Journal of Coastal Research	4	1	81-91	Charlottesville, Virginia	Winter 1988

Beach Ridge Data and Sea Level History from the Americas

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ABSTRACT

TANNER, W. F., 1988. Beach ridge data and sea level history from the Americas. Journal of Coastal Research, 4 (1), 81-91. Charlottesville (Virginia) ISSN 0749-0208.

Many types of information can be obtained from beach ridge plains. Twelve important categories of beach ridge plain data are included here: (1) Position in a 5-D space-time-equilibrium framework, (2) relative age, (3) absolute age, (4) deformation, warping or tilting, (5) vertical position, (6) parallelism, subparallelism and abrupt ends (sand source was offshore), (7) curvature, taper and change in orientation (sand source was generally offshore), (8) eolian decoration or dune strips (historical pauses), (9) spacing between ridges (data about littoral power gradient, wave energy gradient, or transverse transport gradient), (10) height (transverse transport rate and/or wave climate), (11) internal bedding (proportions of wind, swash, overwash and storm surge deposition), and (12) sediment parameters and their areal distribution (data about the offshore sand pool, the variable rate of sand delivery to the beach, and therefore changes in sea level or wave climate).

Comparisons along one ridge, from one ridge to another, from one set to another, or from one beach ridge plain to another, may provide useful additional information. Topographic profiles on the plain may produce valuable data (items 3, 4, 5, 10), including information about mean sea level (MSL) changes of one to two meters or more. Cycles of grain size change, along the same profiles, may yield information about MSL changes of a meter or so, or wave climate changes, or both. St. Vincent Island has at least 12 beach ridge sets, containing roughly 180 ridges, spanning about 4, 000 or 5, 000 years of late Holocene time. Topographic profiling indicates two important MSL rises, and one drop, each exceeding one meter. Grain size studies hint at additional MSL changes, each much less than one meter. The smaller changes are largely clustered in the second half of the beach ridge plain history.

ADDITIONAL INDEX WORDS: *Beach ridge plain, beach ridge history, beach ridges, swash ridges, beach ridge parallelism, beach ridge sand source.*

INTRODUCTION

The Late Holocene is that time interval when post-glacial sea level stood approximately at its present position. This is roughly the most recent 5, 000 years. Many coastal segments were aggradational during a good part of this time span, and are now marked by extensive beach ridge plains. The present report is a summary of some of the findings which have arisen out of study of more than 60 of these beach ridge plains, in various parts of Canada, the U. S. A., Mexico, Colombia, Venezuela and Brazil (Figure 1).

Well-developed Late Holocene beach ridge plains may contain up to about 200 individual beach ridges, and hence record Late Holocene events in time slices as small as some few tens of years, in the best cases. Such plains can be found along various parts of the world coastline. They offer a tremendous amount of historical information, at present largely untapped.

There are several different kinds of beach ridges. The beach ridge plains under discussion here are made up essentially of one kind only: what is here termed the "simple" beach ridge or swash ridge. By this is meant a ridge with a rather clearly developed three-dimensional geometry (including measurable side slopes commonly initially in the 3°-10° range), internal bedding largely showing swash work rather than eolian or wash-over effects, and a reasonably-well defined crest line. If eolian decoration was added at a later time, it is not to be included in the statement about the origin of the ridge.

Wash-over ridges, on the other hand, generally do not make up extensive beach ridge plains. Instead, they tend to occur singly, or at

***Presented at the 98th Annual Meeting of the Geological Society of America, Orlando, Florida, 27 October 1985, in the symposium titled "Holocene Sea-Level History and Depositional Response along the U. S. Middle Atlantic and Southeastern Coast."*

85048 received 19 December 1985; accepted in revision 26 August 1986.

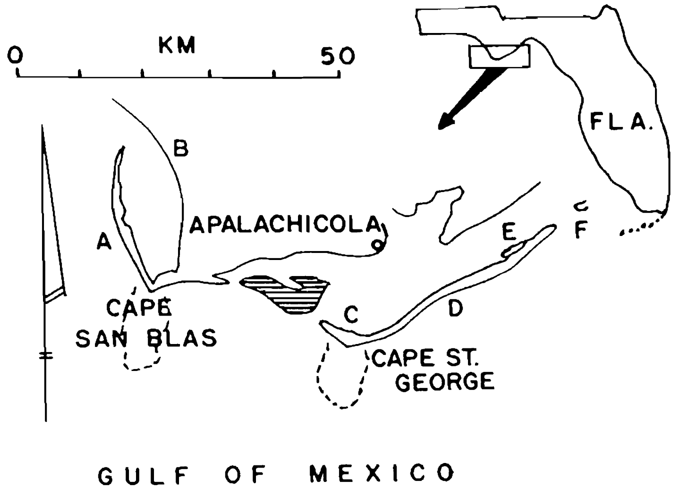

Figure 1. Map of Florida showing the study area (box); and detailed map of the study area, with St. Vincent Island marked by shading; the horizontal lines do not represent beach ridges. Each of the two named capes is located at the northern edge of a large submarine shoal, having complicated bathymetry. St. Vincent island is in the embayment between the capes (and hence between the shoals). Capital letters: A. St. Joseph peninsula; B. Pine Point; C. Little St. George Island; D. St. George Island; E. Gap Island; and F. Dog Island.

least with very wide swales between them. The upper part is typically flat (unless dune decorated, or channeled). The side dips are low, the internal bedding is ordinarily convex-upward, and wash-over fans and deltas occur on the landward side. Such ridges represent repeated wash-over events, and may or may not be migrating landward.

