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EPISODIC BARRIER ISLAND GROWTH IN SOUTHWEST FLORIDA: A RESPONSE TO FLUCTUATING HOLOCENE SEA LEVEL?

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ABSTRACT

Holocene barrier islands in Lee County, Florida, are composed of beach ridges organized into distinct, unconformable sets bounded by erosion surfaces. Beach-ridge pattern suggest both lonshore and direct onshore sand transport. These beach- ridge sets are further differentiated on the basis of average elevation. Low sets are about 1 m and high sets are about 2 m above local mean sea level. In this region barrier islands have grown by shoal emergence. The oldest preserved beach-ridge sets were deposited approximately 3000 BP. Elevationally distinct and geographically adjacent beach-ridge sets having apparently identical radiocarbon depositional-ages record a major sea-level and/or energy fluctuation. The date of this fluctuation is within the 200- to 400-year error margin associated with the radiocarbon technique. Five such fluctuations have been identified in these islands: 1) a rise-increase at 2000 BP, 2) a fall-decrease at 1500 BP, 3) a rise-increase at 1000 BP, 4) a fall-decrease at 500 BP, and 5) a rise-increase over the past hundred or so years. The 500-year cyclicity is only apparent and reflects the precision of estimating the depositional age of clastic deposits by radiocarbon-dating their constituent clasts. The geomorphology, internal structure, and lateral continuity of individual beach ridges, the geographic extent of beach-ridge sets, and the partial covering of beach-ridge sets with mangroves and/or fresh-water marsh vegetation argue that the primary component of these fluctuations was a change in sea-level position rather than energy condition. Each of these fluctuations resulted in barrier island growth or creation. Sand was supplied by erosion of the near shore region and existing barrier islands.

Each fluctuation had an initial depositional phase followed by an erosional phase when the sand supply rate fell below a critical threshold. The decrease in sand supply rate reflects a source depletion and/or a redirection of the transport path.

INTRODUCTION

Relating a given deposit to a sea-level datum and determining the age of the deposit are fundamental to developing the sea-level history of an area. Holocene sea-level studies in the southeastern United States have utilized estuarine basal peats, archeologic sites, and intertidal deposits. Detailed botanic and palynologic analysis, including petrographic examination, may well be needed to accurately determine the depositional environment of an estuarine basal peat (Cohen, 1970; Cohen and Spackman, 1977; Davies, 1980). Aboriginal shell middens are frequently used archeologic sites and, in and of themselves, indicate only upper bounds of sea-level positions. The precision of sea-level position estimates based on intertidal deposits is, to a certain extent, inversely related to tidal range and wave-energy: the less the range and energy, the better the estimate.

Largely because of the scarcity of 1) preserved datable materials and 2) exposures for sampling, barrier-island deposits in general and beach ridges in particular have been little used in determining Holocene sea-level history in the southeastern United States. This lack of exposure is a severe limitation to collecting numbers of mollusk shells suitable for radiocarbon dating. Unless articulated specimens are dated, a suite of individual shell valves must be analyzed so that reworked shells can be identified and the time of deposition better estimated (Stapor and Mathews, 1976, 1983).

Holocene barrier islands found in the Lee County region of southwest Florida are composed of quartz sand that contains an average 20 per cent by weight mollusk shells (these islands are in a low wave-energy, microtidal environment). The measured significant wave height in southwest Florida is 36 cm (Thompson, 1977) and the tidal range in Lee County is 80 cm (U. S. Dept. of Commerce, 1980). The barrier islands are composed of beach ridges organized into distinct, unconformable sets, an indication that these islands have experienced a complex history of repeated periods of alternating deposition and erosion. Longshore and direct onshore sand transport are reflected in the geographic patterns of beach ridges comprising these sets. Neither of the two rivers entering the Gulf of Mexico in this region transport sand across their estuaries (Haung and Goodell, 1967): nearshore erosion of Pleistocene and earlier Holocene coastal deposits has provided the sand to build these islands. These composite barrier islands that contain relatively abundant, preserved, datable materials and that formed in a low tidal- range, low wave-energy environment present an excellent opportunity to examine the relationship between sea-level and coastal progradation.

PREVIOUS WORK

Studies of Holocene sea level in southern Florida in general and southwestern Florida in particular have primarily utilized mangrove peat deposits in the Everglades and Florida Bay regions (Spackman et al., 1966; Scholl et al., 1967, 1969; Davies, 1980; Robbin, 1988). Shier (1969) studied intertidal vermetid gastropod reefs in the Ten Thousand Island area of Collier and Monroe Counties, Florida, on the northwest border of the Everglades National Park. All of these studies indicate a uniform asymptotic rise of Holocene sea level to its present position. Woodroffe (1981), using mangrove peats from Grand Cayman Island, also reports a uniform asumptotic rise for the past 2000 years. However, Roberts et al. (1977) on the basis of shell dates from coastal levees northeast of Lake Ingraham concluded that sea level had reached its present position in the southwestern Everglades by 2000 BP (Before Present or 1950).

Missimer (1973) from a study of Sanibel Island beach ridges inferred that sea level 2000 BP was significantly above its present position, perhaps by as much as 2 m. Stapor and Mathews (1980) presented preliminary data from the Lee County, Florida, barrier islands that indicated sea

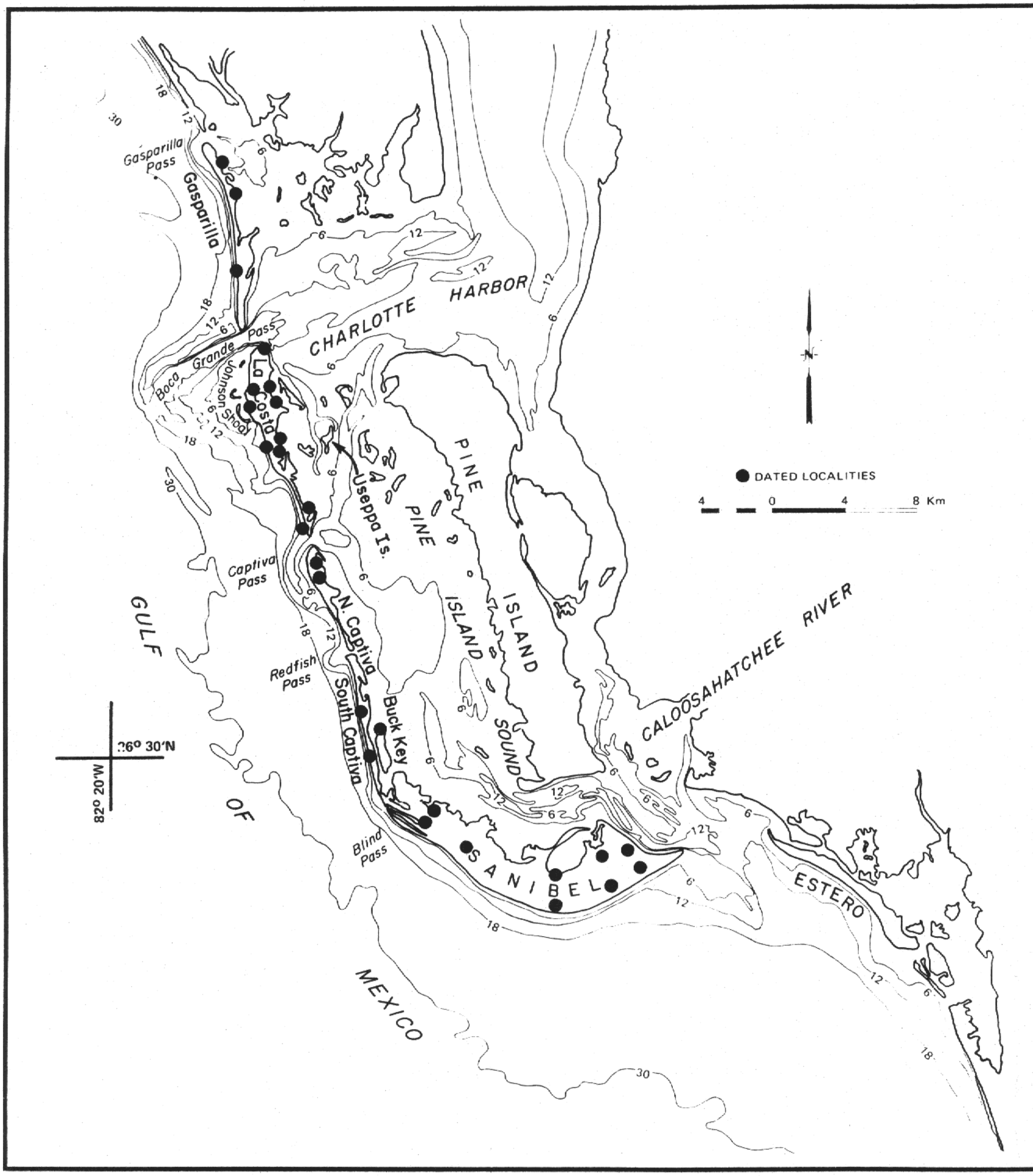

Figure 1. Location map of the Lee County, Florida, barrier islands studied in this investigation. The Holocene barriers are (from north to south): Gasparilla, La Costa, North Captiva, South Captiva, Buck Key, and Sanibel. The filled black circles locate beach ridges where suites of mollusk shells were collected and radiocarbon dated.

level 3000 BP was within 1 m of and 2000 BP above its present position; some of the dates in this study were later revised (Mathews and Kearns, 1982). Beach- ridge sets on Cat Island, Bahamas, indicate that sea level stood above its present position three times in the past 3000 years (Lind, 1969).

The Holocene sea-level history inferred from mangrove peats apparently contradicts that inferred from barrier-island deposits. This apparent contradiction well illustrates the difficulties inherent in dating intertidal deposits and relating them to a sea-level datum. Four major factors contribute to this paradox: 1) the precision of the radiocarbon dating technique-- it can resolve differences only on the order of 200 to 400 years, 2) correct identification of intertidal deposit, be it peat or barrier island, and its relation to sea level, 3) erroneous radiocarbon analyses because of contamination -- younger rootlets in the case of peats and calcium carbonate recrystallization in the case of shells, 4) age assigned to barrier-island deposits is only a maximum because of shell reworking. In addition, an elevational bias has been introduced by the basic sampling of these two contrasting depositional environments. Peats are sampled at depth by means of coring; barrier islands are sampled, typically, within 1.5m of their respective subaerial surfaces, which are usually no lower than the uppermost portion of the local tidal range. Thus there is a bias for peats to preferentially record lower, and the barrier islands to record higher, sea-level positions. Furthermore, peats formed during lowstands may be preferentially preserved because emergence would tend to destroy peats formed during highstands (Fairbridge, 1974). In the mangrove peat environments of the southwestern Everglades, sea-level fluctuations less than or nearly equal to the 1.5 m tidal range may be very difficult to detect.

Geophysical modeling (Walcott, 1972; Chappel, 1974; Clark et al., 1978) suggests that the southeastern United States lies beyond the collapsing glacial forebulge located in the middle Atlantic and southern New England region. The continual subsidence predicted by geophysical models is verified by sea- level curves determined for New York City (Newman et al., 1980) and Delaware (Belknap and Kraft, 1977).

These geophysical models predict a markedly different history for the southeastern United States, namely, that Holocene sea level should have reached its present position 3000 or so years ago. Data indicating that sea level has fluctuated to within 1 m of its present position for the past 4500 to 3000 years have been presented for South Carolina (Colquhoun et al., 1980; Stapor and Mathews, 1983) and Georgia (Depratter and Howard, 1981). The New Orleans barrier trend was formed 5000 BP when sea level was slightly higher than its present-day position (Otvos, 1978). The South Hancock barrier trend of southwest Mississippi formed 3600-3000 BP when sea level stood very close to its present-day position (Otvos, 1978). Cheniers of southwestern Louisiana indicate that sea level has been at its present position for the past 3000 years (Gould and McFarland, 1959). Galveston Island, Texas, was initiated 4500-3000 BP when sea level was very close to its present position (Bernard et al., 1959). Behrens (1966) reports a raised beach deposit in northeastern Mexico that is 2000 BP and is approximately 1 m above present sea level. Ebanks (1967) reports that mangrove peats at Ambergris Cay, Belize, indicate sea level reached 1.5 m below present 5000 BP and has remained within 1 m of its present position ever since.

Investigations of the barrier islands of Lee County, Florida, have concentrated either on stratigraphy or dynamic processes. Those dealing with stratigraphy have been previously mentioned except for the natural history study of La Costa Island by Herwitz (1977) in which he recognizes that the island is composed of beach-ridge sets bounded by truncation or erosion surfaces, a situation identical to that observed on Sanibel Island by Missimer (1973). Harvey (1979) detailed the response of various sections of these barrier islands to tidal inlet dynamics. He prepared a sand budget by means of bathymetric chart differencing that identified a series of littoral drift cells which feed sand from eroding beaches to ebb-tidal deltas. Silberman (1979) and Neale (1980) also prepared sand budgets by means of bathymetric chart differencing but concluded that a significant volume of material eroded from these islands is lost offshore.

Barrier-island deposits probably contain the data most pertinent to determining the fundamental nature of Holocene sea- level history in southwest Florida: either a uniform asymptotic rise or one that reached to within 1 m of present position 4500- 3000 BP and subsequently has fluctuated both above and below this level.

GEOLOGIC SETTING

The Holocene barriers of Lee County, Florida, are perched on the seaward edge of a Pleistocene sand sheet. Dunes of probable late Pleistocene age are found within Pine Island Sound on Useppa Island and Cabbage Key (Figs. 1 and 7 for location). The age assignment, although tentative, is based on the dark yellow color for the quartz sand, similar to that of dune sands found at Marco Island, Collier County, Florida, and at other Florida coastal localities. Shell beds of probable Sangamon age (D. G. Belknap, personal communication) underlie Pine Island at depths less than 2 m below sea level.

Both ebb- and flood-tidal deltas occur at inlets along this microtidal, low wave-energy coast. However, ebb-tidal deltas are preferentially developed over flood-tidal deltas at the major inlets. Boca Grande Pass, the main tidal channel into Charlotte Harbor, has maximum throat depths of 70 feet and is entrenched into pre-Pleistocene bedrock. The largest ebb-tidal delta in the region is located at this inlet; Johnson Shoal, the larger southern portion of this delta is both a sediment source and 'breakwater' for adjacent La Costa Island (Fig. 1). Another large ebb-tidal delta is developed at the eastern tip of Sanibel Island where flow exiting Pine Island Sound and, to a lesser extent, the Caloosahatchee River (more correctly estuary) has intercepted longshore drift moving east along Sanibel Island. A smaller and much more lunate ebb-tidal delta is located at Captiva Pass that separates La Costa and North Captiva Islands. Harvey (1979) presents a detailed dicussion of the dynamic processes active at these inlets and the associated sediment movement.

Well-developed ebb-tidal deltas are not typically observed along microtidal coasts. In southwest Florida the diurnal tide has a spring range of only 80 cm. However, the tidal prisms of both Charlotte Harbor and Pine Island Sound are quite large. In addition, the wave energy is low, with a significant wave height of only 36 cm (Thompson, 1977). These two factors predict 1) significant tidal flow at inlets and 2) wave energy insufficient to transport sand away from ebb-tidal deltas.

A pronounced break in slope at the 12-foot isobath marks the division between the upper and lower shoreface. The lower shoreface extends seaward to approximately the 30-foot isobath: coast-oblique sand ridges appear at the boundary between the lower shoreface and the inner shelf, e.g., offshore of Gasparilla Pass, Fig. 1. The inner shelf contains significant bedrock outcrops, judging from the lithified siltstone pebbles and phosphorite sand found on these beaches. Silberman (1979) and Neale (1980) identified areas of long-term net erosion and deposition located on the shoreface and inner shelf off La Costa, North Captiva, South Captiva, and Sanibel Islands.

