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BEACH-CUSP FORMATION

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ABSTRACT

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Field experiments on beach-cusp formation were undertaken to document how the cuspate form develops and to test the edge-wave hypothesis on the uniform spacing of cusps. These involved observations of cusps forming from an initially plane foreshore.

The cuspate form was observed to be a product of swash modification of an intertidal beach ridge as follows. A ridge, cut by a series of channels quasi-equally spaced along its length, was deposited onto the lower foreshore. The ridge migrated shoreward with flood tide, while the longshore positions of the channels remained fixed. On ebb tide, changes in swash circulation over the ridge allowed the upwash to flow shoreward through the channels and the channel mouths were eroded progressively wider until adjacent mouths met, effecting a cuspate shape.

Measured spacings of cusps, ranging in size from less than 1 m to more than 12 m, agree well with computed spacings due to either zero-mode subharmonic or zero-mode synchronous edge waves. Edge-wave-induced longshore variations in run up will cause water ponded behind a ridge to converge at points of low swash and flow seaward as relatively narrow currents eroding channels spaced at one edge-wave wavelength for synchronous edge waves or one half wavelength for subharmonic edge waves. The channels are subsequently modified into cusp troughs as described above.

INTRODUCTION

Beach cusps are crescentic shoreline features, concave seaward, that are characterized by a quasi-uniform longshore wavelength ranging from less than 1 m to at least 60 m (Russel and McIntyre, 1965). Giant cusps, which are similar in form to beach cusps, but are spaced 150—1500 m (Shepard, 1952; Dolan, 1971) and are associated with rhythmic offshore bars, may be genetically different from beach cusps and are not considered here. Giant cusps are discussed at length in Komar (1976).

Numerous hypotheses on beach-cusp formation have been published, but there is no apparent consensus as to which, if any, are valid. Development of the cuspate form has been attributed to accretional processes (Branner, 1900; Kuenen, 1948; Komar, 1971; Sanders et al., 1976), erosional processes (Johnson, 1910; Rivas, 1957; Smith and Dolan, 1960), or both (Otvos, 1964; Gorycki, 1973; Guza and Inman, 1975). Proposed mechanisms controlling the uniform spacing of cusps include adjustment of initial foreshore irregularities

(Johnson, 1910), edge waves (Galvin, 1964; Bowen and Inman, 1969; Komar, 1973; Guza and Inman, 1975), instabilities in breaking waves (Cloud, 1966) or swash (Gorycki, 1973), and a variety of mechanisms requiring a non-normal incident wave approach to the shoreline (Branner, 1900; Rivas, 1957; Schwartz, 1972; Dalrymple and Lanan, 1976).

The hypotheses are based primarily on theoretical grounds, laboratory experiments, conjecture and/or field observations of cusps whose form and spacing were established before the observations. Few detailed observations of beach cusps forming in the field have been reported. The approach taken here was to occupy a beach after a storm of sufficient energy to leave a plane foreshore, and then to monitor sediment-level changes and pertinent wave parameters through cusp formation. The primary objectives of the study were to document how the cuspate morphology develops and to test the edge-wave hypothesis on the uniform spacing of cusps.

DEVELOPMENT OF THE CUSPATE FORM

Field observations

In order to facilitate acquisition of surf-zone data, a relatively protected beach on the north end of Parramore Island, Virginia, was chosen for study. After a storm, a grid composed of narrow rods driven into the sediment surface 2 m apart was laid out across the foreshore and extending 10 m parallel to the shoreline. After the elevation of the top of each rod was measured with respect to a datum, periodic measurements of the lengths of exposed rods revealed the changing form of the foreshore.

The foreshore did not change appreciably for several days. During this time, wave crests formed an oblique angle with the shoreline and breaker heights averaged approximately 15 cm. Prior to cusp formation the incident wave field changed to a normal approach to the shoreline and breaker heights were approximately 20 cm.