FRAMEWORK

Beach ridge sets, or sequences, were built in a framework made up of geometrical dimensions (width, length, height), time, and an equilibrium parameter. The equilibrium parameter is here taken to reflect the degree of adjustment of wave measures to the given sea level position and bathymetry. The construction of a beach ridge plain shows that the coastal segment of interest is located in an equilibrium of abundance (TANNER & STAPOR, 1972). In this scheme, an apparent equilibrium form is maintained, but it is shifted slowly seaward as new ridges are added to the plain. Should the equilibrium be balanced perfectly (something that can be discussed, theoretically, but cannot be demonstrated in the field), there will be no net gains or losses on the beach front, and the plain will cease to grow. Once the aggradational history is over, erosion sooner or later begins to attack the youngest ridge, and we can commonly say that the coastal segment appears to be in an equilibrium of scarcity. This shift, from equilibrium of abundance to equilibrium of scarcity, has taken place, on various beach ridge plains, at various times over the last few centuries, or in a few cases has not yet taken place, indicating that sea level changes such as those observed in historical times are not responsible for the change.

RELATIVE AGE

Each beach ridge plain displays the same kind of time sequence as a simple stratigraphic section. The ridge closest to the mainland (or farthest from the sea) is the oldest member of the group. The ridge immediately adjacent to the beach is the youngest. All of the others fit, in sequence, between the extremes, and therefore have relative ages. In a few cases, two or more ridges are located immediately adjacent to the modern beach. In such places, one of those young ridges truncates the others, and therefore is the youngest.

On Late Holocene beach ridge plains, the youngest ridge is still growing, or its growth has been terminated in historical times. If it is one ridge among 100 or 200, it is still growing, or growth ended within the latest few decades. If it is one ridge among 10, such narrow time limits cannot be specified.

The moment of observation (now) is precisely fixed in time. The instant of initiation of the oldest ridge in the group may not be so obvious. Clearly, no open-ocean beach ridge, of Holocene age, was built more than, roughly, 5, 000 years ago. The younger limit, for initiation, was perhaps commonly some 3, 000- 4, 000 years ago. Extensive beach ridge plains having relatively simple map geometry commonly represent all of that time interval: from 4, 000 or 5, 000 years ago, to the last few decades. Therefore each ridge in the group can be assigned an approximate age within rather narrow limits.

ABSOLUTE AGE

Beach ridges made of shells are well within the best part of the range of the ^{14}C method, and can be dated accurately (*e.g.*, Stapor and Mathews, 1980). A few ridges, made of quartz sand, are associated with kitchen middens which establish a limiting date. And a few other quartz sand ridges contain wood fragments (^{14}C dating) or artifacts (sawed lumber, nails, bottles) which permit dating (STAPOR, 1973).

However, datable materials cannot be found in many quartz sand ridges. In such cases it may be possible to establish a local dating scheme, based on the fact that, once a ridge has been built and then isolated from wave action by a younger ridge, the side slopes change steepness in a systematic way. Such a scheme has been developed for the sand, wave climate and atmospheric conditions of the Florida Panhandle (TANNER & HOCKETT, 1973). It can be expressed as:

$$\text{Ln } t = 12.37 - i$$

(Where t is age in years, and i is slope angle in degrees). This statement appears to be good, in the study area, back to about 150, 000 years. This permits ridges in one group to be dated, approximately, on an absolute basis, for comparison with ridges in other nearby, but not contiguous, groups (Figure 2).

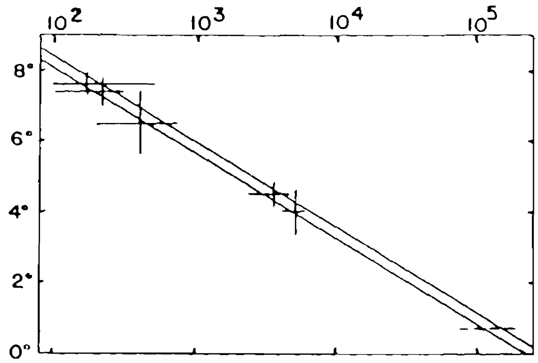

Figure 2. Age-vs-side slope diagram for the sands and climate in the coastal strip southwest of Tallahassee, with age (in years) on the horizontal ordinate and beach ridge side-slope angle (in degrees) on the vertical axis. The narrow diagonal band includes all of the regression lines that were fitted to the data. Vertical bars represent one standard deviation on each side of the mean of measured angles; horizontal bars show the range from minimum to maximum value for the age determinations or estimates. The dashed horizontal line (lower right hand corner) provides an estimate of the age (slightly more than 100, 000 years) of Sangamon (?) ridges in the area. This diagram is not intended to be used outside of the region for which it was constructed. (From TANNER & HOCKETT, 1973).