Littoral drift has a cellular nature along these islands. Harvey (1979) used a sand budget determined by bathymetric map differencing to identify six littoral drift cells between Boca Grande Pass and the eastern tip of Sanibel Island. He concluded that these cells are only partially integrated. Ebb-tidal deltas at Captiva Pass, Redfish Pass, and the eastern tip of Sanibel Island serve as deposition sites, underscoring the importance of tidal processes in the partitioning of littoral drift (Harvey, 1979). It should be noted, however, that the significant wave period is low, 5 sec, and the offshore bathymetry irregular, a situation that results in a complicated wave-refraction

Figure 2. Swash-zone, planar laminae that are gently inclined seaward (to the right) characterize the internal structure of beach ridges. This view is of the east side of the North Captiva canal, locality 1 of Figure 12.

Figure 3. Close-up view of swash-zone bedding that characterize beach ridges in southwest Florida. This site is along the North Captiva canal, locality 2 of Figure 12.

pattern. This complicated pattern should cause a partitioning of littoral drift independent of any tidal effect.

RADIOCARBON DATING

Mollusk shells contained within barrier-island deposits are clasts potentially derived from sources other than recently dead organisms and, as such, can have a variety of radiometric ages. Given the susceptibility of shells to mechanical abrasion (Force, 1969), the mode in any clastic deposit should be recently dead shells, the age of which equals the age of deposition. In selecting shells for radiocarbon dating, however, the bias towards the largest, most robust (hence most resistant to abrasion), least weathered specimens maximizes the potential for selecting reworked, older shells.

In using this sampling procedure, a number of shells must be dated at each locality so that the presence of reworked shells can be identified and their significance evaluated. If a range of ages is obtained, then a cluster of overlapping ages at the younger end of the spectrum best estimates the age of deposition. The spectrum provides information about source beds: in the case of reworked shells, these source beds are in close geographic and topographic proximity. If fluvial sources are not actively contributing material to prograding coastal deposits, reworking of juxtaposed older deposits should be expected. This situation presently exists along much of the southeastern United States Atlantic and Gulf of Mexico shorelines.

All radiocarbon dates in this study are presented as uncorrected ^{14}C-years BP with BP referring to Before Present or 1950. Dates are reported to one sigma counting error and are based on a ^{14}C half-life of 5570 years using 0.95 NBS oxalic acid as the modern standard. Shell dates reported in this study that are greater than 15,000 BP are in all likelihood dead to radiocarbon (greater than 35,000 BP), their finite ages reflecting small amounts of modern ^{14}C which is analytically undetectable (Broecker, 1965; Olsson, 1968; Morner, 1971; Stapor and Tanner, 1973). The following radiocarbon laboratories made analyses for this study: Marine Resources Research Institute (MRRI), Queens College of CUNY. (QC), University of Miami (UM), and Krueger Enterprises (GX).

BEACH-RIDGE GEOMORPHOLOGY AND ORIGIN

Beach ridges that make up prograding Holocene barrier islands in the southeastern United States are not the products of large storms and/or eolian activity (Stapor, 1975; Stapor and Mathews, 1976). These ridges have smooth, regular, curvilinear crest lines (Figs. 7 and 17). They are composed of laminae characteristic of the foreshore or swash zone: planar, gently- dipping laminae that are inclined seaward (Figs. 2,3, and 4). Even the uppermost portion of the 9-foot high Wulfert ridge on Sanibel Island, the highest beach-ridge set in this region, is composed of foreshore laminae (Missimer, 1973b), see Fig. 4. Washover and eolian deposition have played minimal roles during the construction of these beach ridges. Rather, swash-zone deposition over years to tens of years is the major mechanism.

Beach-ridge height is directly related to wave energy (Tanner and Stapor, 1972). Lower ridges are produced by less energetic waves than are higher ridges. This relationship is well demonstrated by ridges formed over the past 125 years on La Costa Island. Ridges formed facing the open Gulf of Mexico (set DD' in Figs. 7 and 10) are higher than ridges of the 'mini' cuspate-headland (sections AA' and BB' in Figs. 7 and 9). These latter beach ridges were formed by waves that either traversed Johnson Shoal and/or were generated on the shoal behind small islands. The DD' ridges have average elevations of approximately 5 feet (Hamrick Aerial Surveys, 1981b). Ridges on the 'mini' cuspate-headland, on the other hand, have average elevations of 2

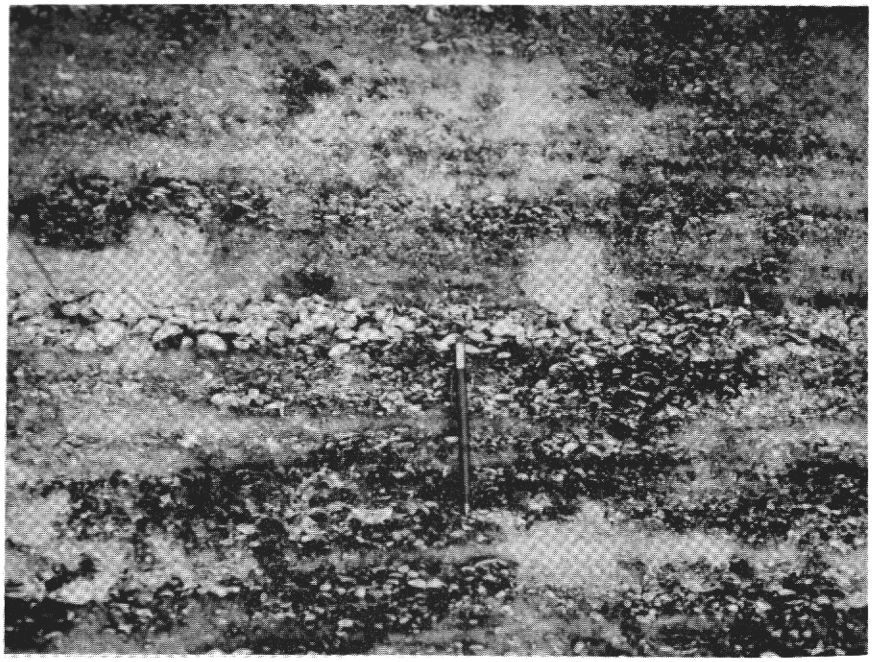

Figure 4. Close-up view of swash-zone bedding in the Wulfert ridge (locality 3 of Figures 16,17, and 18) at an elevation of about 9 feet MSL.

to 3 feet (Hamrick Aerial Surveys, 1981c). Thus, different wave climates have produced beach ridges of significantly different heights.

Beach-ridge spacing is controlled in large part by the sediment-supply rate, the interaction between energy (wave and/or tidal) and the amount of available sediment. This is based primarily on the observation that beach ridges constructed from sand supplied by littoral drift converge or decrease their spacing in the downdrift direction, the direction of decreasing sediment supply. The wider the spacing between beach-ridge crests, the more rapid the rate of sediment supply. A very slow supply rate produces the amalgamated beach-ridge sets in which individual crests are not readily discernible, e.g. locality 1 on North Captiva Island (Figs. 2 and 11) and the Wulfert Ridge on Sanibel Island (Fig. 16).

Directions of sediment transport can be inferred from beach- ridge patterns. Littoral or shore-parallel transport is indicated by 1) spit-type or convex-seaward and 2) fan-shaped or concave-seaward beach ridges. Littoral sand-movement is toward the direction of closing for the concave-seaward sets. Beach- ridge spacing and the volume of deposited sand both decrease in the direction of decreasing Q, the volume of littoral sand- transport (see the "A-B-C..." model of littoral transport, Tanner (1974)). Parallel beach ridges indicate direct-onshore transport with a minimal littoral component (Tanner, 1974; Stapor, 1975). In addition, the degree of parallelism shown by fan-shaped ridges indicates the importance of onshore transport during their formation.

Beach-ridge geomorphology results from the interaction between the energy and the sediment available within the littoral zone. Oceanographic parameters largely determine the available energy and geologic-geographic factors largely control the available sediment. From beach-ridge geomorphology, we can make inferences concerning the rate of sediment supply, the magnitude of energy at the shoreline, and the angle with respect to the shoreline at which energy was applied.

BEACH-RIDGE GEOMORPHOLOGY AND SEA LEVEL

Sea level is the common datum for both energy condition and the geomorphology of sedimentary deposits within the shoreface barrier-island system. Barrier islands composed of beach-ridge sets of differing elevations records variations in energy and/or sea level. Energy variations on a time-scale of hundreds of years probably result largely from changes in climate that alter storm tracks and effect a general raising or lowering of wave heights. However, on low-energy coasts subtle changes in mean sea-level may sufficiently alter water depth relative to nearshore wave heights to produce a similar result: higher position, greater incident energy, and lower position, lesser incident energy. The relative importance of energy versus sea- level variations in the formations of beach-ridge sets of differing elevations should not be evaluated by considering elevational differences alone. Other geomorphic elements such as the geographic extent of beach-ridge sets and the effect of biologic factors, swamp and marsh development, must be considered in determining whether: 1) energy condition changed with sea level remaining essentially constant or 2) sea level changed with energy condition undergoing only minor modification. Adjacent beach-ridge sets of apparently identical radiocarbon age but of different geomorphology and/or elevation imply a major change in sea level and/or energy condition. This change occurred over a time period equal in magnitude to the precision of the radiocarbon technique, 200 to 400 years. The beach-ridge sets only appear to be the same age; the more seaward set is, of course, younger than the more landward.

Lateral continuity and geographic extent are perhaps the geomorphic aspects most important in evaluating the relative importance of these two interdependent variables. A significant reduction in energy-level alone should result in geographically restricted or localized beach-ridge sets reflecting the compartmentalization or disintegration of earlier, higher energy, littoral-drift systems. This would not be expected to result from a subtle shift in sea-level position accompanied by only minor energy-level modification. Obviously preservation is a key factor in the interpretation of "restricted" versus "widespread." Thus the larger islands such as La Costa and especially Sanibel should be primarily used to evaluate lateral continuity and ìgeographic extent. The partial covering of beach ridges by mangroves or marsh vegetation implies a sea-level rise subsequent to ridge formation: the intertidal zone now covers deposits of the supratidal zone. When swash-zone bedding is found several meters above the maximum level at which it occurs in beach ridges formed within the past 100 years, that condition implies a sea- level position significantly higher in the past than in the present.

ISLAND GEOMORPHOLOGY AND RADIOCARBON CHRONOLOGY

Gasparilla Island

Six beach-ridge sets can be readily identified on this island (Figs. 5 and 6). The spit-type pattern of beach ridges making up the sets adjacent to Gasparilla and Boca Grande Passes indicates the existance of two littoral drift cells, one directed northward and the other southward. Southward transport only is suggested by the patterns of the three beach-ridge sets that comprise the bulk of the island (sets 1, 2, and 3 of Figs. 5 and 6). However, the marked parallelism of their constituent ridges argues for a significant onshore component of sand transport (Stapor, 1975). A pronounced change in shoreline orientation from east-west to north-south occurred prior to the deposition of set 3. These older beach-ridge sets decrease in age southward. They are not juxtaposed, but rather are separated by intervening younger sets. The long-term direction of island progradation has been southward, but this growth has been interrupted by periods of significant erosion. Since 1860 the Gasparilla Island shoreline has retreated along the southern two thirds of the island and advanced seaward along the northern third. This historic accretion in the vicinity of Gasparilla Pass probably involves sand being driven ashore from the ebb-tidal delta as well as that being transported north along the island.

Beach-ridge sets 1 and 2 are quite low in elevation, both falling below the 5-foot contour. Set 1 is partially covered with mangroves. Ridge elevations in set 2 range between 2.5 and 3.8 feet MSL (Hamrick Aerial Surveys, 1981d). Beach-ridge set 3, on the other hand, lies generally above the 5-foot contour which serves to outline individual ridges. Beach ridges constructed south of Gasparilla Pass since 1860 are also outlined by the 5-foot contour; however, much of this beach-ridge set lies below this elevation.

Mollusk shells were collected at beach-ridge set 1 from a shallow pit dug into a beach-ridge crest. The ten shells collected at this site range in age from 2400 to 7600 BP; deposition occurred approximately 2400 BP, the age of the youngest shell (Appendix Table 1). Reworking is clearly demonstrated to be of significant concern when shell clasts are used to estimate age of deposition. The three youngest shells have overlapping ages and may best approximate the age of deposition. This set is assigned to the informal time- stratigraphic unit Sanibel 1, those ridges deposited between 3000 and 2000 BP.

Spoil from shallow drainage ditches (less than 1 m deep) dug for mosquito control was sampled at beach-ridge set 2. Radiocarbon ages of fifteen individual shells range from 900 to 5300 BP (Appendix Table 2). The articulated *Spisula raveneli* specimens provide the best estimate of depositional age, approximately 1000 BP. However, even these articulated shells show evidence of reworking; the 1500-year-old specimen is in all likelihood older than the others. Among the disarticulated shells analyzed from this locality there is no cluster of overlapping ages at the younger end of the spectrum, an indication, confirmed by the articulated samples, that the age of deposition is younger yet. This set is assigned to the informal time-stratigraphic unit Buck Key, those beach ridges deposited 1500 to 1000 BP.

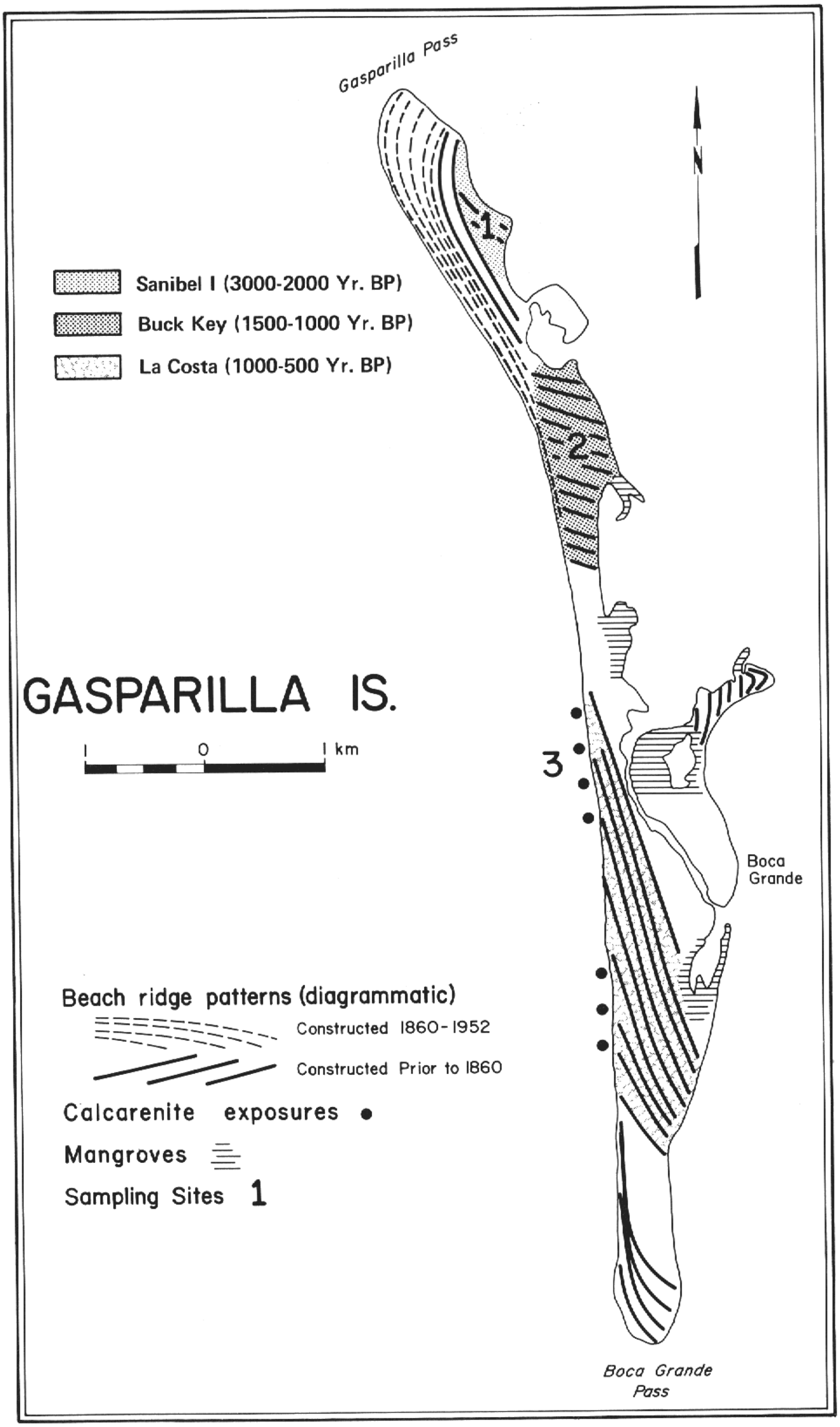

Figure 6. The radiocarbon chronology of beach-ridge sets preserved on Gasparilla Island, Lee County, Lee County, Florida. Beach-ridge patterns are diagrammatic within the various sets and were mapped from 1944 U.S. Department of Agriculture aerial photography. The designations Sanibel I, Buck Key, and La Costa are informal time-stratigraphic units. Thirty-three radiocarbon dates of individual shells collected from localities 1,2, and 3 are the basis for the chronology of this island.