On the flood tide following this change in wave characteristics, a shore-parallel ridge of sediment cut by a series of channels quasi-equally spaced along its length was accreted onto the lower foreshore (Fig.1A). The swash flowed up the seaward face of the ridge, was partially ponded behind the ridge crest and the ponded swash was released seaward through the channels. In response to this circulation and the flooding tide the ridge migrated shoreward, while the longshore positions of the channels remained fixed. On ebb tide, the seaward regression of the swash zone stranded the ridge on the upper foreshore and a stage was reached where the swash could no longer effectively overtop the ridge and supply the channel currents. The swash then flowed shoreward through the channels and eroded the channel mouths progressively wider until adjacent mouths met, effecting a cuspate shape (Fig.1B). The swash circulation over the cuspate form was then the often-described case of upwash dividing at the horns of cusps, converging in the troughs and backwash confined to the troughs (e.g. see Bagnold, 1940). This

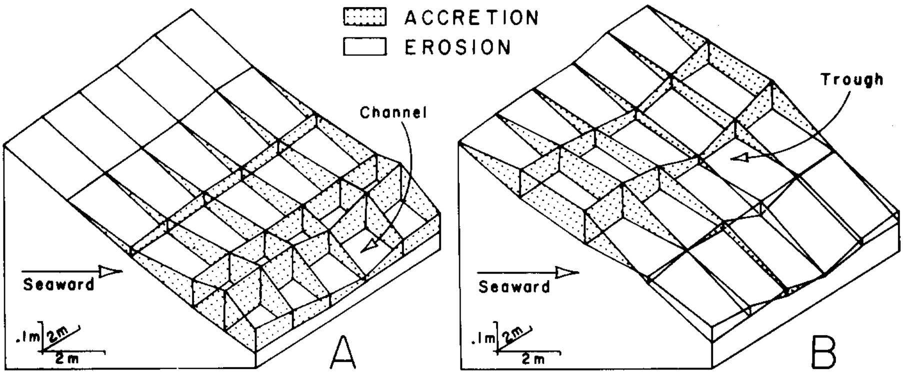

Fig.1. Block diagrams showing the development of the cuspate form.
A. During flood tide a ridge was deposited onto the foreshore with equally spaced channels distributed along its length. The crest of the ridge lay between lines of rods and its position and approximate form have been added to the diagram.
B. The ridge migrated shoreward with the flooding tide. On ebb tide the mouths of channels were progressively widened by swash erosion until adjacent mouths met, effecting a cuspate shape.

sequence of events leading to the development of the cuspate form was also observed on a lower-energy estuarine beach in the Chesapeake Bay.

The development of the cuspate form was a product of both erosion and accretion, but resulted in net accretion to the foreshore (Fig.2A). On another occasion, a series of profiles was surveyed on Parramore Island when no cusps were present and these were resurveyed the next day after beach cusps had formed. The change in foreshore elevation is plotted in Fig.2B and again cusp development resulted in net accretion. The results agree with previous observations that beach cusps develop during accretional phases of the beach cycle (Hayes and Boothroyd, 1969).

In support of the general applicability of these results, Smith and Dolan (1960) and Mii (1968) observed erosional internal structures within beach cusps that are consistent with the observed transformation from a ridge to cusps. Laminations within a horn along a cross-section parallel to the shoreline are horizontal and are truncated at the sloping horn surfaces (Mii, 1968). The horizontal laminations are what would be expected within the body of a ridge, and the truncations would be the expected result of swash erosion of channels in creating troughs. Along a cross-section normal to the shoreline through a horn, the laminations are truncated at the relatively steep, seaward-facing slope (Mii, 1968). This would be the expected result of migration of the ridge shoreward.

Observations of foreshore morphology along certain shorelines have provided both additional evidence on the role of ridges in cusp development and an indication of conditions under which a ridge-and-channel system would not be transformed into cusps. Fig.3A—C illustrate the foreshore morphology at three sites along a concavely shaped beach at the northern end of Parramore Island (Fig.3). A well-developed ridge-and-channel system