DEFORMATION

Warping and tilting effects produce two classes: those ridge crests that are no longer parallel to the water plane, and those ridges that still are parallel. Like a tilted terrace, a tilted beach ridge in the first class would have measurable vertical differences along its alignment. A warped ridge merely has had a complicated tilt pattern. No Holocene beach ridges known personally to the present writer fit clearly into the first class, except in obviously deformed areas. This means that, for Late Holocene time, many extensive beach ridge plains appear to have been stable.

The second class is more difficult to identify and some tilt-free uplift certainly occurs. But the time span is so short (a few thousand years), and the oldest ridges in a given group so close in altitude to the youngest (although not identical), that is is thought that sea level changes were responsible for most, if not all, of the visible changes in altitude in apparently stable areas.

VERTICAL POSITION

Sea level changes, in the 5, 000 or so years of Late Holocene time, have been, perhaps, two or three meters or less. The larger changes have

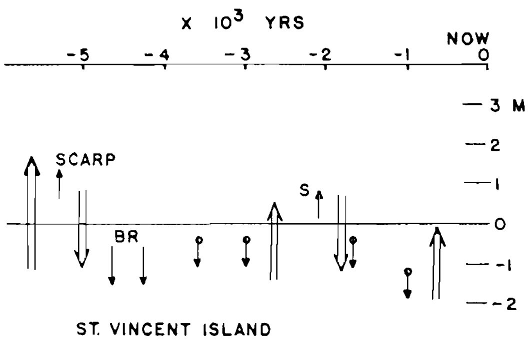

Figure 3. Mean sea level positions in the St. Vincent Island area, Florida. Small arrows indicate whether MSL was high, or low (relative to its present position). Large double arrows show changes in position of sea level. Notes on the small arrows indicate the source of information: SCARP = mainland scarp, of Mid-Holocene age, immediately landward of the island, with a toe elevation of about 2.0 m; BR = plane-table data on four sets of beach ridges which stand lower than most other ridges on the island; S = Carbon-14 date on marine shell bed; Circles = Indian site information. Precise positions of MSL are not shown, but the limits are about 2.0 m above present MSL, and perhaps 2-4m below. (From STAPOR & TANNER, 1977.)

been very roughly 1, 000 years apart; there have been smaller events also. Therefore we are thinking in terms of maximum rates of change of probably 5 to 20 mm per year. This is faster than known warping, in more or less stable areas, or in fact, present MSL changes. However, it is likely that MSL fluctuations less than about 30 cm do not have any visible effect on beach ridge geometry (BERQUIST & TANNER, 1974).

St. Vincent island, in panhandle Florida, with about 200 ridges built in 4, 000-5, 000 years, shows evidence for five "major" MSL changes (1 to 3 m; STAPOR & TANNER, 1977) (Figure 3). Three of these can be measured by plane tabling relief changes at the discontinuities between successive ridge sets. Two older ones (a rise, then a fall) must be deduced from the position and geometry of a mid-Holocene scarp at +1.5 m, landward of the oldest ridge (TANNER, 1983).

My work on beach ridge plains on the Atlantic and Pacific Coasts of North America has not included plane-tabling. Therefore it is not known (a) if such vertical discontinuities are present, and (b) if they would have been developed at all where the wave climate was much more energetic than along the shores of the Gulf of Mexico. Very small changes in MSL (*e.g.* , <30 cm ±) apparently leave no geometrical evidence. However, sand grain size data show hints of such events. Indeed, the entire history of late Wisconsin and Holocene sea level events tells us that ups and downs of various magnitudes are common, and that truly stable MSL is a myth.

PARALLELISM

Beach ridges within a single set are commonly essentially parallel to each other, and small departures from parallelism generally are seen where a younger set truncates an older set in the same group. These departures are typically at very small angles, and belong in the category of sub-parallelism, which is a special case of parallelism.