Figure 5. Uncontrolled aerial photo mosaic of Gasparilla Island, Lee County, Florida. The photographs were taken by the U.S. Department of Agriculture in 1944. Shells were collected for radiocarbon dating from the numbered localities.

Lithified calcarenites exposed in a wave-cut cliff (filled black circles in Fig. 6) provided shells at beach-ridge set 3. The eight samples range in age from 1000 to 6900 BP (Appendix Table 3). However, the three youngest samples have overlapping ages that estimate the age of deposition to be approximately 1000 BP. The sampled site is located in the older portion of this beach-ridge set. This set is assigned to the informal time- stratigraphic unit La Costa, those beach ridges deposited 1000 to 500 BP.

The beach-ridge sets present on Gasparilla Island indicate intermittent, southward progradation from about 2400 to some time since 1000 BP when bidirectional, northward as well as southward, accretion began. About 1000 BP, immediately prior to deposition of beach-ridge set 3, a marked sea-level rise and/or increase in energy condition occurred. Sand transport during the deposition of these beach-ridge sets had a significant onshore component. Nearby, older Holocene coastal deposits, ranging in age from 7600 to 3000 BP, were reworked during the deposition of the beach- ridge sets preserved on Gasparilla Island. None of these older deposits have been found preserved in this region.

La Costa Island

Thirteen beach-ridge sets are present on La Costa Island (Figs. 7 and 8). All but two are located on La Costa "proper," that part of the island immediately landward of Johnson Shoal, or the southern portion of the Boca Grande Pass ebb-tidal delta. Two sets are present at the southern tip of the island adjacent to Captiva Pass. Herwitz (1977) recognized 12 beach-ridge sets on La Costa "proper," many of which correspond to those identified in this tudy. He did not recognize beach-ridge sets at the southern tip of the island and he concluded that the oldest beach-ridge sets recognized in this study, based on truncating relationships, were deposited by waves generated in Pine Island Sound and not the Gulf of Mexico.

Two beach-ridge sets have formed on La Costa "proper" since the 1860's: one on the southern border (section DD', Figs. 7 and 10) and one in the center (section BB', Figs. 7 and 9). This latter set is a "mini" cuspate headland formed tombolo-fashion behind an island on Johnson Shoal. The symmetric beach-ridge pattern of this cuspate headland indicates that it has been supplied equally by northward and southward littoral drift. Beach ridges of the set located on the southern border of La Costa "proper" have a fan-shaped pattern opening to the north, facing into the direction of littoral drift. This fan-shaped pattern results from littoral transport across a change in shoreline orientation and into a local, shallow embayment.

Five of the pre-1860 beach-ridge sets present on La Costa "proper" have fan-shaped patterns (sets 2, 4, 6, 7, and 9 of Figs. 7 and 8); northward littoral transport is indicated by all five sets. Parallel beach ridges, indicative of direct onshore transport, make up three sets (1, 5, and 8 of Figs. 7 and 8), two located on La Costa "proper" and one adjacent to Captiva Pass. Beach-ridge set 3 at the southern tip of the island (Fig. 8) contains a spit-type pattern of ridges. Beach ridges comprising the set located on the northwest tip of La Costa "proper" (unnumbered set in Figs. 7 and 8) indicate tombolo-type progradation. The beach-ridge sets preserved on La Costa Island indicate northward littoral or onshore sand transport during their construction. Only the set formed since 1860 on the southern edge of La Costa "proper" resulted from southward littoral transport.

Beach ridges making up the "mini" cuspate-headland formed between 1860 and 1950 (sections AA' and BB', Fig. 9) decrease in elevation (Hamrick Aerial Surveys, 1981c) with decreasing age. This geomorphology reflects a relatively low and continually decreasing wave energy. This situation resulted from the emergence and landward migration of small islands on Johnson Shoal, the history of which is depicted in Figures 22 and 23 of Harvey (1979). Beach

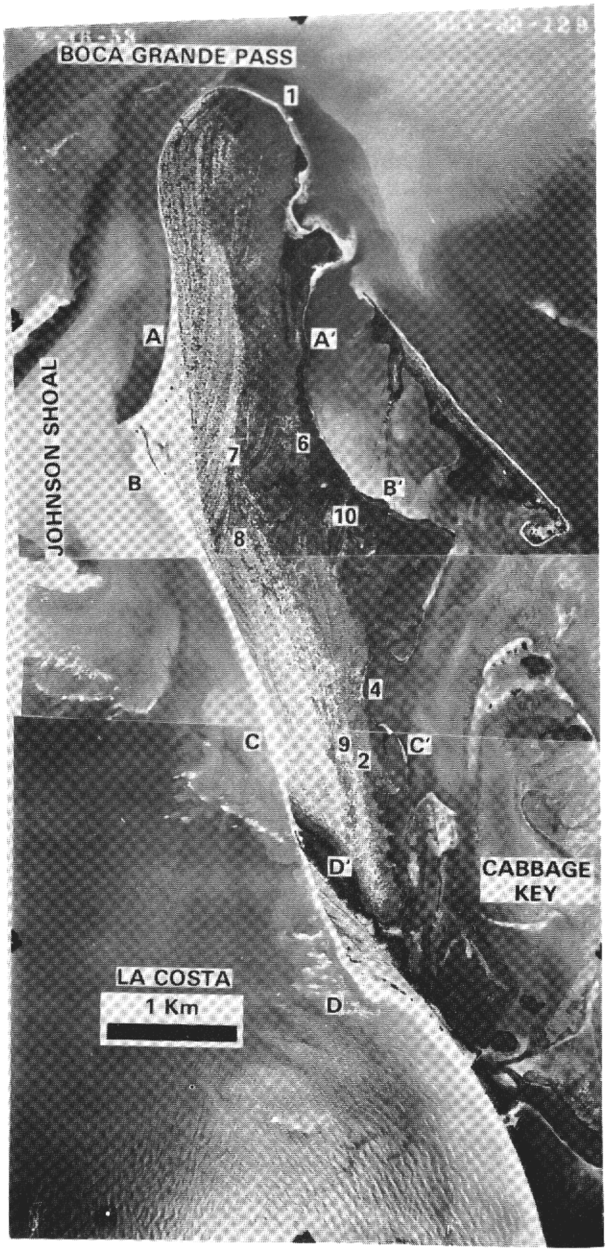

Figure 7. Uncontrolled aerial photo mosaic of La Costa Island, Lee County, Florida. The photographs were taken by the U.S. Department of Agriculture in 1953. Shells were collected for radiocarbon dating from the numbered localities. Topographic cross-sections were constructed along the lettered lines from commercial photo-topographic maps.

ridges built during this same period at the southern edge of La Costa "proper" (section DD', Fig. 10) that face the open Gulf of Mexico show no systematic decrease in elevation. They have an average elevation of about 5 feet MSL (Hamrick Aerial Surveys, 1981b). These two beach-ridge sets illustrate the control of wave energy on beach-ridge elevation.

Beach-ridge sets 3, 4, 6, 9, and 10 are low in elevation compared with sets 1, 2, 5, 7, and 8. The low sets have average elevatiuons of 2 to 4 feet and the high sets 6 to 8 feet above MSL (see Figs. 9 and 10). The low sets are partially covered by mangroves and marsh vegetation. All sets have relatively widely spaced beach ridges.

Mollusk shells were collected for radiocarbon dating at ten of the eleven beach-ridge sets constructed prior to 1860, sampling sites 1-10 of Figures 7 and 8. Lithified calcarenites exposed in low sea-cliffs were sampled at sites 1, 4, and 5; the remaining sites were sampled by shallow pits. Suites of the most robust and unweathered shells were collected at each site, usually *Mercenaria sp., Strombus alatus, Dinocardium robustum, Busycon sp.*, and *Noetia ponderosa*. Articulated *Spisula raveneli* were found at sites 1, 3, and 5. The radiocarbon dates determined on individual mollusk shells collected at these ten sites are found in Appendix Tables 4 through 13.

Beach-ridge sets 10, 4, and 6 are the oldest sets present on La Costa "proper," based on truncating relationships. The writers considered these ridges to have been formed facing the open Gulf of Mexico and not Pine Island Sound, as interpreted by Herwitz (1977) and Harvey (1979). Beach-ridge set 10, the oldest, was deposited 3000 BP, Appendix Table 4. The very small range in ages indicates that reworking was minimal. Beach-ridge set 4, the next oldest, was also deposited 3000 BP, Appendix Table 5, based on the cluster of overlapping ages at the younger end of the 1500-year range of dates. However, the 1500-year range in ages indicates that reworking of previously deposited shells was significant. The synchroneity with set 10 deposition is apparent, reflecting the 150-300 year range of precision of radiocarbon dating. Beach-ridge set 6 was deposited 2000 BP, Appendix Table 6. Again, reworking was a factor as evidenced by the 700-year range of the dates. These sets are assigned to the informal time-stratigraphic unit Sanibel I, those beach ridges deposited 3000 to 2000 BP.

Beach-ridge set 1 was deposited approximately 1700 BP, Appendix Table 7, based on the cluster of overlapping ages at the younger end of the 3000-year range of dates. Articulated *Spisula raveneli* collected at site 1 have a 900-year range, indicating that reworking was a factor even in these specimens. Storms scouring a long-existing sand shoal could supply articulated mollusks of differing ages for incorporation into prograding beach ridges. These data are an indication not only of the age of Johnson Shoal but also of its importance as a sediment source for La Costa Island. These ridges have elevations ranging up to 8 feet with average elevations between 5 and 6 feet (Hamrick Aerial Surveys, 1981e). The parallel pattern of these beach ridges indicates direct onshore transport during their deposition.

Beach-ridge set 2 was deposited no earlier than 1700 BP, Appendix Table 8. This age of deposition is only a maximum estimate because there is no cluster of overlapping ages at the younger end of the 900-year range of dates found at this locality. The beach-ridge pattern indicates northward littoral transport. Beach-ridge sets 1 and 2 are assigned to the informal time-stratigraphic unit Wulfert, those beach ridges deposited 2000 to 1500 BP.

Beach-ridge set 9 was deposited 1100 BP, Appendix Table 9, based on the cluster of overlapping ages at the younger end of the spectrum of dates reported at this locality. The 2800-year range of ages demonstrates that reworking of previously deposited shells was a significant factor. The beach-ridge pattern reflects northward littoral transport. These beach ridges are assigned to the informal time-stratigraphic unit Buck Key, those ridges ldeposited 1500 to 1000 BP.

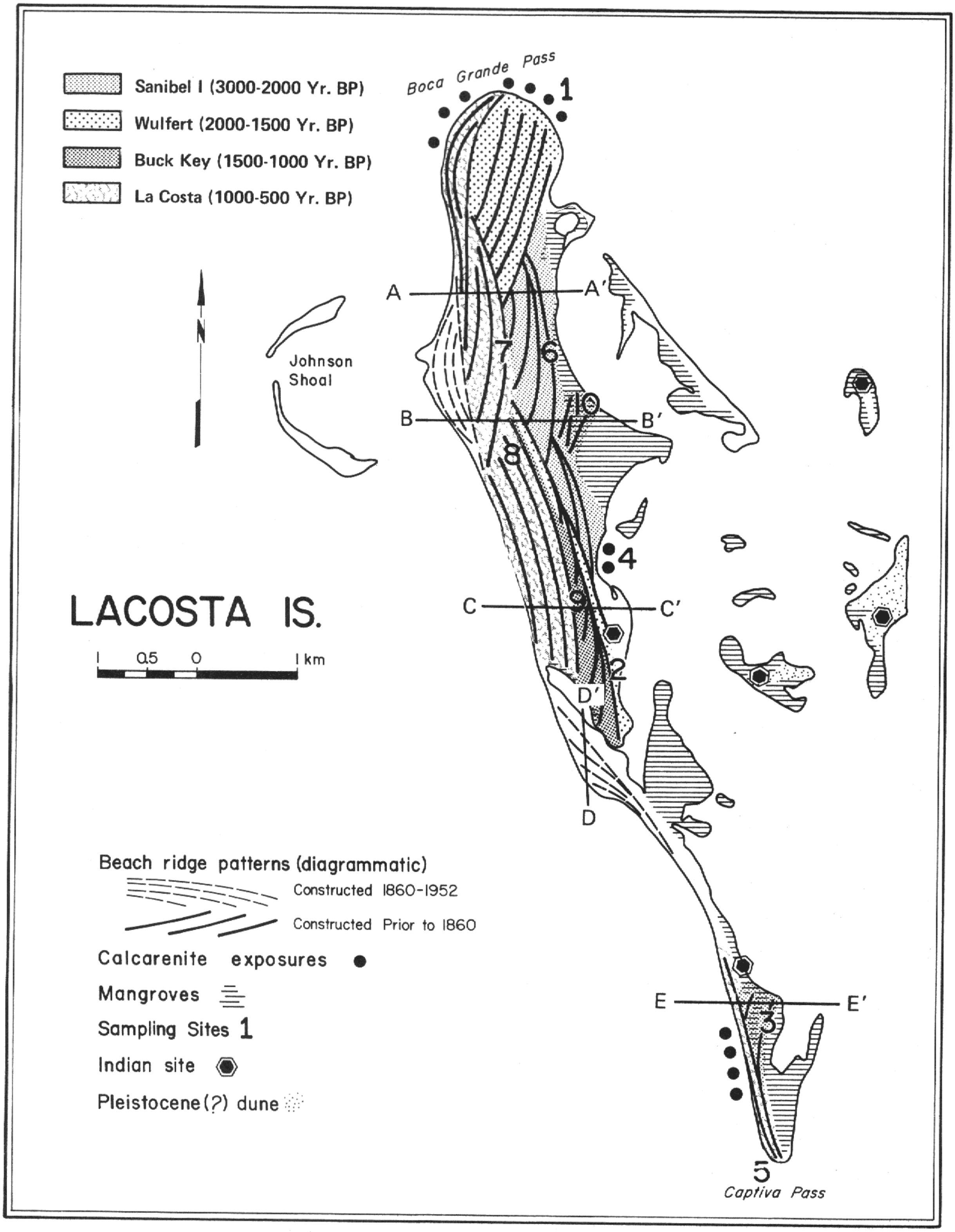

Figure 8. The radiocarbon chronology of beach-ridge sets preserved on La Costa Island, Lee County, Florida. Beach-ridge patterns are diagrammatic within the various sets and were mapped from 1944 U.S. Department of Agriculture aerial photography. Topographic cross-sections AA' through EE' were made from Hamrick Aerial Surveys (1981) photo-topographic maps with a 1 foot contour interval (see Figures 9 and 10). The designations Sanibel I, Wulfert, Buck Key, and La Costa are informal time- stratigraphic units. Eighty-seven radiocarbon dates of individual shells from ten localities are the basis for the chronology of this island.

