonality, with dominant southward progradation during the fall and winter and a northward transport during spring and summer.

Oertel (1975b) proposed a complex scenario to explain the mosaiclike pattern of truncated sets of beach ridges found at the north end of St. Catherines Island (fig. 8.1), and some of the other Sea Islands. He hypothesized that historical changes in the sedimentary dynamics associ-

Fig. 8.5. Photograph of beach ridges adjacent to Picnic Point. View to the north.

ated with the inlets (sounds) and marginal ramp shoals bordering the inlets led to sequential aggradation and degradation (truncation) of beach ridge sets related to Holocene constriction of inlet throats. The wedgelike beach ridge sets at the northern end of St. Catherines Island, Oertel (1975b) noted, are oriented divergent to the Pleistocene shoreline and, he surmised, a result of depositional influence of "deltaic barriers of the early Holocene Savannah River system." Oertel (1975b, 1977) attributed the multiple sets and subsets of truncated beach ridges at the north end of St. Catherines Island to intervals of attachment and detachment of the ramp-margin shoal through the Holocene. Subsequent workers (Chowns et al., 2008, and this volume, chap. 9; Bishop et al., 2007) have also noted the anomalous pattern of beach ridge accretionary morphology at the northern ends of St. Catherines Island and some of the other Sea Island (e.g., Jekyll Island), suggestive of ongoing inlet adjustment or even migration.

The models of Kana, Hayter, and Work (1999) and Oertel (1975b, 1977) are quite similar in terms of microscale dynamics, and only differ in terms of macroscale focus. Kana, Hayter, and Work emphasized the impact of shoal bypassing on shoreline configuration and Oertel was mainly concerned with origin and evolution of beach set ridges. Our observations along Picnic Point bluff following Hurricane Hugo highlight the role of single storm events in triggering rapid construction of beach ridge sets. These three beach ridges formed so rapidly because postattachment shoal spreading, with a dominant southerly vector, occurred between Picnic Point bluff and the shoreface. The cause of deposition of multiple sequential beach ridges is less clear, although it may reflect separate, but weaker, storm events. Intervals of truncation, following either Kana, Hayter, and Work (1999) or Oertel (1975b, 1977) would appear to indicate erosion during longer, somewhat stable intervals, when spillover ebb flow could pass southward due to a more detached marginal shoal.

Storm events, if demonstrable as precursors to the genesis of earlier beach ridge sets, present an unexpected complement to Oertel's model. We surmise that the extensive mosaic of truncated beach ridge sets north of Picnic Point possibly formed in a manner similar to the post-Hugo set—that is, they were triggered by storm events. Of course, aerial photograph coverage is not available for the late Holocene to directly test this hypothesis. We wondered, however, whether the last 50 or so years of available photographs might be adequate to evaluate longer-term trends of beach ridge set formation caused by storm events. Continuous single-year aerial photograph coverage is not available even for the last 50 years. However, sufficient photographs exist to evaluate the effects of clusters of violent storms upon ramp-margin shoal deposition and beach ridge set formation, and to determine whether the cascading pattern observed after Hurricane Hugo is scalable upward to longer intervals of alternating storm violence and quiescence. A significant cyclicity in Atlantic coastal storm activity has been demonstrated by Davis and Dolan (1993). The interval between the mid-1940s and mid-1960s was particularly stormy, and a noticeable decline in storm activity occurred between the mid-1960s and mid-1970s, followed by a variable intensity pattern since then (Pottinger, 1996). Figure 8.8 presents a summary of this temporal variation in storm intensity.

A temporal comparison of aerial photographs of the marginal shoal at the northeastern margin of the island indicates that a surplus of sediment debouched through St. Catherines Sound during the stormy interval between the mid-1940s and mid-1960s, apparently represented by the extensive low-tide exposure of a marginal shoal that was diminutive and barely emergent during the 1940s (fig. 8.9). By 1951, the blunted but arcuate cojacent shoreline sug-