Thinking has been dominated for so long by the "river of sand" concept that we can see past this misleading hypothesis only with very great difficulty. However, we can approach the problem in at least two ways (TANNER, 1974, 1987). The first is to observe that, in shore-parallel transport along a geometrically simple beach (where wave parameters do not change very much from one end to the other), the volume-rate of littoral transport of sand (q; L^3T^{-1}) must be constant along the beach (because q is a rigorously-defined function of wave height and approach angle; May, 1974). If q = constant, then dq/dx, the deposition rate with distance (x) along the beach, must be zero. That is, with these constraints, there is no deposition. Consequently, parallel beach ridges were not built from any "river of sand, " and must have been derived from an offshore source. The other approach is to note that if, during a brief constructional episode, building a parallel system, we find x Kg of sand deposited in the terminal sea-front linear meter of beach, then 2x Kg must be introduced 2 m from the terminus, 10x Kg 10 m before the terminus, and 1, 000x Kg 1.0 Km before the terminus. Such a beach may be 10 Km long. This now requires that waves of constant height along the beach move 10, 000x Kg of sand at one end, only x Kg at the other. This disparity is completely unacceptable. The two approaches are actually equivalent to each other. They lead to one important conclusion:

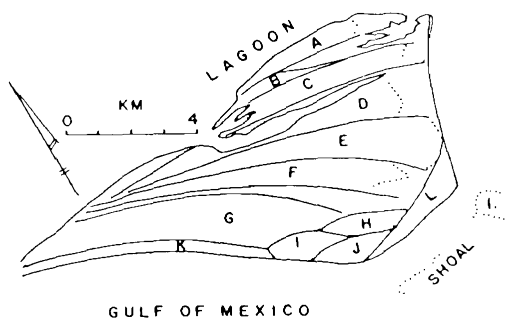

Figure 4. Map of St. Vincent Island, taken from air photos. Only beach ridge sets are shown, and these are lettered (A, B, etc.) from oldest to youngest. Each set contains numerous ridges, all essentially parallel with each other. Ridges in one set may stand, as a group, higher than those in an adjacent set, or lower, in either case indicating a change in mean sea level. The dotted lines on the island mark the eastern ends of individual ridges, which grew without attachment to any island or shoal to the east. The dotted outlines along the eastern edge of the map show the locations, respectively, of the western end of St. George Island, and a lunate bar which extends to the southwest from the end of that island. That island was not in position as recently as Set E, which continues without important curvature to the eastern shore of St. Vincent Island. St. George Island may have been present while Set F was forming, but the bar did not develop until during or after the deposition of Set G; evidence for this statement appears in Sets H, I and J, which were built of sands driven shoreward onto St. Vincent Island from the east and which therefore are not part of the history of general shoreward transport of sand that built Sets A through G plus Set K. The seaward edge of Set K has been eroding in the latest 25 years.

Parallel and subparallel beach ridges were built from offshore.

A totally different observation is also pertinent here. Many beach ridges were built with both ends standing in open water. That is, there was no attachment, at either end, to headlands, mainland, spit, island, reef, dike, fault, scarp, or anything else, and hence no "up drift" source. St. Vincent Island has more than 100 beach ridges for which this is true (Figure 4). There was no "updrift source" of any kind from which sand could have come. It must have come from offshore (TANNER, 1974).

The same holds for Dog Island (SPICOLA, 1984), St. George Island (SCHADE, 1985), St. Joseph Peninsula, and many others. This observation is simply: a ridge having two unattached tips was built from offshore sand. The observation that beach ridges, in general, grow seaward, rather than lengthwise, was made at least as far back as 1919, although without elaboration or detailed analysis (JOHNSON, 1938, p.408).

The interaction between MSL changes, the wave climate, and the offshore sand pool produced the beach ridge plain. Looking back in time from the present, we use beach ridge geometry in an effort to disentangle sand pool, wave climate, and MSL histories.

CURVATURE AND TAPER

The concept of parallelism does not require perfectly straight ridges having precisely constant spacing at all points. Many a curved beach has been built in response to wave parameters that were determined by wave refraction effects. The beach ridges north and south of Acapulco, Mexico, are straight and parallel. Those on St. Vincent Island are concave seaward and sub-parallel to parallel. In each case the sand came from offshore. But subparallelism, taper, and curvature must also hold additional meaning. In the case of St. Vincent Island, the concave-seaward curvature is due to the fact that the island is located between two large submarine shoals. Like many other sand bodies, these move with time (STAUBLE, 1971). As they move, wave refraction must change, hence subparallelism. Furthermore, the bay floor near the closest shoal has a better supply of sand than does the deeper part of the bay. Therefore, it is not surprising that some of the ridges taper from a maximum width closest to the shoal.

In some cases, a *small* component of shore-parallel transport may result in taper of individual ridges. On the other hand, where there is a small shore-parallel component of supply, it is *not* necessary that the wide end be the updrift end (MURALI, 1973).

It is also possible that a change in wind patterns can produce a different average wave approach direction, hence a small reorientation in the beach ridge crest line. This seems to be a minor effect, especially in those beach ridge plain histories where the reorientation is consistently in a single sense (*e.g.*, clockwise) rather than alternating. Consistent sense of reorientation suggests systematic changes in the offshore sand pool. These changes may show up in grain size parameters also.

