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PRELIMINARY FIELD OBSERVATIONS ON BEACH CUSP FORMATION AND CHARACTERISTICS ON TIDALLY AND MORPHODYNAMICALLY DISTINCT BEACHES ON THE NIGERIAN COAST

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Abstract

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Between November, 1984 and December, 1986 observations of cusps were made on some tidally and morphodynamically distinct beaches on the Nigerian coast with a view to assess their origin, conditions for formation, distribution, dimensional and textural characteristics. No conclusive evidence can be forwarded at present with respect to their origin. Nevertheless, after formation, subsequent development and destruction are effected by swash action.

Field examination of most of the commonly cited cusp-dependent parameters indicates cusp existence and extinction to be primarily controlled by foreshore slope. Two levels of cusps were typical of the coarse to medium-grained, reflective and microtidal beaches of Badagry and Victoria. The lower-level cusps were consistently absent on the above beaches when mid-tide level slope exceeded 13° and 15°, respectively. On the contrary, the fine-grained, mesotidal and largely dissipative beach at Ibeno depicted only a single set of cusps which were consistently extinct on slopes less than 3°.

Cusps were most prevalent during calm coastal condition (November–January) and on foreshore segments depicting reflective beach-state. The regularity of cusp spacing was noted to improve with increase in beach reflectivity. The coarser beaches showed higher cusp relief while cusp length was longer on the fine-grained beach. In general, the spacing, slope, grain-size statistics and permeability of cusps noted in this study conform with those of earlier investigators on other beaches.

Temporal changes in dimensional characteristics of cusps are considered essential for evaluating the potentials of cusps as signatures of beach and surf-zone morphodynamics. The above defines the direction of further studies.

Introduction

Beach cusps are common foreshore features of sandy shorelines. Cloud (1966) has given an elaborate definition and description of cusps. Essentially, cusps are made up of more or less equally spaced projections or horns. Between the horns are depressions or bays.

The literature of cusps extends over a century. Detailed assessment of the documented opinions on the origin of cusps and the regularity of their spacing indicate contradictions and inconsistencies. However, an exhaustive review of the diverse ideas on origin, development and characteristics of beach cusp is not the aim of this report. Excellent and up-to-date accounts are provided in the following reports: Schwartz (1972), Gorycki (1973), Komar (1973), Guza and Inman (1975), Dalrymple and Lanan (1976), Dubois (1978), Sallenger

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(1979), Inman and Guza (1982), Allen (1982), Takeda and Sunamura (1983), Kaneko (1985) and Seymour and Aubrey (1985).

As rightly noted by Dubois (1978), and even up to the present time, studies on cusp formation have been attributed to certain physical characteristics of the incident waves, edge waves and beach topography. To what extent each or all of the above factors influence the existence or extinction of cusps on beaches under different circumstances is yet to be adequately resolved. On the other hand, it is likely that cusp formation demonstrates a classic example of equifinality. The latter concept implies, in a simplistic sense, the attainment of an end-product (in this case cusp formation) through different processes or pathways.

While the nature and mechanism of cusp formation remain a subject of controversy, experimental and model studies such as reported by Dalrymple and Lanan (1976), Guza and Bowen (1981), Inman and Guza (1982), Takeda and Sunamura (1983) and Kaneko (1985) have been rewarding in that equations have been proposed for predicting the occurrence, spacing and other dimensional characteristics of cusps. To varying extent, the different equations have been useful; however, the ultimate solution to the current controversy on cusp formation lies in a systematic field observation.

Besides a casual observation of the presence of cusps on some beaches flanking the Niger Delta by Allen (1970) and the initial measurements of cusp dimensions on the Victoria Beach (Antia, in press), no other investigation on cusps has been reported from the Nigerian coast. The objective of this preliminary investigation was to examine cusp characteristics and assess the critical conditions for their formation on three representative beaches fringing the 800 km long Nigerian coastline. The beaches exhibit a clear contrast with respect to grain size, tidal range and morphodynamic beach state. Beach state as employed in this report follows the usage of Wright and Short (1984). Finally, the significance of some of the commonly cited conditions for cusp generation and development are also assessed.

Study sites and procedure

The study is based on bi-monthly to monthly field visits of 1–4 days duration undertaken, with some interruptions, between November, 1984 and December, 1986 on the beaches at Badagry, Victoria and Ibeno (Fig.1). Badagry and Victoria beaches are located west of the Niger Delta and are microtidal (tidal range < 2 m); their grain sizes are medium to coarse (0.55–0.61 mm) and they modally depict a reflective beach state. Ibeno Beach is located east of the Niger Delta. It is mesotidal (tidal range 2–4 m) and fine-grained (0.34 mm); the beach state is largely dissipative.

The stretch of the beaches investigated was limited to 3 km for effective measurement of pertinent cusp characteristics and wave-state. Unlike the microtidal beaches, Ibeno Beach

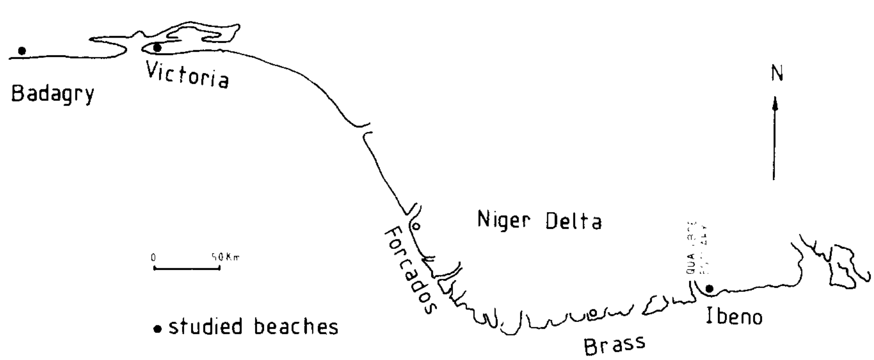

Fig.1. Outline of Nigeria's coast showing the beaches studied.

showed morphological variations in beach state in the longshore direction. A high dissipative beach-state is typical of the beach segments adjacent to the Qua-Iboe River estuary. Increased reflectivity is evident eastwards of the estuary.