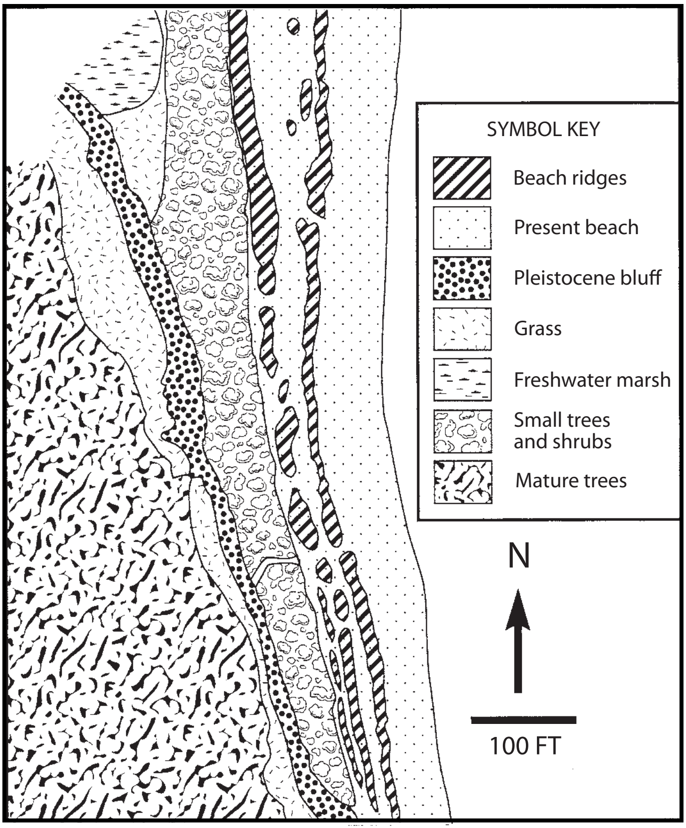


Fig. 8.6. Schematic map of vegetational zones, Picnic Point beach ridges.

gests that either (1) a previously detached bar had grounded and was subject to downdrift sediment dispersal by wave and flood attack, after the model proposed by Kana, Hayter, and Work (1999), or (2) an ebb-tidal spillover channel was shunted to the south, erosionally beveling the shoreface. The several small emergent bars scattered in the marginal flood channel suggest that the first explanation may be more likely. Another arcuate bar appears nearly detached and isolated. Renourishment in the form of beach ridges is just visible in the Picnic Point area (fig. 8.10). By 1963 the shoal has moved oceanward and has reduced low tide exposure, suggesting diminished sediment supply (fig. 8.11).

A comparison of the 1963 inlet margin with that of 1972 indicates a period of overall stability and the exposed shoal had moved offshore (fig. 8.12). Short-term variability was more complex, however, as indicated by the presence of an attached bar in 1972, which becomes erosionally dispersed over the ensuing decade.

Relative stability continued between 1972 and 1980 (fig. 8.13). The exposed shoal increased in size, but maintained the same relative offshore position. Between 1980 and 1990 the shoal again moved shoreward, creating a shallow flood tidal and wave platform, which supplied sediment to beach ridges opposite Picnic Point (fig. 8.14). The entire sequence of photographs is summarized in figures 8.15 and 8.16, and appears to demonstrate several years of shoal bypassing, followed by more than two decades of relative stability, and then, additional years of bypassing continuing to the present.

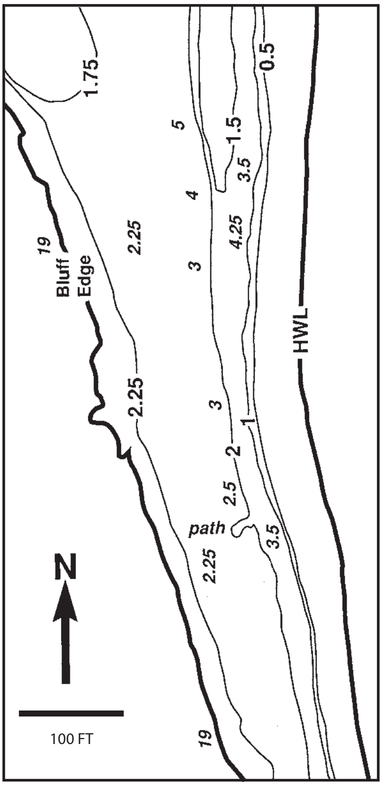


Fig. 8.7. Topographic map of Picnic Point beach ridge set. Elevations in feet about the high water line (HWL).