Beach-ridge set 8 was deposited approximately 1000 BP, Appendix Table 10. This age should be regarded as a maximum estimate given that the younger dates obtained at this site do not form an overlapping cluster. The parallel beach-ridge pattern indicates direct onshore transport. Beach-ridge set 8 is used to define the informal time-stratigraphic unit La Costa, those beach ridges constructed 1000-500 BP. This unit can be identified on Gasparilla Island,, North Captiva Island, South Captiva Island, Sanibel Island, and Siesta Key.

Set 7 truncates set 8 and thus is younger. However, its youngest shell indicates a depositional age of 1300 BP, Appendix Table 11. The lack of a cluster of overlapping dates at the younger end of the 1300-year range argues that reworking has not been adequately accounted for and thus the youngest date is only a maximum estimate of the depositional age. The beach-ridge pattern reflects northward littoral transport.

The southern third of La Costa Island is a very recent addition to La Costa "proper." Two now-filled passes separated beach-ridge sets 3 and 5 from La Costa "proper": Murdock Bayou landward of beach-ridge set DD' and an unnamed pass immediately northward of beach-ridge set 5 --see Herwitz (1977) and Havey (1979) for discussion. Beach-ridge set 3 was constructed 2000 BP, Appendix Table 12, based on a cluster of overlapping ages at the younger end of the spectrum reported for this locality. Reworking was a factor not only in the disarticulated shells but also in the articulated *Spisula raveneli* as well. This set represents the northern spit-like tip of a barrier that extended across what is now Captiva Pass. Beach-ridge set 3 is assigned to the informal time-stratigraphic unit Sanibel I, those beach ridges deposited 3000 to 2000 BP.

Beach-ridge set 5 was formed 1100 BP, Appendix Table 13, and is the remnant of a set that also extended across what is now Captiva Pass. This set is assigned to the informal time-stratigraphic unit La Costa, those beach ridges deposited 1000 to 500 BP. Beach-ridge set 5 indicates that Captiva Pass was cut subsequent to 1000 BP.

The beach-ridge sets of La Costa "proper" indicate a history of alternating deposition and erosion with sediment being supplied by direct onshore and northward littoral transport. Johnson Shoal appears to have existed throughout the 3000-year history of this island although present-day Captiva Pass probably dates back to no more than 1000 BP. This suggests that Johnson Shoal may be primarily a relict Pleistocene sand mass, a hypothesis somewhat supported by the existence of Pleistocene dunes on adjacent Useppa island and Cabbage Key. Three major fluctuations in sea level and/or energy condition are suggested by these beach-ridge sets: 1. a rise-increase at about 2000 BP, 2. a fall-decrease subsequent to 1700 BP (beach-ridge set 2) and prior to 1100 BP (beach-ridge set 9), and 3. a rise-increase at about 1000 BP back to present-day position and/or energy condition.

North Captiva Island

The progradational beach-ridge sets present on North Captiva Island are located adjacent to the Captiva Pass ebb-tidal delta (Figs. 1 and 11). This shoal is both the primary sediment source and the low-energy shadow that promotes shoreline deposition. Over the past 100 years shifting tidal currents have created localized areas of ewrosion and deposition (Fig. 22 of Harvey, 1979). The remainder of North Captiva is a narrow, eroding barrier with washover fans projecting eastward into Pine Island Sound. A hurricane in 1921 cut Redfish Pass and separated the original Captiva into North and South (Harvey, 1979). The Redfish Pass ebb-tidal delta serves as the deposition site for littoral drift approaching from both north and south (Harvey, 1979).

Three beach-ridge sets make up this barrier island, identified in Figures 11 and 12 by the localities 1,2, and 3. A canal bank provides a 500-m long continuous exposure of swash- zone laminations--planar, gently dipping--that make up the portions of beach-ridge sets 1 and 2 above MSL. Mollusk shells were collected along this exposure for radiocarbon dating.

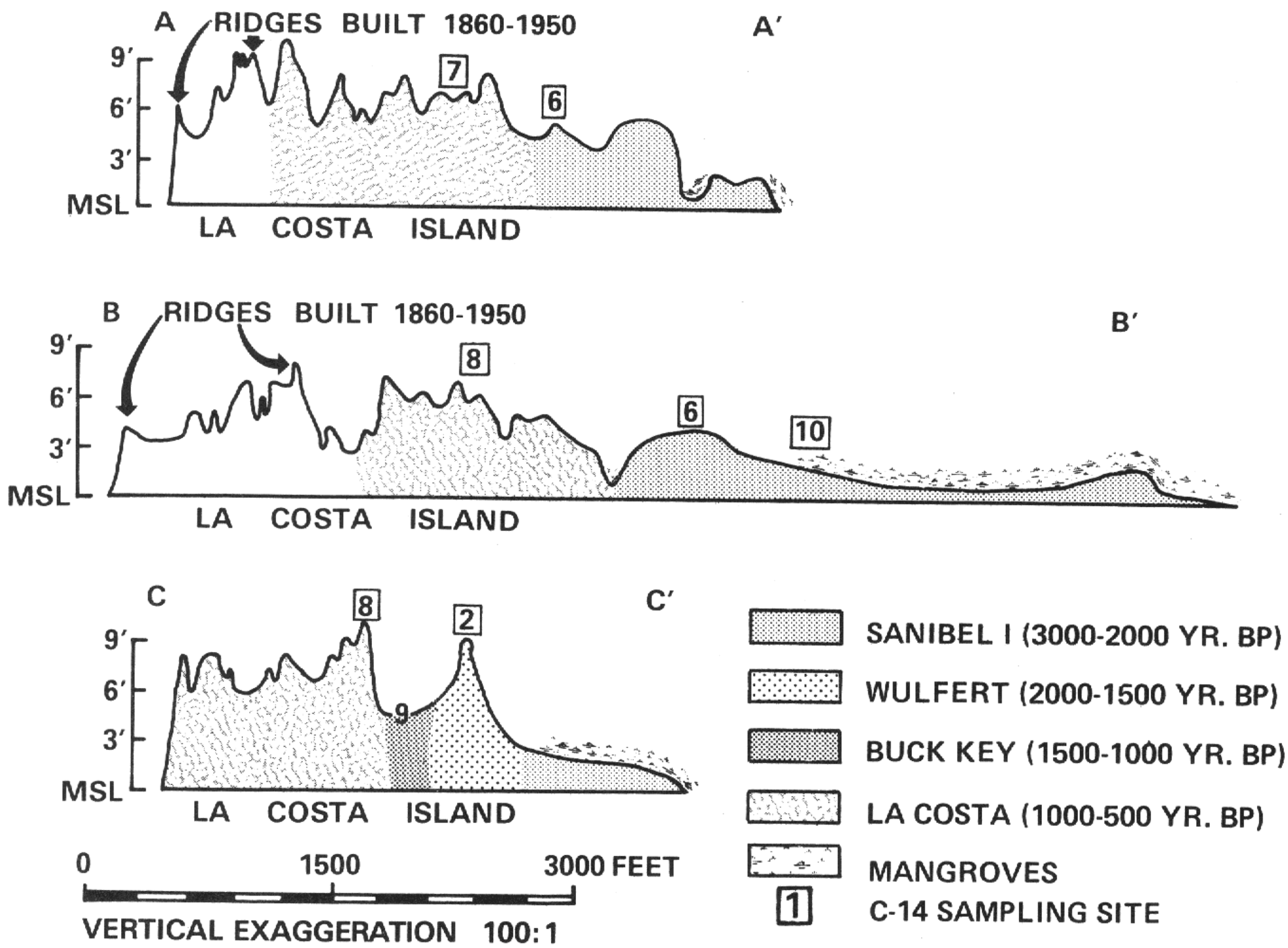

Figure 9. Topographic cross-sections of La Costa Island prepared from Hamrick Aerial Surveys (1981) photo-topographic maps with a 1-foot contour interval. The Gulf of Mexico is to the left and Pine Island Sound is to the right. The locations of these sections are shown in Figures 7 and 8.

The oldest set, labeled 1 in Figs. 11 and 12 is very small in geographic extent and rather narrow, essentially an erosional remnant. It has an average elevation of slightly over 3 feet (section FF', Fig. 10). This beach-ridge set was deposited approximately 1300 BP, Appendix Table 14. Shells reworked from older deposits are a significant factor at this locality. However, there is a cluster of overlapping ages at the younger end of the 3000-year range of ages. This set is assigned to the informal time-stratigraphic unit Buck Key, those beach ridges deposited 1500 to 1000 BP. This beach-ridge set in all likelihood extended to the north across the area that is now Captiva Pass.

Beach-ridge set 2 makes up the bulk of the North Captiva beach-ridge plain. Beach ridges are 5 to 6 feet in average elevation (section FF', Fig. 10). These beach ridges form a cuspate headland pattern that suggests tombolo-like growth toward the Captiva Pass ebb-tidal delta. The twenty individual shells radiocarbon-dated from this locality yield a 4200-year range of ages, Appendix Table 15. The lack of a cluster of overlapping ages at the younger end of the spectrum of disarticulated shell dates suggests that the age of deposition is younger than 1900 BP. This suggestion is confirmed by the articulated *Spisula raveneli* dates that indicate deposition began about 600 BP. Reworking was a very significant factor at this locality and can be recognized in the articulated as well as the disarticulated specimens. This beach-ridge set is assigned to the informal time-stratigraphic unit La Costa, those beach ridges deposited between 1000 and 500 BP. There was a sea-level rise and/or energy-condition increase up to that of present day between the formation of sets 1 and 2.

Beach-ridge set 3 is located on the northeastern tip of North Captiva and faces Pine Island Sound. These parallel ridges are low lying with maximum elevations between 2.5 and 3.5 feet, Hamrick Aerial Surveys (1981f). In addition, the ridges are more closely spaced, with smaller wave lengths, than are the ridges of set 2. Set 3 ridges were constructed by waves coming across Pine Island Sound and from sand transported directly onshore. The sediment source is an adjacent sub-tidal flat of the Captiva Pass flood-tidal delta. This set postdates the formation of beach- ridge set 2.

Captiva Pass was cut sometime between 1300 and 600 BP, either by the enlargement of a pre-existing minor channel or by the separation of a narrow barrier island. The 2000 BP set 3 of the adjacent southern tip of La Costa Island (Fig. 8) and the 1300 BP set 1 of North Captiva demostrate that islands existed in this location prior to the cutting of Captiva Pass. The reworked shells found at these sites adjacent to Captiva Pass indicate that Holocene coastal deposition in this immediate vicinity dates to 4800 BP.

Buck Key

This small, low-lying key is located immediately eastward of South Captiva Island across the 200-m wide Roosevelt Channel--see Figures 1 and 13 for location. Beach ridges average between 3 and 4 feet in elevation, section HH' of Fig. 15. Buck Key is fringed with mangroves that also extend inland along drainage ditches dug for mosquito control. A complex history of episodic deposition and erosion can be inferred from the occurrence of at least five distinct beach-ridge sets. The fan-shaped and parallel beach-ridge patterns indicate southward littoral and direct onshore sediment transport, respectively.

Spoil from a shallow drainage ditch was sampled for mollusk shells at one of the younger beach-ridge sets preserved on Buck Key, locality 1 of Figs. 13 and 14. Deposition of this set occurred 1200 BP, Appendix Table 16, based on the cluster of overlapping dates at the younger end of the 1800-year range reported at this locality. The rest of Buck Key is slightly older. Shells from deposits up to 3000 BP were reworked during the formation of this beach-ridge set. These sets formed on top of an emergent shoal (Otvos, 1981), as opposed to spit migration or the

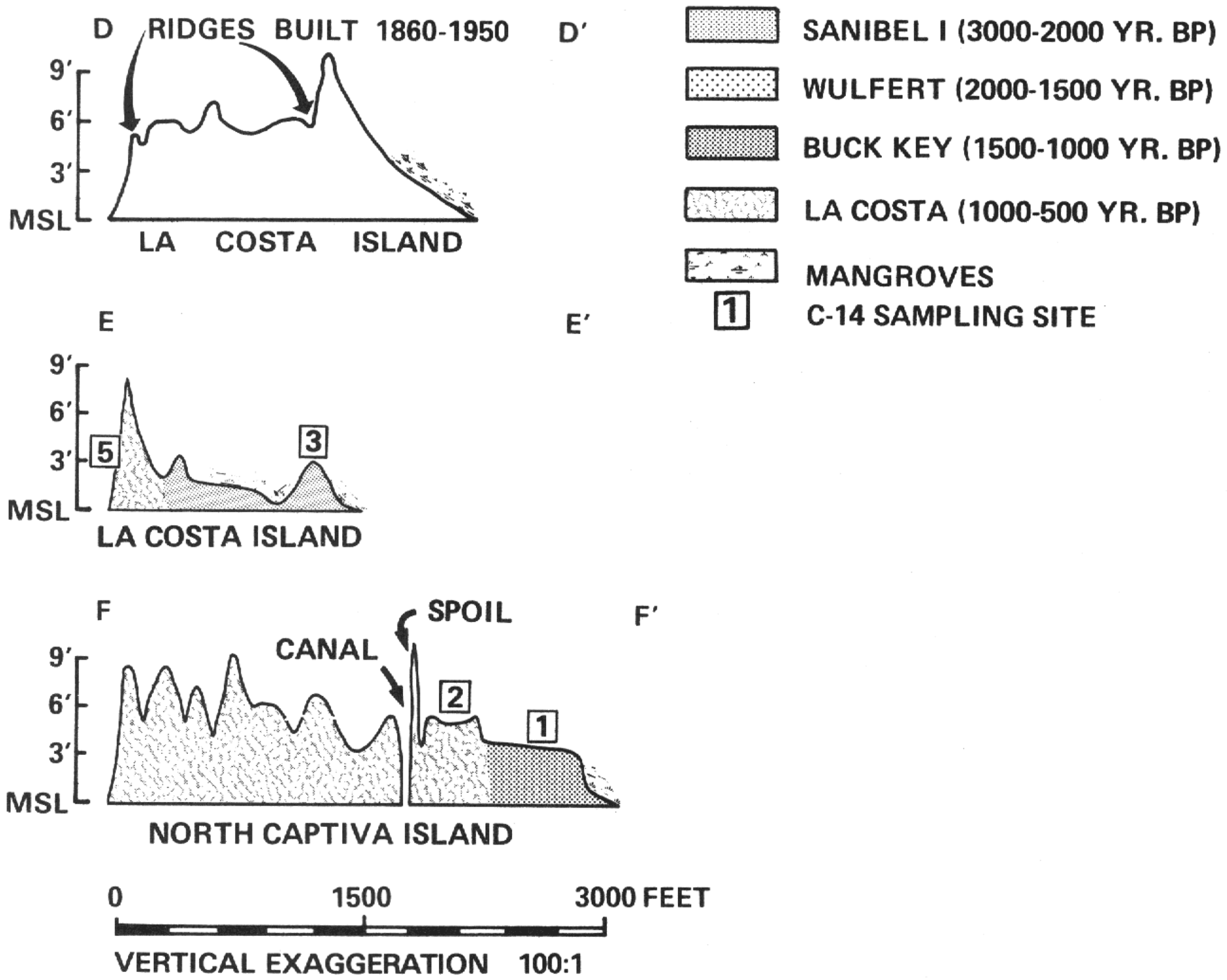

Figure 10. Topographic cross-sections of La Costa and North Captiva Islands prepared from Hamrick Aerial Surveys (1981) photo-topographic maps with a 1-foot contour interval. The Gulf of Mexico is to the left and Pine Island Sound is to the right. The locations of these sections are shown in Figures 8 and 12, respectively.

drowing of an existing dune ridge. These beach-ridge sets are used to define the informal time-stratigraphic unit Buck Key, those beach ridges deposited 1500-1000 BP. This unit can be identified on Gasparilla, La Costa, North Captiva and Sanibel Islands and may be present on South Captiva Island.