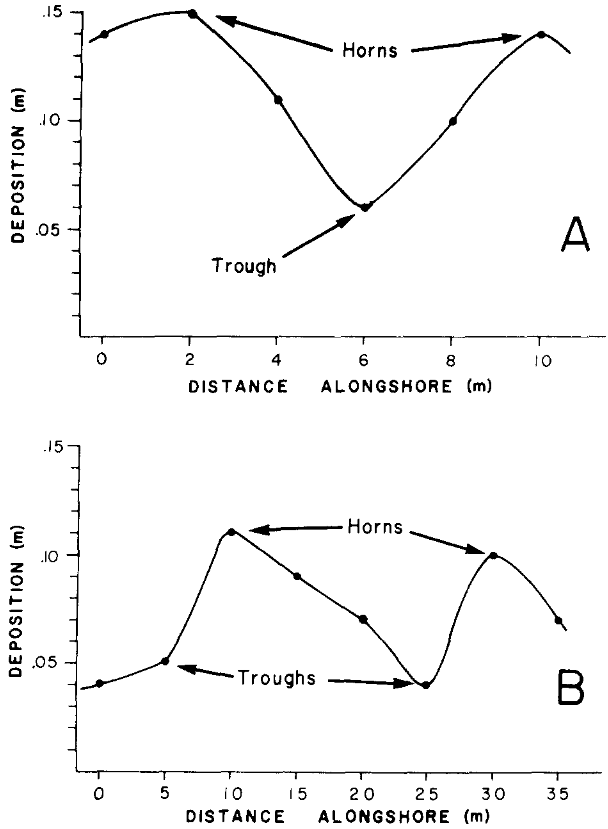

Fig.2. Longshore changes in foreshore elevation in response to cusp formation.
A. Adapted from Fig.1.
B. Derived from profiles taken before and after cusp formation at a different time from Fig.1, but on the same beach. In both cases, cusp formation resulted in net accretion to the foreshore.

was observed at the easternmost part of the shoreline (Fig.3A); well-developed beach cusps at the center (Fig.3C); and a transitional feature, similar to cusps, but also ridge-like, halfway between (Fig.3B). These were not three isolated observations, but a clear progressive longshore change in morphology. For waves approaching from the north-northeast, which could lead to a normal wave approach to the concave segment of shoreline due to refraction, the wave energy should be maximum at C and minimum at A due to relative differences in spreading of wave orthogonals. Assuming that a ridge was initially deposited along the shoreline, my interpretation would be that the wave energy was sufficient for swash to erode channels into cusp troughs only at C, the swash was moderately effective at B and left a transitional feature, and was ineffective at A. Similar trends in foreshore morphology were observed on several occasions at this location and along an irregularity in the shoreline near False Cape, Virginia where again the ridge and channel

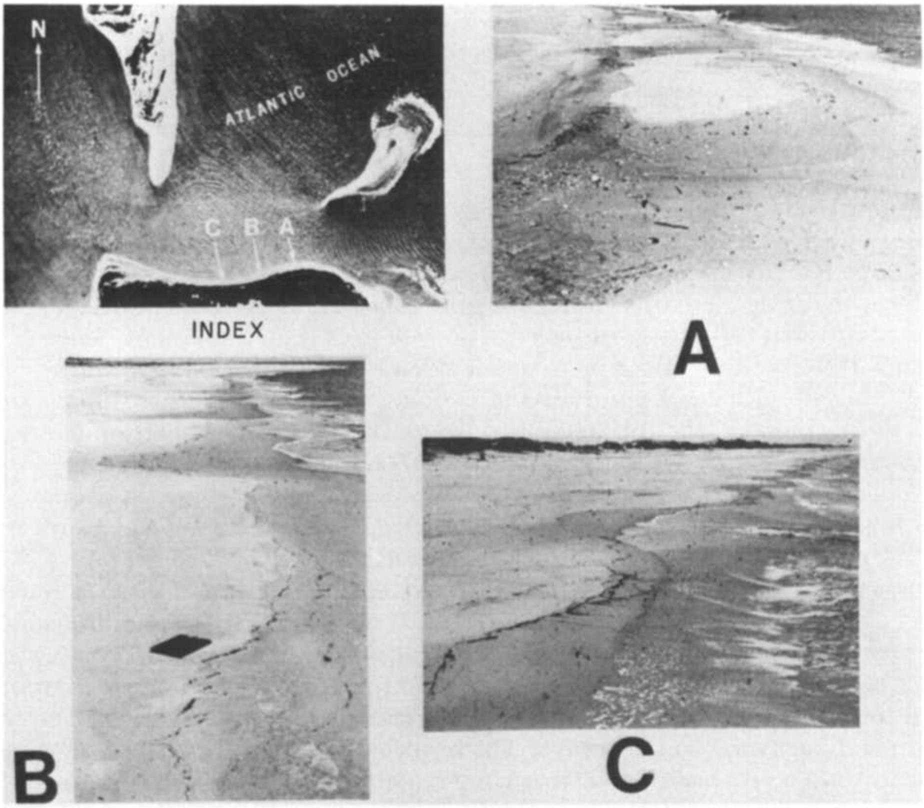

Fig.3. Observations of foreshore morphology at three locations along a shoreline at the northern end of Parramore Island, Virginia.
A. Well-developed ridge-and-channel system.
B. Transitional features between well-developed beach cusps and ridge-and-channel system.
C. Well-developed beach cusps.

system occurred in the most protected portion of the shoreline.