EOLIAN STRIPS

There is a popular opinion that geometrically regular beach ridges were formed by wind action (*e.g.*, PRICE, 1958). However, detailed field, map, air photo and granulometric study of various examples shows clearly that (1) they differ significantly in external form from adjacent dunes and none-dune eolian accumulations, (2) the internal bedding is not of an eolian type, and (3) the granulometry is more like that of beaches than dunes.

Beach ridges of the simple kind considered here (sand; seaward internal dips) are built primarily by swash action (70- 100%), with minor components of overwash and wind work. The time needed for construction is typically in the range 5-40 years. During that time, the swash is continuously reworking any eolian laminae on the beach face, and adding new sand (mostly from offshore).

But if there is a long pause in construction (*e.g.*, 30-100 years), wind work may become more important, producing first "eolian decoration" on top of the swash ridge, and if time permits, converting it into a dune ridge and perhaps even a dune complex (TANNER, 1971). Eolian decoration is common on sand ridges (but not on shell debris or other gravel). Dune ridges, however, are relatively rare. They do not, and cannot, represent marked erosion, nor can they indicate rapid growth. Because they mark either long pauses in, or termination of, the beach ridge plain history, they most likely have to do with changes in MSL, the offshore sand pool, or the wave climate. The third, of these three, is least likely. The first should be either measurable or minor (<30 cm). the second is ordinarily the preferred explanation, unless there was a change in MSL >50-to-100 cm. Even in dry climates, such as around Paraguaipoa, Venezuela, dunes develop only on certain ridges, not over the plain in general (TANNER, 1971) (Figure 5).

Whether the modern beach-edge dune strip represents a long pause, or termination, is a different matter. In some cases, even this problem can be resolved; in some places, it is termination, but in others, it is not (TANNER, 1975). This dichotomy of results indicates that MSL change itself does not control many of the pauses; if it did, the results should be global, instead of local.

RIDGE SPACING

Tapered ridges obviously have a spacing that changes from one end to the other. This taper is discussed in another section. In the present section, "spacing" deals with measurements taken along a line orthogonal to one or more sequential ridge sets. Therefore, the pertinent idea is ds/dt, or change of spacing with time.

The method of construction of simple sand beach ridges is clear, primarily swash run-up. What is not so clear is the mechanism that forms the swales, *i.e.* the processes that stop the building of one ridge and then later start the building of another. In at least some cases, a single ridge is constructed above a stranded bar (formed during one major storm; COLEMAN, 1977, 1978)) or a partially welded bar. But the procedure for terminating the build-up, well before another ridge is started, is not known.

Because the time interval between simple ridges is typically some 5-40 years, a storm origin for the initial stranded bar is very attractive. If correct, the spacing between ridges is a function of storm frequency and shoreward transport rate from the offshore sand pool. This latter rate depends on wave parameters, bottom slope, and sand size.

In simplistic form, the spacing S is:

$$S = 2\,(H_R \cot i)$$

where run-up height (HR) depends largely on wave parameters; and beach slope (i) depends primarily on sand size. This form ignores many items, however.

RIDGE HEIGHT

The original full height of any given ridge must be taken to exclude eolian decoration (which modifies the crest in ragged fashion) and flood-time introduction of fines into the swales or intervening wetlands (swamp or marsh). With a given beach slope (controlled basically by grain size) height is determined by run-up distance, which—in a general sense—has its maximum value at the crest of the fully developed ridge (TANNER & STAPOR, 1972). Therefore, the terminal height is a function of some part of the long-term wave spectrum, and is in some real sense an index to local wave energy levels. Although there are complications (*e.g.*,