South Captiva Island

This relatively narrow barrier island consists of three beach-ridge sets, Figs. 13 and 14. Presently the northern third ìof South Captiva is undergoing marked coastal erosion: 300 m of shoreline retreat occurred between 1926 and 1967 (Harvey, 1979) and approximately 10 million cubic meters of sand were removed between 1880 and 1960 (Silberman, 1979). Sand removed from this eroding beach is transported: 1) north to the Redfish Pass tidal deltas, 2) south to migrating spits at Blind Pass, and 3) offshore. A sand budget prepared by comparing the 1880 and 1960 bathymetric charts indicates that only 60% of the eroded material is retained within the littoral zone, being largely transported to and deposited on Sanibel Island; 40% is assumed lost offshore (Silberman, 1979).

The northernmost and oldest beach-ridge set contains parallel beach ridges, indicative of directg onshore sediment transport, that have elevations ranging up to 3 feet (Hamrick Aerial Surveys, 1981g). A 1000 BP aboriginal shell midden (Calvert et al., 1978) is located in the southeastern corner of this set (Fig. 14), adjacent to Pine Island Sound. This set predates the shell midden and probably dates to either 3000 to 2000 BP (Sanibel I) or 1500 to 1000 BP (Buck Key).

The next youngest beach-ridge set, number 2 in Figs. 13 and 14 contains spit-type beach ridges that record a southward migration. These ridges have average elevations between 4 and 5 feet MSL, section GG' of Fig. 15. Deposition occurred bout 600 BP, Appendix Table 17. This should be considered only a maximum estimate as there is no cluster of overlapping dates at the younger end of the 3600-year range reported at this locality. Reworking of shells from older deposits was a significant factor at this locality. The spit-type patter clearly indicates continual erosion of previously deposited beach ridges to provide material for subsequent ones. There was a rise in sea level and/or increase in energy condition up to those of present day between the formation of the northern set and set 2.

The youngest beach-ridge set preserved on South Captiva Island, number 3 in Figs. 13 and 14, is composed of parallel beach ridges with a slight spit-type curvature at their southern ends. This geometry suggests a significant onshore component of sand transport. These ridges average between 5 and 7 feet MSL, section HH' of Fig. 15, and were deposited about 500 BP, Appendix Table 18. This is only a maximum estimate as there is no cluster of overlapping dates at the younger end of the 2100-year range of ages reported at this locality. The 2100-year range of dates indicates that reworking of shells from older deposits was a significant factor. The 16,500 BP date (QC-1205 of Appendix Table 18) may actually represent a "dead" Pleistocene shell contaminated with analytically undetectable abounts of modern carbon. Sea-level position and/or energy condition were at least equal to that of present-day during the deposition of this beach-ridge set. Sets 2 and 3 are assigned to the informal time- stratigraphic unit La Costa, those beach ridges deposited 1000 to 500 BP.

Three distinct depositional events and one fluctuation in sea-level position and/or energy condition are recorded by the beach-ridge sets preserved on South Captiva Island. The oldest set (the northern one) was formed on an emerging shoal by means of onshore or landward sediment transport, identical to the formation of Buck Key. The major Holocene depositional sites of La Costa and Sanibel Islands are located north and south, respectively, of this area. Captiva Island, a relatively narrow and long barrier, represents the amalgamation of isolated island masses scattered along the seaward margin of a major shoal. This amalgamation is

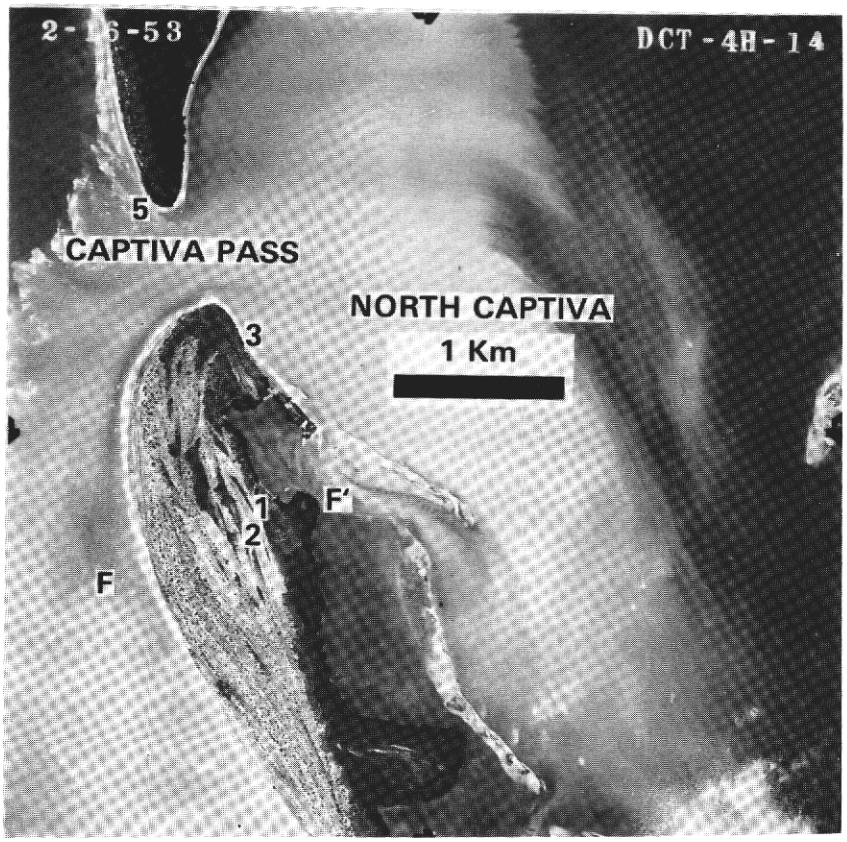

Figure 11. Aerial photo of North Captiva Island, Lee County, Florida. The photograph was taken by the U.S. Department of Agriculture in 1953. Shells were collected for radiocarbon dating from numbered localities 1 and 2. A topographic cross- section was constructed along the lettered line FF' from commercial photo-topographic maps.

accomplished by littoral drift and washover migration and inhibited by the cuttin of passes by major storms, i.e., Redfish Pass cut during the 1921 hurricane.

Sanibel Island

Sanibel is the largest Holocene barrier island in southwest Florida and also one of the most low-lying, the bulk of the island being about 3-feet MSL. Over the past 125 years, the period covered by accurate maps and charts, Sanibel has been one of the most stable barriers in southwest Florida (Missimer, 1973b; Banks, 1975). During this period three separate spits migrated southeastward from South Captiva Island across Blind Pass (Fig. 16), attached themselves to the northwestern shore of Sanibel and were eventually breached updrift (Harvey, 1979). As a result of this spit migration and attachment, the northwestern shore of Sanibel adjacent to Blind Pass has prograded seaward approximately 2000 feet. Sanibel Island beach ridges are orientated east-west; only those ridges adjacent to Blind Pass have the northwest-southeast orientations characteristic of beach ridges present on all other southwest Florida barrier islands. This represents the major change in shoreline orientation in southwest Florida and could reflect a fault system aligned northeast-southwest along the Caloosahatchee River with Sanibel Island located on the upthrown block (Bond et al., 1981).

Missimer (1973) identified ten separate beach-ridge sets on Sanibel Island based on the erosional truncation of one set by another. His basic stratigraphy can be recognized in the beach-ridge sets shown diagrammatically in Figure 18. However, more than ten distinct beach-ridge sets have been identified in this study. Beach-ridge patterns indicate eastward littoral and direct-onshore sediment transport.

Fan-shaped beach-ridge sets opening to the west (localities 2, 7, and 6 in Figs. 17 and 18) and spit-type sets curving to the northeast (localities 4 and 5 in Figs. 17 and 18) indicate eastward-directed littoral sand transport. Parallel beach ridges (localities 1, 3, and 9 in Figs. 17 and 18) indicate direct onshore sand transport. The oldest preserved beach-ridge sets (between localities 1 and 8, Figs. 17 and 18) reflect primarily direct-onshore sediment transport with a minor component of eastward-directed littoral transport. Sand transport during the construction of the next oldest sets (localities 2,4,5, and 7 in Figs. 17 and 18) was primarily by eastward-directed littoral drift. The youngest east-west orientated sets (localities 6 and 9 in Figs. 17 and 18) reflect primarily a direct-onshore sand transport. Sand was transported directly onshore during construction of the two oldest sets adjacent to Blind Pass (locality 3 in Figs. 16 and 18). The younger sets reflect southeastward-directed littoral transport across Blind Pass. The significant sediment source for Sanibel Island appears to have moved from west to south during the construction of the island.

The Sanibel Island beach-ridge set with the highest elevation is that of locality 3 (section II' in Fig. 15), the Wulfert Ridge of Missimer (1973), which rises to 9 feet MSL (Bosworth Aerial Surveys, 1976). Swash-zone laminations (Fig. 4) characterize the internal structure of this ridge (Missimer 1973b). Unfortunately the 1976 phototopographic maps cannot be used in most parts of Sanibel because they were made after the island's original topography had been significantly modified by development projects. The beach-ridge sampled at locality 6 rises to 7 feet MSL (Bosworth Aerial Surveys, 1976b). Several sets resulting from spits migrating southeastward across Blind Pass within the past 125 years have elevations above 5 feet MSL. The remainder of the island is low-lying with elevations typically reaching only 3 feet MSL.

Mollusk shells were collected at nine localities for radiocarbon dating. Spoil removed from shallow ditches and canals was sampled at localities 2, 4, 5, 6, and 7. The walls of a borrow pit 2-m deep were sampled at locality 3. A 0.5-m high road-cut was sampled at locality 9 and a shallow pit was dug at locality 1. At each locality the largest, most robust shells were collected.

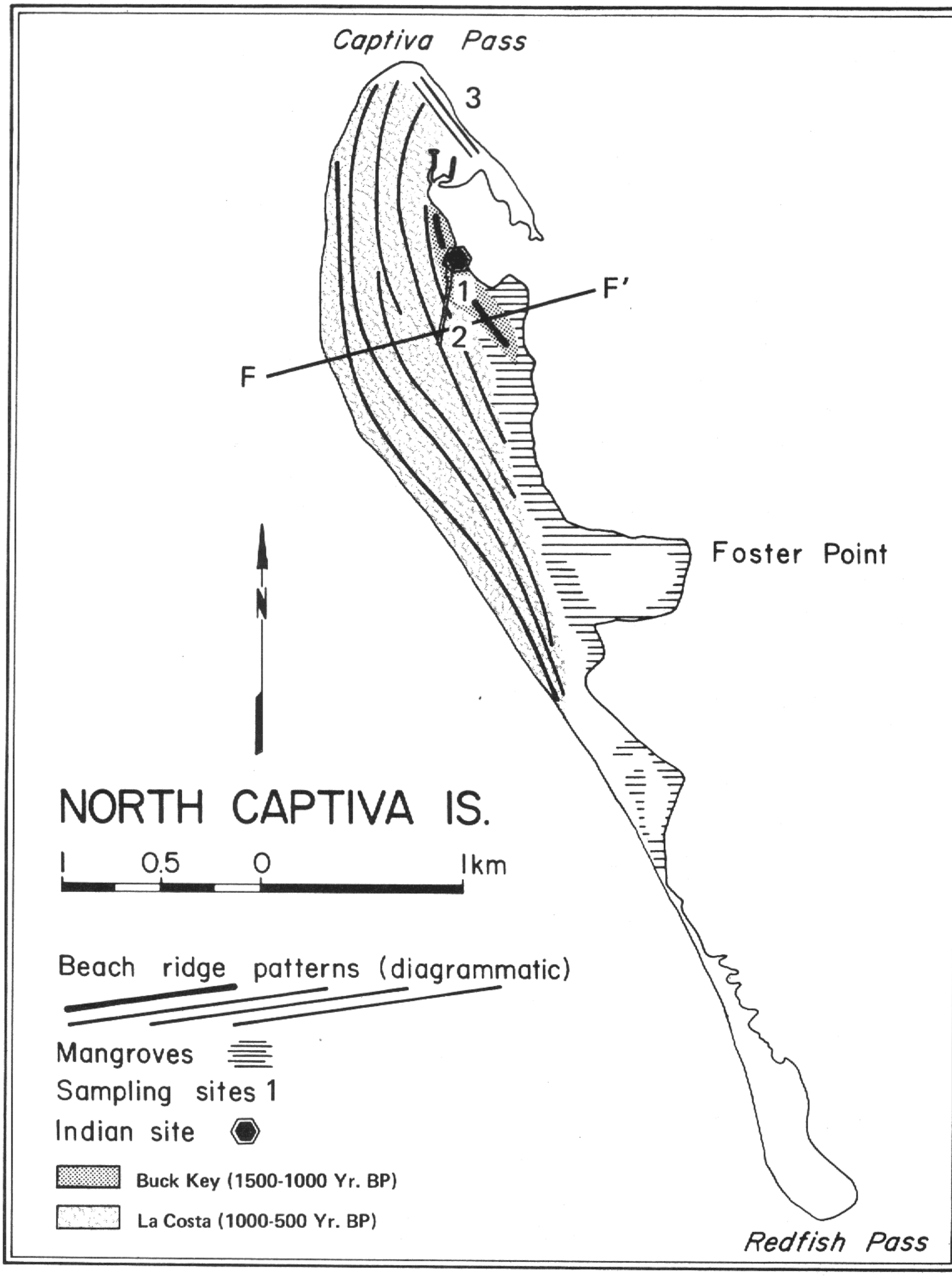

Figure 12. The radiocarbon chronology of beach-ridge sets present on North Captiva Island, Lee County, Florida. Beach- ridge patterns are diagrammatic within the various sets and were mapped from 1944 U.S. Department of Agriculture aerial photography. Topographic cross-section FF' was made from Hamrick Aerial Surveys (1981) photo-topographic maps with a 1-foot contour interval (see Figure 10). The designations Buck Key and La Costa are informal time-stratigraphic units. Twenty-nine radiocarbon dates of individual shells collected at two localities are the basis of the chronology of this island.

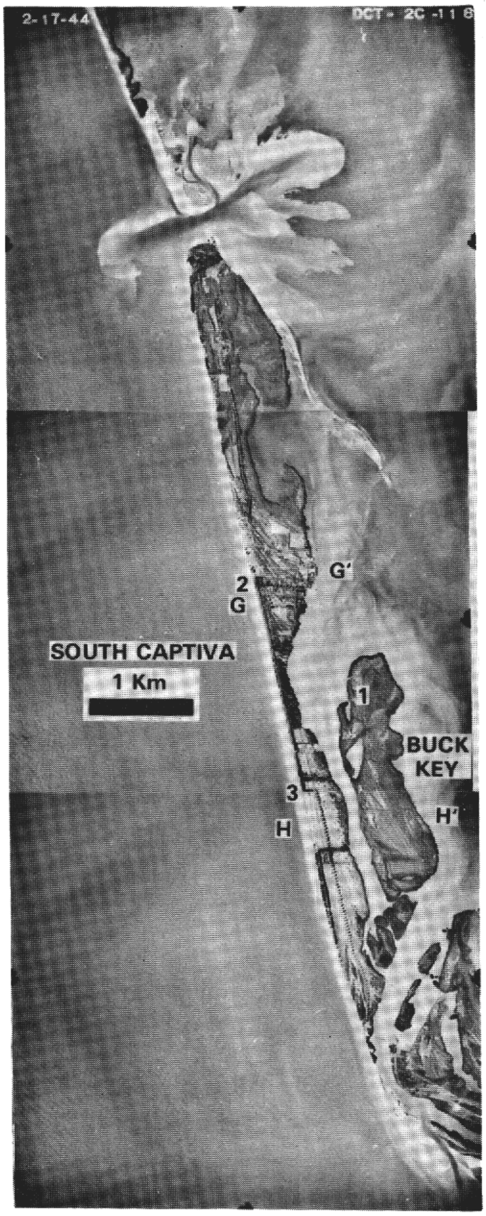

Figure 13. Uncontrolled aerial photo mosaic of Buck Key and South Captiva Islands, Lee County, Florida. The photographs were taken by the U.S. Department of Agriculture in 1944. Shells were collected for radiocarbon dating from the numbered localities. Topographic cross-sections were constructed along the lettered lines from commercial photo-topographic maps.