CONCLUSION

Our study demonstrated that a single storm event (Hurricane Hugo) was correlated with the construction of a set of three beach ridges adjacent to Picnic Point, near the north end of St. Catherines Island. The storm event apparently represented the initiation of an interval of net import of sediment shoreward in this area, interrupting the normal ebb-dominant export of sediment to a more offshore marginal shoal. This reversal of inlet dynamics appears noticeable over mesoscale intervals of time correlating with fluctuating intervals of violent and quiescent Atlantic coastal storm activity.

NOTES

1. This research was supported by grants from the E.J. Noble Foundation, administered by the American Museum of Natural History. We thank N.J. DeLillo, R.G. Kyshakevych, and J.C. Rollins for assistance in field mapping. R. Hayes, St. Catherines Island Foundation, provided valuable logistic support and advice.

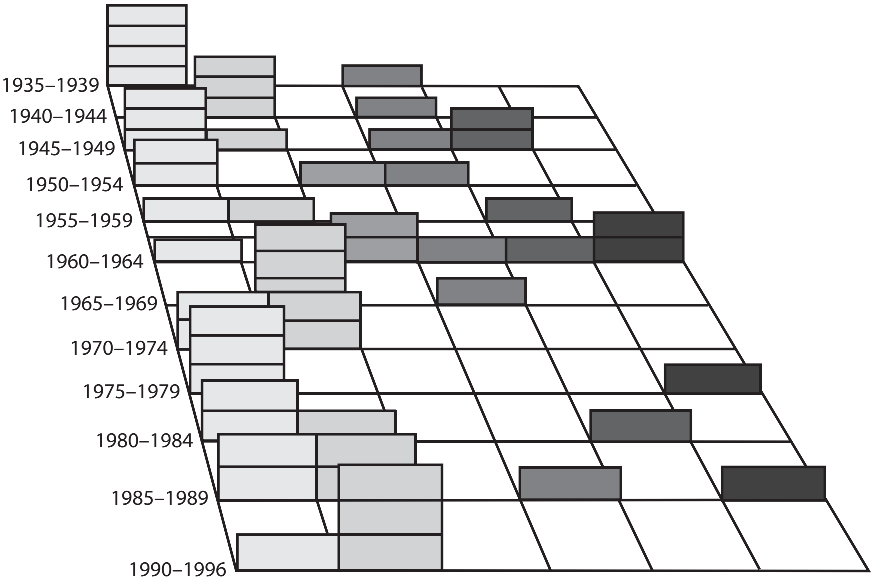
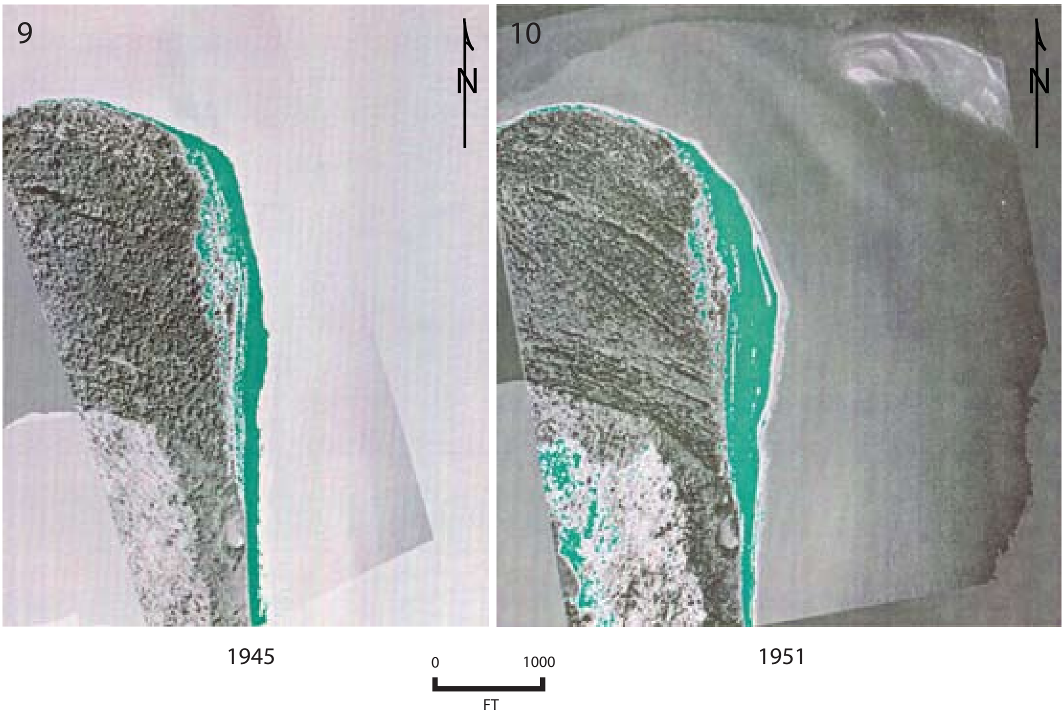
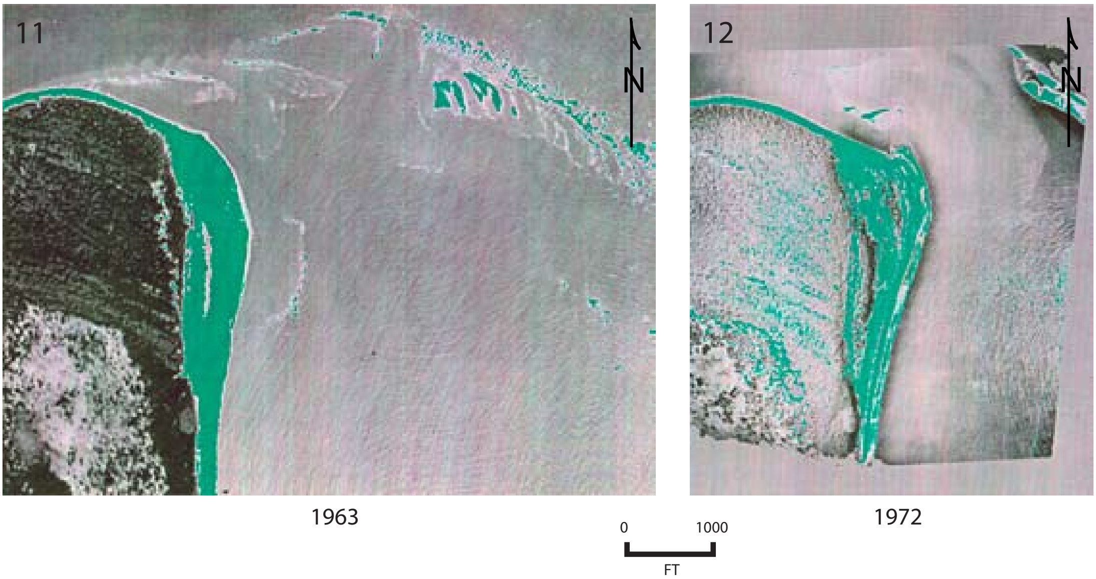