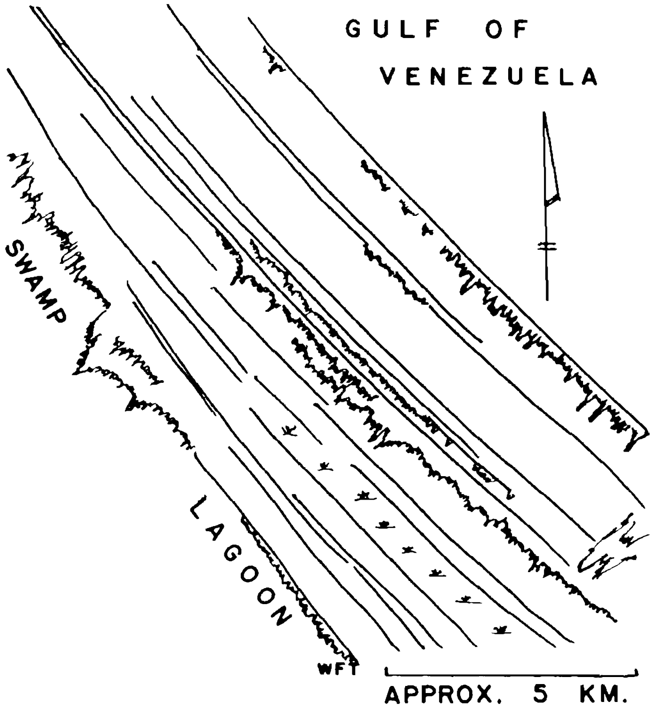

Figure 5. Map of the central part of the beach ridge plain on the southwestern shore of the Gulf of Venezuela. The city of Maracaibo, and Lake Maracaibo, are located to the south of the study area. A few selected beach ridges are shown, particularly those that have produced dune strips. The dunes, in each case, are located in strips or areas, each of which has a beach ridge to the northeast, and a ragged outline (edge of migrating sand) to the southwest. Ordinary beach ridges (classical type), showing little or no wind work, are not shown, except in the case of a few unusually well-developed ridges. The essential parallelism, shown here, extends to the rocky northern limit, as well as to the southern limit at the Rio Limon (a non-alluvial river). The entire plain is roughly 22 Km long (NW-SE). The town of Paraguaipoa is located immediately northwest of the mapped area, and the town of Sinamaica immediately to the southeast. The number of beach ridges shown is about 10% of the total. The effective wind blows from northeast to southwest. Mapped from air photos, without ground control, and hence scale is only approximate.

due to marked difference in grain size), big waves tend to make big ridges. Heights may be only 10 cm, or so, on the shores of a small lake, but are commonly up to a meter on the open ocean coast. A few simple sand ridges are 3-4 m high, and gravel ridges may be this tall or taller.

Height is also a function of age. TANNER & HOCKETT (1973), studying simple sand ridges in the Florida panhandle, found that

$$\ln t = 12.37 - i$$

(Where t is age in years and i is the side slope angle). Then $H_{BR} = 0.5\ S\ (\tan i)$, and $= 0.5S\ (\tan\ (12.37 - \ln t)\ )$. Where the spacing is constant, the change in height (with time) is a function of the reduction of the side-slope angle. The changes in side-slope angles, over 1, 000 years or so, are very small. Therefore, short-term changes in height are also small.

After about 150, 000 years (in the study area) simple ridges no longer have measurable height. What one sees is coalesced ridge sets, or washover ridges (CARTER & ORFORD, 1981; CARTER *et al.*, 1984) or ridge set patterns without significant relief (TANNER & HAJISHAFIE, 1978). Ridge height must not be confused with ridge altitude. The latter represents land vs. sea position, and the former, wave energy levels.

INTERNAL BEDDING

Extensive beach ridge plains are commonly made up of only one or two kinds of ridges (plus possible eolian effects). These are the simple beach ridge and the washover ridge. The former is extremely common, and initially typically has slopes in the 4°-10° range (but these decrease with time). The latter is wider and flatter, tends to have more of a whale-back shape, may have washover fan or deltas on the landward side, and has very gentle initial side slopes (perhaps 1°-4°).

The definitive distinction between them is based on internal bedding. The former contains largely swash-built bedding (70-100%), dipping seaward at ordinary beach slope angles. Eolian and washover bedding are minor or absent. The latter is made dominantly by more or less concentric concave-down bedding having zero dips in the central part. This looks like the stranded bar (COLEMAN, 1977) on a grand scale, but unlike the latter is not built in a single storm. Most of the discussion in the present paper deals with the simple swash-built ridge, and should not be transferred to the washover ridge, which owes its characteristics to repeated storm-surge overtopping, perhaps for hundreds or thousands of years.

SEDIMENT PARAMETERS

The selection of grain size parameters may be based on statistical, hydrodynamic, or perhaps other considerations. Sample-suite statistics tend to have a hydrodynamic basis. The variability (standard deviation) of moment measures (and other parameters) within a suite has very high discriminatory power, for hydrodynamic reasons having to do with such concepts as grain- induced turbulence.

If the entire suite (mid-swash samples only; LADER, 1974) is deliberately taken from a single beach ridge plain, variability measures can only confirm that selection. One now needs a different kind of analysis, in an historical framework. The purpose is now one of deciphering changes in at least some of the basic controls: MSL, wave climate, sand pool. The procedure is to examine the pertinent measures, one at a time, starting with the mean size, and plotting against arbitrary relative time (oldest to youngest). A bivariate plot (*e.g.*, mean size vs. standard deviation) can be given a time sense by numbering the samples from No.1 (oldest ridge) to the youngest, and then connecting them sequentially with arrows. If the number of ridges is large enough, and the sampling procedures were appropriate (SOCCI & TANNER, 1980), two trends may emerge. One is a long-term trend representing general depletion of the offshore sand pool; in some instances the sand becomes finer and better sorted. The other is a kind of cyclicity that appears to result from changes in wave parameters and/or minor changes in MSL. If only a few ridges make up the plain, or if sampling density or sampling procedures are not adequate, the cyclicity may show up as noise, beyond the power of any statistical tool to resolve.