Radiocarbon dates obtained on shells collected at these nine localities are listed in Appendix Tables 19 through 27.

The oldest preserved beach-ridge set on Sanibel Island was deposited approximately 3000 BP (Appendix Table 19). This age is a maximum estimate only, there being no cluster of overlapping ages at the younger end of the 3400-year spectrum reported for this locality. Reworking of shells from older deposits was a significant factor. The beach-ridge set sampled at locality 8 was deposited 2700 BP (Appendix Table 20). Although reworking of older shells is indicated by the 3000-year range of dates, there is a cluster of overlapping dates at the younger end. This 2700- year age indicates fairly rapid deposition for the beach-ridge sets between localities 8 and 1. In addition, these sets reflect primarily a direct-onshore sand transport during their construction.

A change to eastward-directed littoral sand transport is indicated by the beach-ridge patterns of the sets sampled at localities 2, 4, and 5. Locality 2 was deposited approximately 2200 BP. However, this is only a maximum estimate as there is no cluster of overlapping dates at the younger end of the 1100-year spectrum obtained at this locality (Appendix Table 21). Locality 4 was deposited approximately 2000 BP. This is also only a maximum estimate as there is no cluster of overlapping dates at ìthe younger end of the 2500-year spectrum reported for this site (Appendix Table 22). Locality 5, the youngest of the three, was deposited 1800 BP. There is a cluster of overlapping dates at the younger end of the 1600-year spectrum determined at this site (Appendix Table 23). Reworking of older shells was a significant factor at all of these localities. Samples QC-1241 and QC-1245 (locality 2, Appendix Table 21) probably represent "dead" Pleistocene shells contaminated with very small amounts of modern 14C rather than 30,000-year-old shells (Broecker, 1965; Olsson, 1968; Morner, 1971; Stapor and Tanner, 1973). These beach-ridge sets may have been deposited in no more than 400 years.

The beach-ridge sets containing localities 1, 8, 4, and 5 are partially covered with mangroves, both red and black, and are locally well within the uppermost portion of the present intertidal zone. The beach-ridge set containing locality 2 is largely covered with fresh-water marsh vegetation. These sets are geographically widespread and contain laterally continuous beach-ridge patterns indicative of major depositional sites. Beach-ridge sets containing localities 1, 8, 2, 4, and 5 are used to define the informal time-stratigraphic unit Sanibel I, those beach ridges deposited bewtween 3000 and 2000 BP. This is the oldest unit preserved on Holocene barrier-islands in southwest Florida. It has been identified on Gasparilla, La Costa, and Marco Islands and inferred to exist on Siesta Key, Sarasota Co., Florida.

The Wulfert Ridge, the beach-ridge set sampled at locality 3 (Figs. 17 and 18), was deposited 2000 BP (Appendix Table 24), subsequent to the deposition of beach-ridge sets containing localities 2, 4, and 5. The 3300-year spectrum of dates from this locality indicates that reworking of older shells was a significant factor. However, the cluster of overlapping dates at the younger end of this spectrum confirms the 2000 BP age reported by Missimer (1973) from two samples (UM-100 and UM-67 in Appendix Table 24). Sand was transported directly onshore during the construction of the Wulfert beach-ridge set. This beach- ridge set is used to define the informal time-stratigraphic unit Wulfert, those beach ridges deposited during the period 2000-1500 BP. It has been identified on Siesta Key, Sarasota Co., Florida, and La Costa Island.

The presence of swash-zone laminae in the Wulfert set 1 up to 1.5 m above the crest of beach ridges formed over the past 100 years argues for deposition at a sea-level position significantly above that of present day. The Wulfert time-stratigraphic unit records two major fluctuations in sea-level position and/or energy condition, a rise-increase at about 2000 BP followed by a fall-decrease at about 1500 BP.

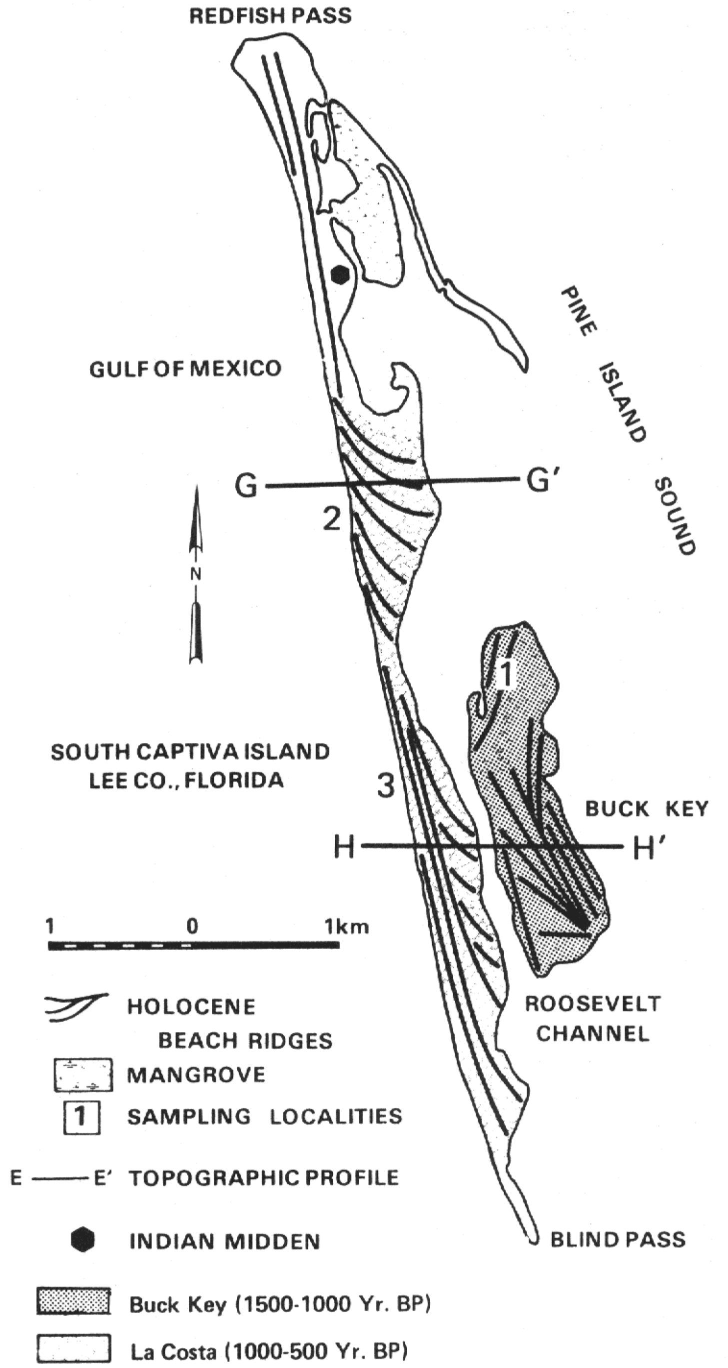

Figure 14. The radiocarbon chronology of beach-ridge sets present on Buck Key and South Captiva Island, Lee County, Florida. Beach-ridge patterns are diagrammatic within the various sets and were mapped from 1944 U.S. Department of Agriculture aerial photography. Topographic cross-sections GG' and HH' were made from Hamrick Aerial Surveys (1981) photo- topographic maps with a 1 foot contour interval (see Figure 15). The designations Buck Key and La Costa are informal time- stratigraphic units. Twenty-seven radiocarbon dates of individual shells collected at three localities are the basis of the chronology of this island.

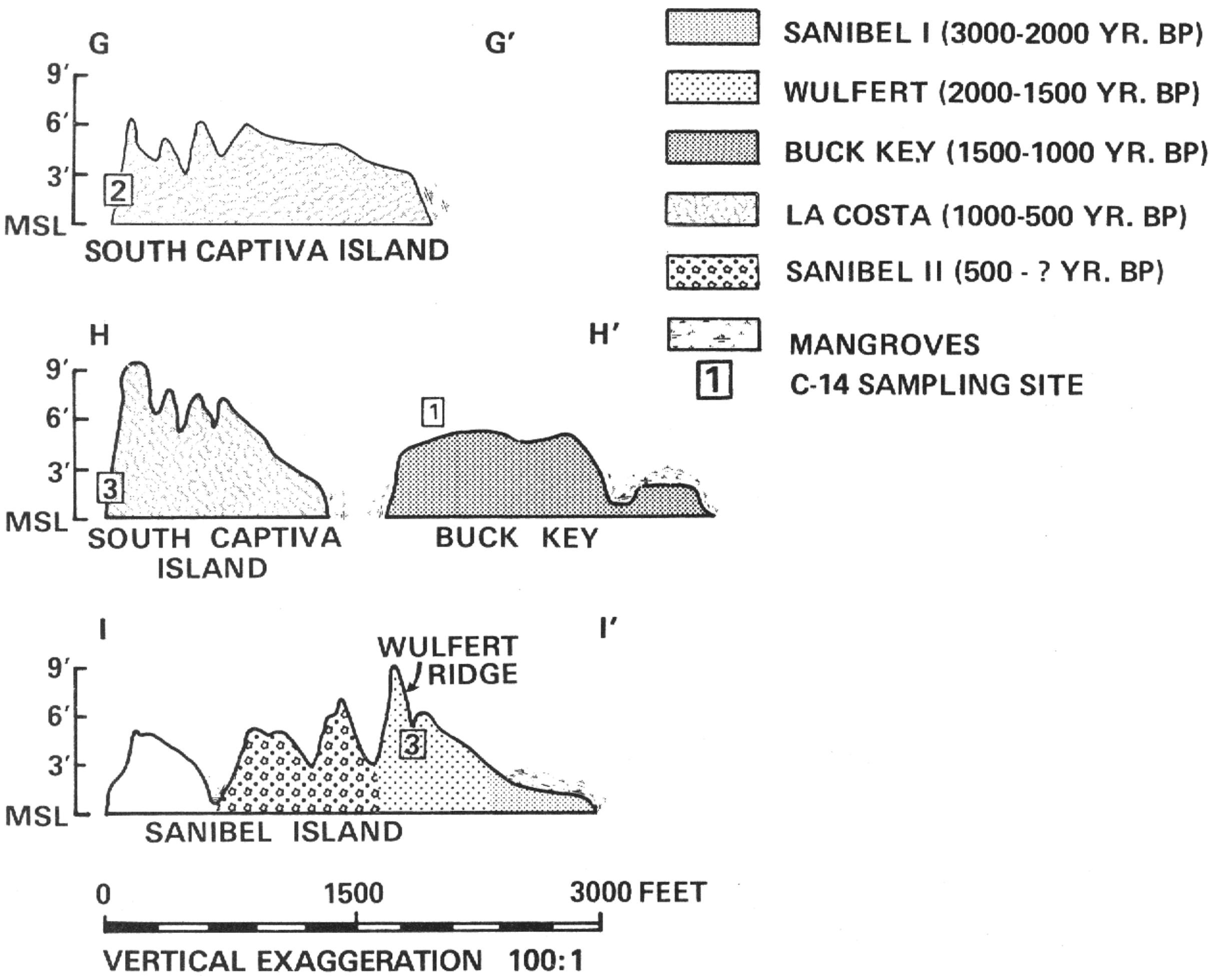

Figure 15. Topographic cross-sections of Buck Key-South Captiva and Sanibel Islands prepared from Hamrick Aerial Surveys (1981) and Bosworth Aerial Surveys (1976) photo-topographic maps with a 1-foot contour interval. The Gulf of Mexico is to the left and Pine Island Sound is to the right. The locations of these sections are shown in Figures 14 and 18.

The beach-ridge set sampled by locality 7 was deposited 1000 BP (Appendix Table 25). Reworking of older shells was significant, but there is a cluster of overlapping dates at the younger end of the 2000-year spectrum reported for this locality. These beach ridges were constructed primarily by eastward-ldirected littoral drift. This low-lying set is largely covered by fresh-water marsh vegetation. It is geographically widespread and is composed of laterally continuous beach-ridges, factors characteristic of a major deposition site. These ridges are assigned to the informal time-stratigraphic unit Buck Key, those beach ridges deposited 1500 to 1000 BP.

The beach ridge sampled at locality 6 was deposited 700 BP (Appendix Table 26). Reworking of older shells was a significant factor at this locality; however, there is a cluster of overlapping dates at the younger end of the3500-year spectrum. These beach ridges rise to nearly 7-feet MSL and are the highest elevations on Sanibel Island outside of the Wulfert Ridge. A major rise in sea level and/or increase in energy condition to that of present day occurred before deposition of these beach ridges. This set is assigned to the informal time-stratigraphic unit La Costa, those beach ridges deposited 1000 to 500 BP.

The beach-ridge set sampled by locality 9 was deposited prior to 400 BP (Appendix Table 27) and subsequent to 700 BP (the age of locality 6). Reworking of older shells was significant at this site; however, there is a cluster of overlapping dates at the younger end of the 4200-year spectrum. Sand was primarily transported directly onshore during the construction of the beach-ridge set sampled at locality 9 and, most likely, at locality 6 as well. This represents a major change in sediment source back to a southern from the eastern source inferred from the beach-ridge sets sampled at localities 2,4,5, and 7. The beach-ridge set sampled at locality 9 is used to define the informal time-stratigraphic unit Sanibel II, those beach ridges deposited subsequent to 500 BP and prior to the period covered by historic maps. This unit has been inferred to be present at Siesta Key, Sarasota Co., Florida.

Beach-ridge sets present on Sanibel Island record a complex history of intermittent deposition. Six distinct progradational units composed of one or more beach-ridge sets are present on this island and are separated from each other by erosional truncations. The oldest such unit, Sanibel I, is 3000 to 2000 BP and the youngest, spits that migrated across Blind Pass from South Captiva, has been deposited over the past 125 years. Sand transport was either eastward-directed littoral drift or onshore from the south during the construction of the Sanibel Island beach-ridge sets.

Fluctuations in sea level and/or energy condition can be interpreted from the geomorphology of adjacent, apparently synchronous, beach-ridge sets. Evidence for five such fluctuations exists on Sanibel Island: 1) a rise-increase at about 2000 BP is indicated by the Sanibel I-Wulfert sets, 2) a fall-decrease at about 1500 BP by the Wulfert-Buck Key sets, 3) a rise-increase at about 1000 BP by the Buck Key-La Costa sets, 4) a fall-decrease at about 500 BP by the LaCosta-Sanibel II sets, and 5) the rise-increase during the past 100 or so years indicated by the Sanibel II-historic sets. The low-lying beach-rridge sets (Sanibel I, Buck Key, and Sanibel II) are geographically widespread and contain laterally continuous beach ridges that are partially covered with mangroves and/or fresh- water marsh-vegeration. These sets probably reflect formation at a sea-level position lower than that of present day, perhaps by as much as 1 m, rather than deposition under energy conditions significantly lower than that of present day. Swash-zone bedding of the Wulfert set located 1 to 1.5 m above beach-ridge crests formed over the past 100 years argues that this set was most likely constructed at a sea-level position above present day, perhaps by as much as 1 m.