In addition to the described development of the cuspate form (Fig.1) several related modes of formation were observed. In response to low-amplitude surging breakers on a well-protected estuarine beach in the Chesapeake Bay a ridge several centimeters in height was deposited near low water on an ebbing tide. The ridge was composed of dark-colored granules and was readily observable on the medium-sand foreshore. The ridge was breached by the swash and shaped into cusps spaced 0.7 m over a period of several minutes. This observation is similar to that reported by Evans' (1945) for cusps forming in a tideless environment. On Parramore Island delta-like deposits were observed seaward of channels incised in a larger-scale ridge. The upwash was divided at the deltas and converged on the ridge areas between deltas. Conceivably, the ridge areas between the deltas could migrate shoreward forming cusp troughs, while the deltas build up into horns, creating a series of cusps one half out of phase from those in Fig.1. This was not, however, observed to completion. In both cases the wave approach was normal to the shoreline.

Discussion

These results support previous investigators' contentions on the applicability of ridges to cusp formation (Jefferson, 1903; Evans, 1938, 1945; Schupp, 1953; Williams, 1973) and are contrary to assertions by Kuenen (1948) that ridges are of significance primarily in tideless seas and Russel and McIntyre (1965) that ridges have no role in cusp development. Since Evans' (1938) observations were under tideless conditions and Schupp's (1953) dealt with cusps composed of cobbles, the genetic relationship between ridges and beach cusps appears not to be confined to special environments or circumstances, but to be broadly applicable.

Once beach cusps are established by erosion of a beach ridge the cuspate form may become better developed, in accordance with Russel and McIntyre's (1965) observations of cusps growing seaward and Otvos' (1964) of horns growing and troughs being eroded deeper, due to the nature of swash circulation over the well-developed cuspate form. If we assume that the dominance of upwash over backwash indicates an accretional environment and backwash over upwash an erosional environment, then the horn will be deposited upon and the trough eroded into equilibrium forms since upwash is confined to the horn and backwash to the trough. The resulting internal structure through a horn would reveal accretional structures superimposed over erosional as observed by Otvos (1964). This circulation would also lead to the characteristic surficial sediment distribution over cusps where the sediment is coarser on the horns and finer in the troughs (Boye, 1954; Russel and McIntyre, 1965). The high permeability of horns relative to troughs (Longuet-Higgins and Parkin, 1962) is in part a product of this grain-size distribution and a positive feedback to the swash circulation.

These results do not, however, preclude additional modes of formation. Williams (1973) and Sanders et al. (1976) have reported cases where the internal structure of cusps indicates an accretional origin. Komar (1971; 1973) has observed cusps spaced 5.8 m apart forming by deposition in the lee of rip currents and relatively small cusps form as ridges normal to the shoreline.

MECHANISM CONTROLLING THE SPACING OF CUSPS

Edge waves

For the observed cases, the mechanism controlling the spacing of cusps must be operable under a normal wave approach and capable of eroding equally spaced channels. Hypotheses dealing with instabilities in breaking waves (Cloud, 1966), or swash (Gorycki, 1973) and edge waves (Galvin, 1964; Bowen and Inman, 1969; Komar, 1973; Guza and Inman, 1975;

Gaughan and Komar, 1977) could conceivably meet these criteria. However, the edge-wave hypothesis is the only one with a strong theoretical basis (Eckart, 1951; Ursel, 1952) that allows it to be adequately tested. Furthermore, edge waves are applicable to cusp formation in wave-tank experiments (Galvin, 1964; Guza and Inman, 1975; Gaughan and Komar, 1977) and their potential significance in the prototype is shown by evidence of edge waves in the field (Huntley and Bowen, 1973).

Edge waves are free modes of nearshore water motion trapped against the shoreline by refraction. Edge-wave amplitudes decay exponentially offshore and vary sinusoidally alongshore. Application of edge waves to channel development involves the influence on swash of regular longshore variations in wave height resulting from edge wave—incident wave superposition. On the passage of every incident wave crest, synchronous edge waves, where the edge-wave period is equal to the incident wave period, will cause a longshore spacing of wave-height maximums equal to one synchronous edge-wave wavelength (Bowen and Inman, 1969). Resulting longshore variations in swash run-up will cause water ponded behind the ridge to converge at points of low swash and flow seaward as relatively narrow currents eroding channels spaced at one synchronous edge-wave wavelength. For subharmonic edge waves, where the edge-wave period is twice the incident wave period, wave-height maximums will alternate with wave-height minimums on the passage of every incident wave crest since the edge wave completes only one-half cycle between successive incident waves. Consequently, positions of swash convergence over a ridge will alternate with divergent areas with every swash cycle. Conceivably, seaward-flowing currents at convergent positions would be capable of initiating channel erosion and once initiated the flows would become topographically controlled and develop channels. The resulting channel spacing would then be one-half the subharmonic edge-wave wavelength. In a wave-tank experiment, Guza and Inman (1975) observed such a case of topographic feedback to subharmonic edge wave induced perturbations in a ridge. For either case, the longshore positions of convergence zones must be fixed. This is satisfied when the incident wave approach is normal to the shoreline (Guza and Bowen, 1975).