ABBREVIATED EXAMPLES

An intensively studied area southwest of Tallahassee (Florida) includes the following:

(1) Sangamon age: Port St. Joe (mainland) (von DREHLE, 1973), and Apalachicola-Carrabelle (mainland) (WEI, 1985); and (2) Holocene: Middle Holocene Scarp (TANNER, 1983), Pine Point (MURALI, 1973), St. Joseph Peninsula (STAPOR, 1973), St. Vincent Island (TANNER, 1974), Little St. George Island, St. George and Gap Islands (SCHADE, 1985), Dog Island (SPICOLA, 1984), and Alligator Point.

Side-slope angles indicate that the first two examples are about 100, 000-125, 000 years old, hence Sangamon in age. No radiometric dates are available, but humate (which apparently requires tens of thousands of years to form, in the area) is present in both sets, and therefore no Holocene age is possible.

All of the other examples were formed in the latter half of Holocene time. The widest spread of ages can be obtained from St. Vincent Island, which was still growing in the first half of the present century, which is rimmed on its landward side by a kitchen midden roughly 4, 000 years old, and which is younger than the mid-Holocene high-sea-level scarp on the mainland. Two radiocarbon dates support this general history, and a few historical dates apply to the seaward side. Other dates must be estimated by interpolation, in a plain of roughly 180 ridges. The ridges are all parallel or sub-parallel; except for minor truncations, ridge tips do not touch any other feature (such as headland, point, or cape). The sand source was offshore.

Dog Island was, apparently, built in the last 3, 000 years or so, in an independent system, in which both ends of the island are marked by beach ridges, and there is no important source of sand except on the beach or offshore. Inlets on both sides of this island are too wide for leakage of sand to or from adjacent areas.

Gap Island was built, from offshore sand, roughly 3, 000 to 2, 000 years ago, and then St. George Island was constructed seaward of it, terminating its history. The northeastern tip of St. George Island is marked by tiny, very-late, Holocene beach ridges indicative of local spit growth.

Little St. George Island appeared and evolved between what were then two wide inlets; St. George Island has since incorporated it. The first appearance in time of the beach ridge plain on Little St. George Island is indicated by a change in orientation of St. Vincent Island beach ridges, very roughly 2, 000-2, 500 years ago.

St. Joseph Peninsula grew initially as two separate bodies; the inlet between them was closed at a later time, (but, contrary to local legend, was not cut by a hurricane in the mid 1800's). There is no information on the time of initiation of either core. However, the bulk of the peninsula has been undergoing erosion for at least 200 years, at rapid rates (up to 11 m/yr near the southern end), and much information has been lost with the elimination of the widest part.

The Pine Point beach ridge plain was built, and then construction was terminated, in response to lengthening of the northern end of St. Joseph Peninsula, and currently has a stable (and probably static) geometry.

St. Vincent Island beach ridges provided the framework for this abbreviated history, but many of the details were obtained, later, by work in other parts of the area. All of this history is best understood in connection with a consideration of the major shoals in the area, two large subaqueous bodies south of Cape San Blas and Cape St. George, respectively. At least one of the two shoals dates back to Sangamon time, when it influenced the patterns of beach ridge plain geometry on what is now the mainland.

CONCLUSIONS

Detailed historical information is best obtained from a wide beach ridge plain, or a set of such plains. Whether any given plain has shifted from an equilibrium of abundance (aggradation) to an equilibrium of scarcity (beach erosion) is an important part of the history. If the shift has already been made, the date of that shift is needed. If it has not been made, a future date can be estimated (in at least some cases).

Geometrical details of beach ridge plain history, obtained from air photo analysis or by ground surveying methods, may provide information on sea level changes, modifications in the offshore sand pool, and perhaps shifts in the wave climate. The third is generally impossible to specify, but must always remain an hypothetical possibility.

The beach ridge plain, or plains, in a given area, typically provide a history quite different from that obtained in some other area. Therefore, each history is basically local, and must not be extrapolated into other regions.

Beach ridge plain growth commonly represents nourishment from an offshore source. That nourishment is controlled by sediment characteristics (measurable, even for older ridges) and wave parameters. When the source has been depleted, either permanently or temporarily, there is a marked change in the history of the plain. Beach-parallel transport is generally minor to negligible.

Historical and/or radiometric dates are needed for resolution of fine details. Where these are lacking, it may be possible to establish an approximate dating scheme by using time-changes in side slope angles. Even less satisfactory is simple interpolation, although relative ages obtained in this fashion may be reliable to perhaps 100 years or less.

Grain size or other sedimentological studies may provide additional information about minor changes in sea level, but a large amount of work is necessary, unless one is willing to settle for general statements about the evolution of the offshore sediment pool.

Sea level changes, during Holocene beach ridge plain growth, have been in the range of centimeters to a few meters. The smaller changes cannot be recovered by present techniques. There have been very few changes in the 1-4 m range; the largest of these appear to have been the oldest (and pre-dated all, or essentially all, Holocene beach ridge construction); and not all beach ridge plains show evidence of any given change.