Siesta Key

Siesta Key is a Holocene barrier island located in Sarasota County, Florida, immediately south of Big Sarasota Pass, the main tidal channel into Sarasota Bay. Siesta Key is over 2

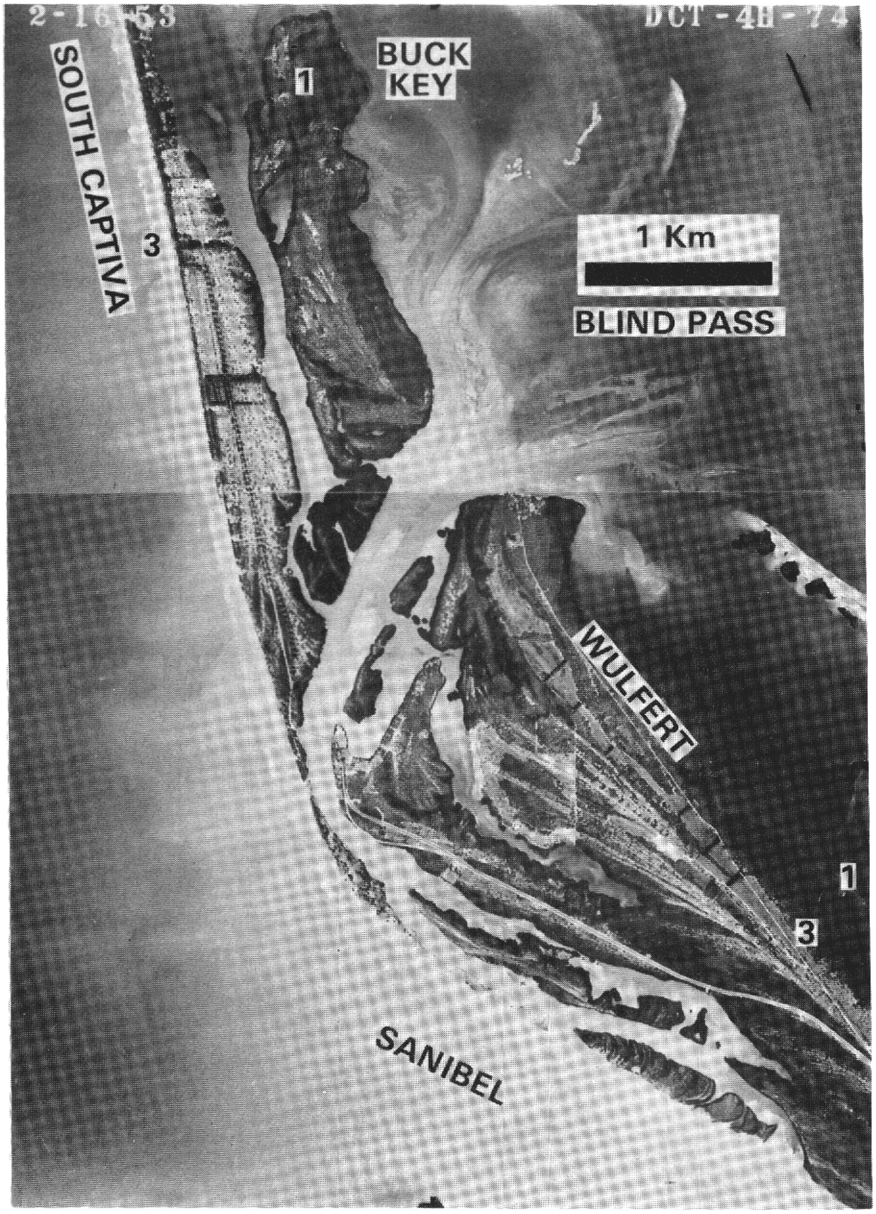

Figure 16. Uncontrolled aerial photo mosaic of the Blind Pass region, Lee County, Florida. The photographs were taken by the U.S. Department of Agriculture in 1953. Shells were collected for radiocarbon dating from the numbered localities. The Wulfert beach-ridge set is labeled on Sanibel Island; individual beach ridges cannot readily be observed in this set, an indication of a slow rate of formation. Blind Pass presently flows into the Gulf of Mexico through a channel located immediately adjacent to South Captiva Island.

kilometers wide adjacent to Big Sarasota Pass and tapers southward to less than 750 meters in a distance of approximately 4 kilometers, a classic "drumstick" barrier island of Hayes (1976) although in a microtidal setting. A calcarenite outcrop near the middle of Siesta Key (locality 1, Figs. 19 and 20) forms a headland extending several hundred meters out into the Gulf of Mexico. Six beach-ridge sets comprise the majority of the northern part of Siesta Key, excluding those sets that separate Sarasota Bay from Roberts Bay (Fig. 20). Beach-ridge patterns within these six sets indicate that sand transport has been either southward- directed littoral or directly onshore during the progradation of the northern part of Siesta Key.

Siesta Key is highly developed and as a result its original topography has been greatly modified. The beach-ridge patterns shown in Figure 20 were mapped from 1948 aerial photography. However, the beach-ridge set sampled at locality 1, the calcarenite headland, is essentially undisturbed, no canals cross it and contour lines describing its topography are concordant with the geometry depicted on the 1948 aerial photography. This set rises to elevations between 10- and 15-feet MSL and forms the highest natural portion of Siesta Key. This "high" beach-ridge set was deposited approximately 1700 BP (Appendix Table 28). Reworking of shells from older deposits was a significant factor; however, there is a cluster of overlapping dates at the young end of the 3000-year spectrum recorded at this locality. This set is equivalent to the time-stratigraphic unit Wulfert of the Lee County, Florida, region. There is not enough preserved of the set to interpret a sand transport direction.

The two beach-ridge sets landward and hence older than that sampled at locality 1 (Figs. 19 and 20) have not been radiocarbon dated. Both sets are below 5-feet MSL on the USGS topographic map. They are tentatively assigned to the informal time- stratigraphic unit Sanibel I (3000-2000 BP). The younger set was deposited from sand transported directly onshore and the older set from southward-directed littoral drift. A rise in sea level and/or increase in energy condition occurred between the ìdeposition of these sets and the set sampled at locality 1.

The beach-ridge set sampled at locality 2 was deposited 1100 BP (Appendix Table 29). There is a cluster of overlapping dates at the young end of the 2400-year spectrum; reworking of shells from older deposits was a significant factor. This set was deposited by northward-directed littoral drift in conjunction with direct-onshore movement. It is outlined by the 5-foot contour line shown on the USGS topographic map. The unit has been tentatively assigned to the La Costa time-stratigraphic unit.

The beach-ridge sets seaward of the set sampled at locality 2 have not been dated. Their convex-seaward geometry suggests tombolo-type growth out onto the adjacent Big Sarasota Pass ebb- tidal delta, the delta serving as source and to localize the coastal progradation. These beach-ridge sets have been tentatively placed in the informal Sanibel II (less than 500 BP) time-stratigraphic unit.

Marco Island

Marco Island, Collier County, Florida, is the southernmost, major deposition-site of quartz sand along the Florida Gulf coast. A Holocene beach-ridge plain composed of at least fourteen distinct beach-ridge sets directly abuts a Pleistocene coastal sand body, Figures 21 and 22. This Pleistocene-Holocene island is bounded on the north by Big Marco Pass and on the south by Caxambas Pass; the ebb-tidal deltas of both have greatly influenced island deposition. These ebb-tidal deltas serve as local sand sources; the northern one contributes material to a southward-directed littoral drift cell and the southern one material to a northward-directed cell. The fan-shaped beach- ridge patterns of the younger beach-ridge sets indicate that now these cells fairly evenly divide the island. However, southward- directed littoral transport has been more important than northward-directed during the Holocene progradation of Marco Island, Figure 21. In addition, direct-onshore sand transport is indicated for one of the larger beach-ridge sets. The

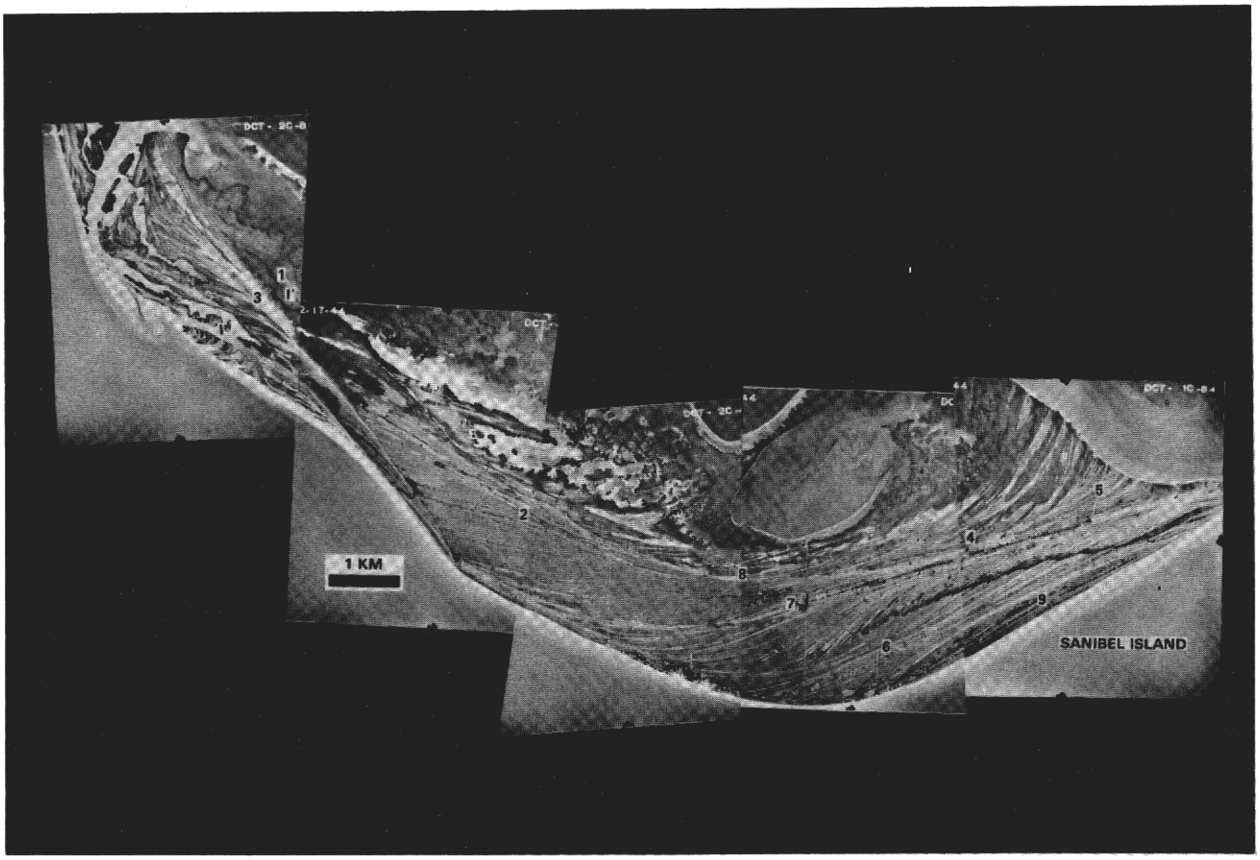

Figure 17. Uncontrolled aerial photo mosaic of Sanibel Island, Lee County, Florida. The photographs were taken by the U.S. Department of Agriculture in 1944. Shells were collected for radiocarbon dating from the numbered localities. A topographic cross-section was constructed along line II' from commercial photo-topographic maps.

northern part of Marco Island appears to have grown, tombolo-fashion, out onto the adjacent Big Marco Pass ebb-tidal delta. The beach- ridge sets preserved on Marco Island record a history of intermittent, seaward progradation.

Marco Island is highly developed and as such its original topography has been severely modified. However, the United States Geological Survey topographic map, made from 1971 aerial potography, indicates that only those Holocene beach-ridge sets comprising the younger half of Marco Island had elevations greater than 5-feet MSL. The beach-ridge patterns shown diagrammatically in Figure 22 were mapped from 1952 aerial potography.

Development has so modified this island that collecting in- place shells is essentially impossible. Spoil removed from a canal under construction was sampled at locality 1 (Fig. 22), one of the oldest beach ridges preserved on Marco Island. Deposition of these ridges occurred 2800 BP (Appendix Table 30). Reworking of older shells is indicated by the 800-year spectrum reported at this site. However, six of the ten dates determined on individual shells form an overlapping cluster at the young end of this spectrum. These beach ridges have been tentatively assigned to the Sanibel I time-stratigraphic unit of the Lee County region. The man-made modifications to Marco Island may well preclude additional shell collecting for radiocarbon dating, except when the provenance can be reasonably ascertained, such as during the active dredging of new canals.

The oldest Holocene beach ridges abut the Pleistocene coastal sand body along a remarkably straght interface, Figures 21 and 22. Although no scarp and terrace have been reported, and, given the present development, are not likely to be recognizable, this interface suggests wave-erosion during a previous sea-level position within perhaps 1 m of the present.

DISCUSSION

The data presented in this study demonstrate that Holocene barrier island in southwest Florida have experienced net seaward progradation over the past 3000 years. However, progradation has been intermittent rather than continuous with periods of costal erosion interrupting seaward growth. Beach-ridge patterns indicate that either 1) shore parallel or littoral, 2) direct onshore, or 3) some combination of both have been responsible for transporting sand to depositional sites. Many of the individual beach-ridge sets making up these prograding barriers record sand transport with a significant onshore component. This situation should be expected given that in southwest Florida sand for coastal progradation can be derived only from the erosion of pre- existing coastal and nearshore deposits, since present-day rivers are not delivering sand. Some process has been delivering sand from nearshore sites for coastal deposition periodically and/or at differential rates depending on geographic position along the southwest Florida shore.

Beach-ridge sets present in this region are either "high" or "low" with respect to elevation. Crest elevations of the "high" sets are approximately 5 to 6 feet MSL and about 3 feet MSL for the "low" sets. The Wulfert set on Sanibel Island and the Point- of-Rocks set on Siesta Key (locality 1, Fig. 12) have crest elevations of about 10 feet MSL. Beach ridges formed facing the open Gulf of Mexico over the past 100 years have crest elevations of about 5 feet MSL. The "low" sets are partially covered with mangroves and/or fresh-water marsh vegetation. Sanibel I (3000- 2000 BP), Buck Key (1500-1000 BP), and Sanibel II (500-1007 BP) beach-ridge sets are "low"; Wulfert (2000-1500 BP), La Costa (1000-500 BP), and the historic (less than 100 BP) sets are "high." Five major fluctuations in sea-level position and/or energy condition are indicated by these beach-ridge sets: 1) a rise-increase at about 2000 BP, 2) a fall-decrease at about 1500 iBP, 3) a rise-increase at about 1000 BP, 4) a fall-decrease at about 500 BP, and 5) a rise-increase over the past 100 or so years.