The wavelength of an edge wave (m) is given by (Ursel, 1952):

$$L = \frac{g}{2\pi} T_e^2 \sin\left[(2n + 1)\beta\right] \cdot$$

where T_e is the edge-wave period (sec), g is the gravitational acceleration (m/sec^2), n is the modal number (a positive integer), and β is the beach slope (rad). Cusp spacing due to synchronous edge waves is L and due to subharmonic edge waves is $L/2$ or $2L$ when $T_e = 2T_i$ where T_i is the incident wave period. For synchronous edge waves, laboratory experiments indicate that n increases with surf-zone width (Bowen and Inman, 1969). For subharmonic edge waves, Guza and Davis (1974) found the zero mode to be the likeliest to occur. In their field experiments, Huntley and Bowen (1973) measured only zero-mode subharmonic edge waves.

TABLE I

Incident wave period (T_i) in seconds, slope (β) in radians and mean cusp spacing (S) in meters for three data sets*

Data set I			Data set II			Data set III		
T_i	β	S	T_i	β	S	T_i	β	S
6.5	0.07	12.3	3.9	0.111	5.4	2.3	0.16	0.7
6.5	0.07	10.9	3.9	0.091	5.4	2.3	0.099	0.7
6.5	0.06	8.6	3.9	0.099	3.6			

*Each data set represents an experiment involving several monitored sites. Data Set I is from Parramore Island, Virginia and II and III are from a beach on the York River estuary in Gloucester Point, Virginia.

Field experiments

During observations of beach cusp formation on different beaches the incident wave period, beach slope and resulting cusp spacing were measured (Table I). The period measurements were based on visual observations of the number of waves passing a fixed point during three, two-minute time intervals. Accurate results using this technique require a narrow incident wave spectrum and suffer from the subjective choice of wave crests, but the measurements are considered to be representative. The slope was measured over a horizontal distance of 0.1 $(g/2\pi)T^2$ seaward of the breakpoint, where the distance is a scaling factor to the edge waves. The spacing of six channels to either side of the position where slope was determined were measured and the mean is reported in Table I. The ridge and channel systems for data set I were transformed into well-developed cusps on ebb tide as was shown in Fig.1. For data set II, some erosion of channel mouths occurred on ebb tide, but the seaward faces of the ridges were not completely shaped into the convex or tapering-seaward form of well-developed cusp horns, so the morphological development of the cusps did not proceed to completion. For data set III ridge deposition, channel development and cusp shaping occurred over a period of several minutes on an ebbing tide. For all cases, the wave approach was normal to the shoreline.

Measured cusp spacings are plotted versus computed spacings due to edge waves in Fig.4. The computed spacings for data sets I and II are based on subharmonic edge waves of $n = 0$. A reasonably good agreement is apparent. The relatively small cusps of data set III show a closer correspondence to computed spacings based on zero-mode synchronous edge waves. Low incident waves of only a few centimeters in height during the formation of these cusps suggest a low mode number due to the very narrow swash zone (Bowen and Inman, 1969).

The breaking wave form during cusp formation for data sets II and III was clearly surging. This agrees with Guza and Inman's (1975) assertion that

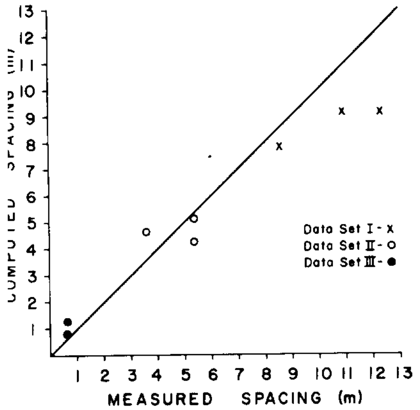

Fig.4. Measured cusp spacing versus computed cusp spacing based on edge waves. Data are from Table I. Computed spacings for data sets I and II are based on zero-mode subharmonic edge waves and for data set III on zero-mode synchronous edge waves.