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☐ RÉSUMÉ ☐

Nombreuses sont les observations que l'on peut obtenir sur les plaines á cordons littoraux. Douze types de données les concernant sont intégrées:

(1) position dans un espace à 5 dimensions espace-temps-équilibre, (2) âge relatif, (3) âge absolu, (4) déformation, gauchissement ou inclinaison, (5) position verticale, (6) parallélisme ou sub-parallélisme et terminaisons abruptes (source de sable au large), (7) courbure, effilement et changement d'orientation (source de sable généralement au large), (8) marques éoliennes ou lambeaux

dunaires (pauses historiques), (9) espacement des cordons (données sur le gradient de la puissance à la côte, sur le gradient d'énergie des vagues, ou celui du transport transversal), (10) hauteur (bilan du transport transversal et/ou règime de houle), (11) litage interne (proportions des dépôts dûs au vent, au swash, au lessivage des tempêtes), et (12) paramètres sédimentaires et leur distribution spatiale (données sur les bâches sableuses du large, les taux variables d'approvisionnement en sable de la plage, et donc les variations du niveau de la mer ou du régime des houles).—Catherine Bressolier, EPHE, UA 910 CNRS, Montrouge, France

□ RESUMEN □

La información obtenida de las formas onduladas de playa es de diverso tipo. En este articulo se han incluido categorias de formas onduladas de playa: (1) posición en un equilibrio 5-D espacio-tiempo, (2) edad relativa, (3) edad absoluta, (4) deformación, (5) posición vertical, (6) paralelismo, (7) curvatura, (8) decoración eólica, (9) espaciamiento entre ondulaciones, (10) altura, (11) deformaciones internas, (12) parámetros sedimentarios y distribución espacial.

Una información útil se obtiene comparando estas caracteristicas entre diferentes ondulaciones.

Los perfiles topográficos producen datos interesantes, items 3, 4, 5 y 10 incluyendo además información de los cambios del nivel medio de uno a dos metros o más. Ciclos de cambios granulométricos a lo largo del mismo perfil pueden dar información sobre cambios de un metro del nivel medio.

St. Vincent Island (SW de Tallahassee, Florida) tiene al menos 12 sistemas de ondulaciones, conteniendo aproximadamente 180 ondulaciones, desarrolladas en 4000 ó 5000 años. Los perfiles topográficos indican dos subidas importantes del nivel medio, un descenso, las tres excediendo un metro de altura. La distribución granulométrica indica al menos diez cambios más del nivel medio del orden de un metro. Los cambios menores se encuentran indicados en la segunda mitad de la historia de las ondulaciones de playa.

□ ZUSAMMENFASSUNG □

Strandkammflachland liefert viele Arten von Auskunft. Zwölf der wichtigsten sind hier eingeschlossen: (1) die Stellung in einem 5-dimensionalen, Raum-Zeit-Rahmen, (2) relativer Alter, (3) absoluter Alter, (4) Entstellung, Verwindung oder Neigung, (6) Parallelismus, Unterparallelismus und plötzliche Enden (küstennahe Sandquelle), (7) Krümmung, Zuspitzung und Änderrung der Orientierung (gewöhnlich eine küstennahe Sandquelle), (8) Eolienverzierung oder Dunenstreifen (geschichtliche Unterbrechungen), (9) Räume zwischen Kämme (Auskunft über littoralischen Transportneigung, Wellenenergieneigung, oder oder Quertransportneigung), (10) Höhe (Quertransportverhältnis und/oder Wellenklima), (11) innerliches Bettzeug (Anteile von Wind, Klatschen, Überwellenschlag und Sturmwogenablagerung), und (12) Sedimentparameter und seine räumliche Verteilung (Auskunft über die küstennahe Sandquellen, das veränderliche Sandlieferungsverhältnis dem Strand, und dabei Änderungen des Meeresspiegels oder Wellenklimas). Topographische Profile des Flachlands liefert wertvolle Daten (Pünkte 3, 4, 5, und 10), die Auskunft über Änderungen des Meeresspiegels. Kreiseläufe von Kerngrössenänderungen, mit diesen Profile, zeigen vielleicht Auskunft über Meeresspiegeländerungen oder Wellenklimaänderungen, oder die beiden. St. Vincent-Insel (südwestens von Tallahassee, Florida) hat am mindenstens 12 Strandkammgruppen, die ungefähr 180 Kämme unter sich haben; seine Älter stehen zwischen 4.000 und 5.000 Jahre (spätholozän). Topographische Profile zeigen zwei Hebungen des Meeresspiegels und eine Senkung; jede Änderung überschreitet 1 meter. Kerngrössenstudien zeigen zasätzliche Ändergungen des Meeresspiegels, vielleicht 10 auch 1 meter, vielleicht wenig. Die kleinere Änderungen finden in der zweite Hälfte der Strandkammflachlandgeschichte.—Stephen A. Murdock, Charlottesville, Virginia, USA