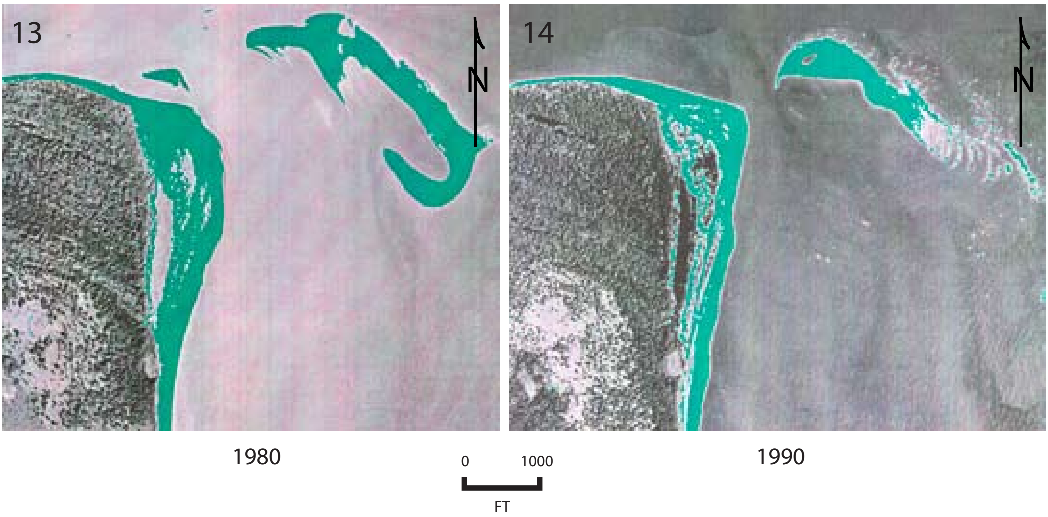
Fig. 8.8. “Cash register” diagram portraying storm intensity and frequency (data from Davis and Dolan, 1993). Intensity ranged, left to right, from tropical storm to Category 5 (Saffir-Simpson scale) hurricane.