either subharmonic or low-mode synchronous edge waves are responsible for cusp formation where incident waves are mostly reflected, which would be the case for surging breakers. The breaking wave form for data set I was, however, plunging. The maximum incident wave height leading to subharmonic excitation is given by (Guza and Inman, 1975):

$$H_i = gT_i^2 \tan^2 \beta / \pi^2$$

which corresponds to the transition region between surging and plunging breakers as defined by Galvin (1972). The calculated H_i for data set I ranges from 15 to 20 cm, where the wave height observed in the field was 15—20 cm. This indicates that the breaking wave form for data set I was in the lower portion of the plunging range and may still fall within the limits of Guza and Inman's (1975) analyses. All data fall within the range of incident wave periods and beach slopes where subharmonic excitation would be expected (Fig.5 in Guza and Inman, 1975). That a better correspondence was found between measured spacings and computed spacings due to synchronous edge waves for data set III may be due to the very low wave heights during this experiment. Guza and Inman (1975) observed small synchronous edge waves in wave tank experiments where incident wave amplitudes were too small for subharmonic excitation. Minimum incident wave height for zero-mode subharmonic excitation was given as:

$$H_i > 1.02 \cdot 10^1 (\nu T_i / \pi)^{\frac{1}{2}}$$

where ν is the kinematic viscosity. For data set III, the minimum wave height is 0.9 cm where the observed wave heights were estimated to be on the order of a few centimeters. Accurate measurement of such low-amplitude waves in the field is difficult by visual means, but the order of magnitude correspondence between calculated minimum wave heights and observed heights suggests that subharmonic excitation was inhibited in this case, allowing the weaker synchronous resonance to develop. For data set II wave heights were on the order of 6—8 cm, well within the theoretical minimum (1.1 cm) and maximum (12—19 cm) for zero-mode subharmonic edge-wave excitation. In none of the field observations was the presence of edge waves confirmed by obvious patterns in the swash. The observations were similar to that described by Guza and Inman (1975) for a laboratory experiment where low-amplitude subharmonic edge waves which were not visible in the swash lead to breaching of a ridge.

Reanalyses of Komar's (1973) field data (Sallenger, 1975; Guza and Inman, 1975) support these results. Komar (1973) presented mean cusp spacing, wave period and horn and trough slopes for cusps found along a lake shoreline. In Fig.5 measured cusp spacings are plotted against computed cusp spacings based on $n = 0$ subharmonic edge waves calculated from both horn and trough slopes. Assuming the slope critical to edge-wave generation falls between the horn and trough slopes, the agreement for seven of nine data sets is reasonable. Guza and Inman (1975) showed that for data point A the incident wave period and beach slope fall outside the range expected for subharmonic excitation, and that the agreement between measured and computed spacing is better for $n = 1$ synchronous edge waves (measured = 21 cm; computed = 21 cm) than for the subharmonic (computed = 13 cm). Furthermore, Huntley and Bowen (1975) noted an apparent correspondence between the spacing of relatively small cusps found in the field and that due to $n = 0$ synchronous edge waves.

Previous investigators have reported that cusp spacing is dependent on the degree of beach exposure (Johnson, 1910; Russel and McIntyre, 1965; Williams, 1973). In Fig.6 it is shown that cusp spacing tended to be largest

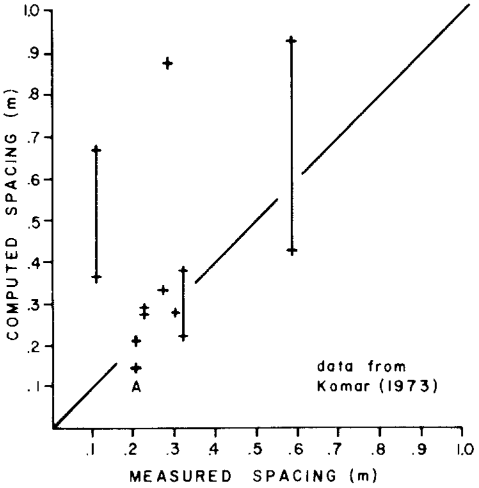

Fig.5. Measured cusp spacing versus computed cusp spacing based on $n = 0$ subharmonic edge waves. Data from Komar (1973). Vertical lines connecting data points indicate the range based on computations using horn and trough slopes.