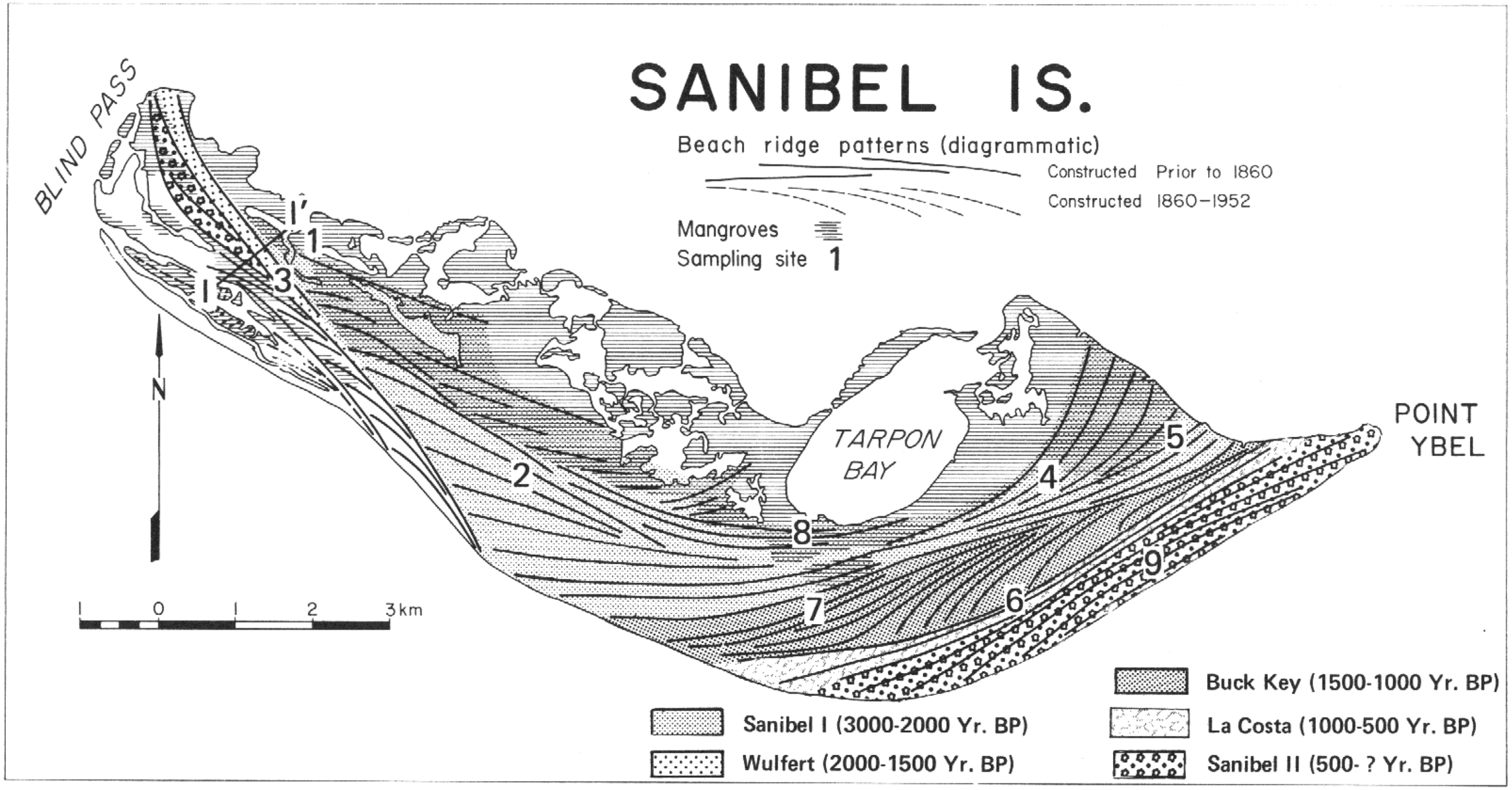

Figure 18. The radiocarbon chronology of beach-ridge sets present on Sanibel Island, Lee County, Florida. Beach-ridge patterns are diagrammatic within the various sets and were mapped from 1944 U.S. Department of Agriculture aerial photography. Topographic cross-section II' was made from Bosworth Aerial Surveys (1976) photo-topographic maps with a 1-foot contour interval (see Fig. 15). The designations Sanibel I, Wulfert, Buck Key, La Costa, and Sanibel II are informal time- stratigraphic units. Eighty-eight radiocarbon dates of individual shells collected at nine localities are the basis of the chronology of this island.

Figure 19. Uncontrolled aerial photo mosaic of Siesta Key, Sarasota County, Florida. The photographs were taken by the U.S. Department of Agriculture in 1948. shells were collected for radiocarbon dating from the numbered localities.

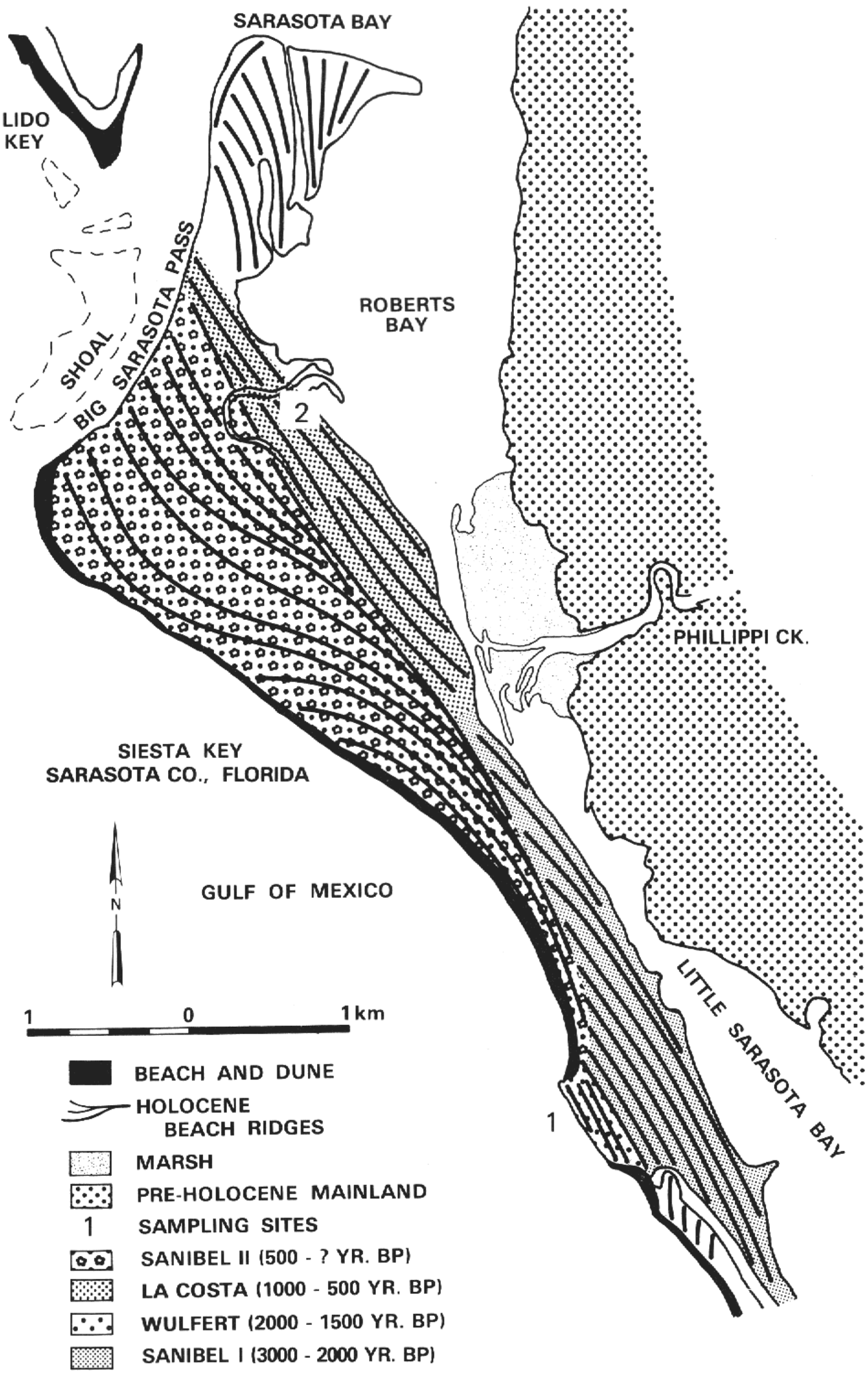

Figure 20. Initial radiocarbon chronology of Beach-ridge sets present on Siesta Key, Sarasota County, Florida. Beach-ridge patterns are diagrammatic within the various sets and were mapped from 1948 U.S. Department of Agriculture aerial photography. The designations Sanibel I, Wulfert, La Costa, and Sanibel II are informal time-stratigraphic units developed for the Lee County, Florida, barrier islands. Nineteen radiocarbon dates of individual shells collected at two localities are the basis of the chronology of Siesta Key.

Figure 21. Uncontrolled aerial photo mosaic of Marco Island, Collier County, Florida. The photographs were taken by the U.S. Department of Agriculture in 1952. Shells were collected for radiocarbon dating from the numbered locality.

The major component of the 2000 BP fluctuation was probably a sea-level rise rather than an increase in energy condition. Swash-zone deposits of the Wulfert beach-ridge set are located about 10 feet MSL, 3 to 4 feet above historic beach-ridge crests and 5 to 7 feet above crests of the preceding Sanibel I beach ridges. Sea level would have stood well above its present-day position, perhaps by as much as 1 m. A similar argument can be made for the 1000 BP fluctuation, in that La Costa beach-ridge crests stand up to 3 feet above those of the preceding Buck Key ridges. Sea level would have stood equal to its present-day position during the deposition of the La Costa ridges. The argument used here is that an upward shift in the position of inter- and supratidal swash-zone deposits of non-storm origin reflects primarily a rise in sea-level rather than an increase in energy condition.

The major component of the 1500 BP and 500 BP fluctuations was also probably a sea-level fall rather than a decrease in energy condition. The Buck Key and Sanibel II sets on Sanibel Island are geographically widespread and composed of laterally continuous beach ridges. These are characteristics of major deposition sites occurring over broad geographic areas rather than local, geographically restricted, minor sites that would be expected to result from a further compartmentalization or disintegration of the littoral-drift system caused by a reduction in energy condition alone. The magnitudes of these falls are no more than 1 m and probably somewhat less.

If these are indeed sea-level fluctuations then they should be recognizable over the southeastern United States, a fairly broad geographic region that is predicted to have experienced the same viscoelastic response to the Holocene sea-level recovery (Clark et al., 1978). Beach-ridge sets located in Charleston and Beaufort Counties, South Carolina, indicate a fall-decrease at about 1500 BP, a rise-increase at about 1000 BP, and a fall- decrease at about 500 BP (Stapor et al., 1985). The 2000 BP raised beach deposits reported from northeastern Mexico by Behrens (1966) are remarkably similar in age and estimated elevation to the Wulfert beach-ridge sets of southwest Florida reported in this tudy. Four Holocene sea-level fluctuations are identified on St. Vincent Island, Florida (central panhandle region near Apalachicola), by Stapor and Tanner (1977). They are 1) a fall subsequent to the cutting of an elevated terrace and prior to 4000-3000 BP shell middens, 2) a rise some time after aboriginal occupation of a 3000 BP midden and prior to the deposition of a 2100 BP subtidal, shell-rich, clay bed now located in the upper third of the intertidal zone, 3) a fall prior to aboriginal occupation of a now submerged 1800-1500 BP midden and 4) a rise subsequent to aboriginal occupation of a now submerged 1500-700 BP midden. These submerged middens necessitate that sea-level was actually lower-than-present during ìaboriginal occupation. This period roughly corresponds to the time of deposition of the Buck Key beach-ridge sets (1500-1000 BP) of this study.

The writers hypothesize that these are primarily fluctuations in sea level and further that they are responsible for pulsing sand landward for shoreline progradation. In addition, the southwest Florida data suggest that the nearshore or shoreface quickly adjusts to new conditions of water depth and passes through at least two states of dynamic equilibrium during a given sea-level fluctuation: 1) "excess" sand moved onshore and 2) sand moved offshore from the shoreline. This suggests either a source depletion and/or a change in the transport path through time. The shoreface in southwest Florida may well achieve new dynamic equilibrium configurations in very short time periods.

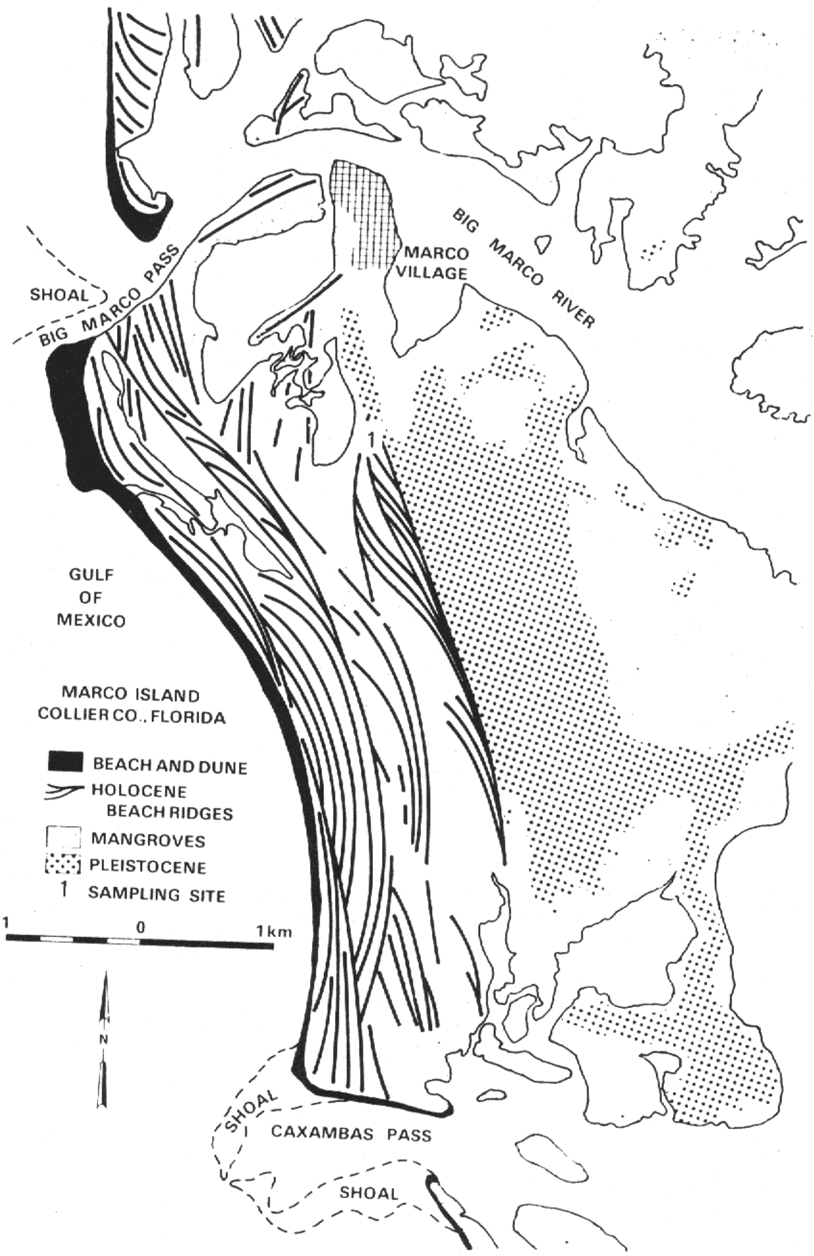

Figure 22. Initial radiocarbon chronology of beach-ridge sets present on Marco Island, Collier County, Florida. Beach-ridge patterns are diagrammatic within the various sets and were mapped from 1952 U.S. Department of Agriculture aerial photography. Ten radiocarbon dates of individual mollusk shells indicate that deposition of the oldest preserved beach-ridge set, locality. 1, began 2700 BP. This is equivalent to the Sanibel I time-stratigraphic unit of the Lee County, Florida, region.

CONCLUSIONS

Geomorphologic and radiocarbon data from the prograding, composite barrier islands of southwest Florida support the following conclusions:

1. Reworking of older shells into younger deposits is a significant factor that can be identified and evaluated by dating a number of individual shells at each sampling site. A cluster of overlapping dates at the young end of any spectrum provides the best estimate for depositional age.

2. Onshore sand transport has been more important during the deposition of beach-ridge sets comprising these barriers than has shore-parallel transport.

3. Coastal progradation in southwest Florida occurred at rates that varied both in time and space. However, many different sites experienced some amount of progradation over the same general time period.

4. Sea level in southwest Florida had reached to within a meter or so of its present position by 3000 BP and possibly by 5000 BP. Five major fluctuations in sea level and/or energy condition have occurred subsequent to 3000 BP in this region: 1) a rise-increase at about 2000 BP, 2) a fall-decrease at about 1500 BP, 3) a rise-increase at about 1000 BP, 4) a fall-decrease at about 500 BP, and 5) a rise-increase over the past hundred or so years. The most recent fluctuation, a sea-level rise occurring at average rates of up to several millimeters per year is documented by mareograph records of the past hundred years (Hicks, 1973). The 500-year spacing of these fluctuations is only apparent and reflects primarily the precision in estimating the age of clastic deposits by radiocarbon-dating their shell clasts.

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