Figs. 8.9–8.10. Enhanced aerial photographs of the northern portion of St. Catherines Island, with green color indicating beach sand: **9,** 1945 enhanced photograph (note that photographic coverage may not have included marginal shoal); **10,** 1951 enhanced photograph of northern portion of St. Catherines Island. Green color indicates beach sand (see text).



Figs. 8.11–8.12. Enhanced aerial photographs of the northern portion of St. Catherines Island, with green color indicating beach sand: **11,** 1963 enhanced aerial photograph of northern portion of St. Catherines Island. Green color indicates beach sand (see text); **12,** 1972 enhanced aerial photograph of northern portion of St. Catherines Island. Green color indicates beach sand (see text).



Figs. 8.13–8.14. Enhanced aerial photographs of the northern portion of St. Catherines Island, with green color indicating beach sand: **13,** 1980 enhanced photograph; **14,** 1990 enhanced photograph.

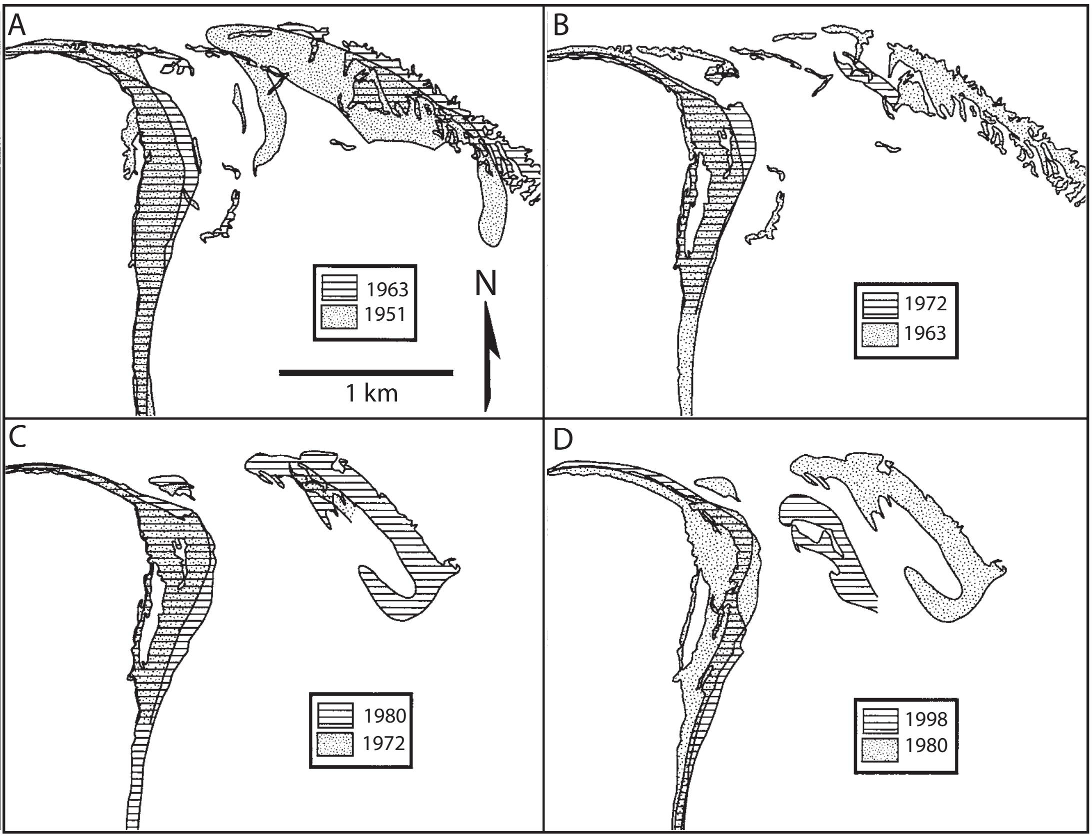


Fig. 8.15. Schematic overlays showing temporal sequence (A–D) of geomorphic changes along the southern marginal ramp shoal area, northern end of St. Catherines Island.