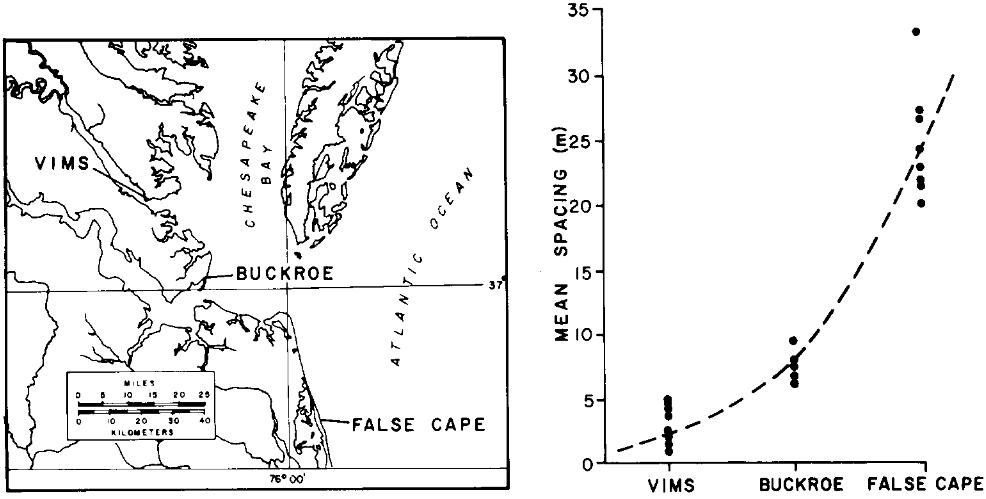

Fig.6. Mean spacings of beach cusps found on a relatively exposed shoreline (False Cape), a beach exposed to a relatively wide estuary (Buckroe) and a well protected beach (VIMS). Each circle represents the mean of a series of cusps.

on an ocean beach (False Cape), intermediate in size on a beach exposed to a relatively wide estuary (Buckroe) and smallest on a well-protected estuarine beach (VIMS) where for these cases exposure is defined as effective fetch length. Since wave period is in part a function of fetch length, one would generally expect that periods affecting these beaches would increase with increased exposure. Edge waves could control these differences in spacing if T^2 is more variable than sin β. Furthermore, the modal number may show a concomitant increase with exposure for synchronous edge waves since wave energy and consequently surf-zone width would tend to increase with exposure.

Cusp spacing also tends to vary concomitantly with beach slope along certain shoreline shapes. In Fig.7 cusp spacings are shown to be largest over salients of giant cusps and decrease into the embayments on either side. Sonu (1973) has shown that slope tends to be largest over salients and decreases into the embayments. Along a bay of log spiral shape, Krumbein (1947) showed that cusp spacing and beach slope increased outward from the concavity of the bay. Since wave period is generally constant alongshore at any given time, these trends in spacing could be explained by edge-wave theory, assuming the theory can be qualitatively applied to these curved shorelines.

Discussion

The results indicate that low-amplitude edge waves, which are not readily observable in the swash, initiate channel erosion along an intertidal beach ridge. Once the channels are initiated the flows become topographically controlled and the channels become fully developed. This positive feedback

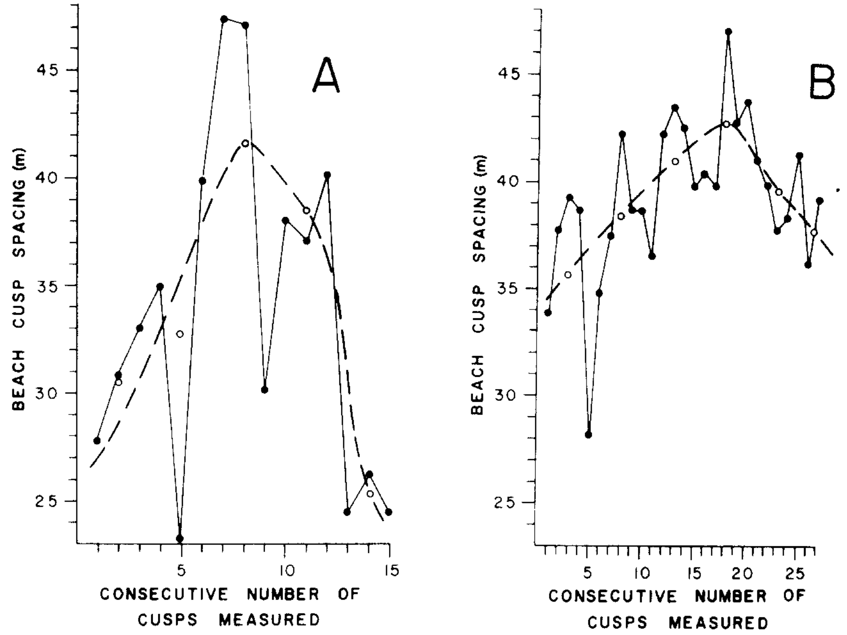

Fig.7. Measurements of cusp spacing around the periphery of giant cusps. The darkened circles with connecting solid lines represent individual measurements and the open circles with connecting dashed lines represent a running average.
A. Data from the False Cape, Virginia area. Cusp 1 was in the center of an embayment of a giant cusp, 8 on the salient and 15 in the adjacent embayment.
B. Data from Kitty Hawk, North Carolina. Cusp 1 was in the center of an embayment, 18 on the salient and 27 in an embayment.

from the foreshore morphology to initial edge-wave-induced perturbations agrees well with Guza and Inman's (1975) laboratory observation. In view of the evidence presented on the general applicability of ridges to cusp formation and the likelihood that edge waves in nature are generally of low amplitude since they are seldom visually observed, it follows that a ridge coupled with subtle edge waves is a viable and perhaps broadly applicable condition leading to cusp formation.

The data presented herein (Table I; Fig.4) support the application of edge waves to cusp spacing in what Guza and Inman (1975) define as reflective environments (i.e. surging breakers). Guza and Inman (1975) conclude that in dissipative environments where wave breaking and nearshore circulation cells are significant, mechanisms other than edge waves may be important. The qualitative agreement with the edge-wave hypothesis of trends in spacing of cusps between beaches of different exposure and along shorelines of variable β, which includes higher-energy environments than considered in Fig.4, suggests that edge waves may be important under dissipative conditions. This is particularly true for cusp spacings shown in Fig.7B, where the cusps were found high on the foreshore above the spring high tide line and presumably were formed during or on the waning stages of a storm. Under dissipative conditions, perhaps swash interactions at the first subharmonic of the incident wave frequency would lead to the development of subharmonic edge waves as suggested by Huntley and Bowen (1975). These trends in spacing, however, can be accounted for by other mechanisms (Sallenger, 1975).

That additional mechanisms are plausible is indicated by the lack of agreement between much of Longuet-Higgins and Parkin (1962) data and the edge-wave hypothesis. Dalrymple and Lanan (1976) showed theoretically and experimentally that incident waves of the same frequency approaching the shoreline at opposing non-normal angles can control the spacing of cusps. This cannot, however, explain the anomalous Longuet-Higgins and Parkin (1962) data since they observed normal wave approaches during cusp formation. Other hypotheses involving the instabilities of the cylindrical wave form (Cloud, 1966) or swash (Gorycki, 1973) can account qualitatively to some extent for variations in cusp spacing along certain shorelines and between shorelines of different exposure (Sallenger, 1975), but have not been sufficiently quantified to be testable. Certainly additional observations of cusps forming in the field and *direct* measurement of the process controlling the spacing are needed, particularly under dissipative conditions.

CONCLUSIONS

(1) Observations of beach cusps forming in the field showed that in response to a normal wave approach, a ridge, cut by a series of channels quasi-equally spaced along its length, was accreted onto the lower foreshore. The ridge migrated shoreward with the flooding tide while the longshore positions of the channels remained fixed. On ebb tide, the mouths of the channels were eroded progressively wider by the swash until adjacent mouths met, effecting a cuspate shape.

(2) The development of the cuspate form was a product of both erosion and accretion, but resulted in net accretion to the foreshore.

(3) Previous investigators have observed erosional internal structures within beach cusps consistent with the observed transformation of ridge to beach cusps.

(4) Along some shorelines, foreshore morphology was seen to progressively grade in form between ridge-and-channel systems to well-developed beach cusps. The cusps occurred in areas of highest expected wave energy and the ridges in areas of lowest energy. This suggests that initially a ridge was deposited onto the foreshore, but wave energy was sufficient to erode ridges into cusps only where the cusps were observed.

(5) Additional observed modes of cusp formation were:

(a) A ridge several centimeters in height was deposited onto the lower foreshore on an ebbing tide. The ridge was breached by the swash and shaped into cusps over a period of several minutes.

(b) Delta-like deposits were observed forming seaward of channels in a ridge. The ridge areas between deltas could conceivably migrate shoreward creating cusp troughs and the deltas build vertically into horns, but this was not observed to completion.

(6) Measurements of cusp spacings as the cusps were forming in relatively low-energy, reflective environments agree reasonably well with computed spacings based on edge waves.

(7) Since cusp spacing due to edge waves is a function of wave period and beach slope, edge waves may be able to explain differences in cusp spacing between beaches exposed to different effective fetch lengths and along shorelines with variable beach slope.

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