Along the Nigerian coast, grain sizes are coarsest on the Badagry Beach and finest eastwards in the direction of the prevailing longshore current. The studied beaches are exposed to a semidiurnal tide and to predominantly southwesterly wind-generated waves. Wave heights off the beaches are typically less than 2 m, ranging mostly between 0.3 and 1.85 m. The highest waves on the beaches were commonly associated with high tidal conditions. The wave period varied between 7 and 13 s while longshore current was normally less than 1 m s^{-1}.

Orientation of the waves with the coast at breaker point ranged from 0° (parallel) to 12°. Compared with Ibeno Beach, plunging breakers were the dominant type at Badagry and Victoria. Multiple spilling breakers commonly occurring on Ibeno Beach (Ibe and Antia, 1983) are typical of the dissipative segment which also exhibits the widest surf zone.

Additional information acquired from the study sites included spacing, length and relief of cusps. The beach slope at the mid-tide level was consistently measured on cusped and non-cusped foreshores. Swash and permeability characteristics were also ascertained. Sediments were sampled from the surface and at depth from corresponding points on cusp horn and bay while the nature of beach lamination was regularly examined from shallow trenches.

In all cases, distance and elevation-dependent parameters were obtained with the aid of graduated tapes and staff. Time-related variables were recorded with a stop watch while a clinometer was employed in measurement of directions and slope of beach variables. In-situ permeability tests were made as previously described by Worrall (1969). Collected sediments were sieved on a Ro-Tap machine for 15 min at half-phi interval. Grain-size statistics were calculated from the sieve data using the method of Folk and Ward (1957).

Results and discussion

For the sake of clarity, cusp data from the three beaches summarized in Tables 1–3 will be discussed as follows: (a) distribution and dimensional characteristics; (b) textural characteristics; and (c) cusp formation and development.

(a) Distribution and dimensional characteristics

The first important disparity observed between the medium to coarse-grained microtidal beaches and the fine-grained, mesotidal counterpart was in the distribution of cusps over time. In contrast with the microtidal beaches, cusps were consistently observed at Ibeno Beach (Fig.2). The more persistent nature of cusps on the fine-grained beach of Ibeno, compared with the coarser-grained counterparts of Badagry and Victoria is at variance with earlier reports of Otvos (1964), Shepard (1973), amongst others. However, while Ibeno Beach exhibited only one level of cusps, extending in most cases from the seaward margin of the berm to slightly below the mid-tide level, the microtidal beaches showed two sets of cusps. The higher level cusps were restricted to the upper foreshore and they demonstrated a greater degree of stability compared with the lower set of cusps on the mid-foreshore.

The fact that lower-level cusps were encountered only once (December, 1984) on the microtidal beaches is indicative of their ephemeral nature. A number of other investigators, notably, Krumbein (1944), Komar (1973) and Williams (1973) had similarly recorded the occurrence of different levels of cusps from their field studies. Each of the cusp levels was related to a different wave-state; the upper level cusps were the consequence of higher wave activity. However, as in previous studies, the present observations did not reveal any remarkable phase difference between cusps of the different levels.

The consistent single cusp level evident on

Fig.2. Beach cusps on the dissipative beach state at Ibeno Beach.

the Ibeno Beach is the result of its low profile (<10°) and the mesotidal nature of this segment of the coastline. While the action of swash during rising tide would have a destructive effect on the lower cusps, if ever formed, the wave-state associated with ebbing tide would negligibly affect cusps on the upper foreshore. On the contrary, the lower tidal range and steeper foreshore of the microtidal beaches (8°–22°) tend to enhance the permanency of the upper-level cusps once formed.

In view of the dynamic nature of cusps on the Ibeno Beach, further discussion on temporal variability would relate to it. However, comparative assessment of the spatial distribution of cusps within the 3 km stretch of the studied beaches in December, 1984 (Fig.3a) indicated cusp density as follows: 11% on Badagry, 64% on Victoria and 63% on Ibeno Beach. Cusp density at Ibeno Beach, related to the previously defined coastal conditions off the Nigerian coast (Antia, in press), revealed a pattern (Fig.3b) which is consistent with the results of Russell and McIntire (1965). The latter noted a tendency for cusps to be well developed during the transition of beach conditions from winter to summer season of lower energy level.

At Ibeno Beach, the frequency of occurrence of cusps was highest (63%) during calm coastal conditions (November–January). The stormy coastal condition during May–October revealed the lowest cusp frequency with a value of 16%. The transitional coastal condition (February–April) had a frequency of 48%.

Measured dimensional characteristics of cusps on the microtidal beaches (Table 1) showed that the upper level cusps had larger spacing and poorer regularity of spacing when compared with the lower series. The noted larger spacing of the higher cusps conforms with the results of Russell and McIntire (1965) and Williams (1973), amongst others. The average monthly mean spacing of cusps on Ibeno Beach (Table 2) does not exhibit any trend. The mean spacing, however, ranged between 26–37 m while the standard deviation was between 3.97 and 11.28. The overall mean for the study period was 31 m.

Comparison of cusp data for the three beaches obtained in December, 1984 reveals that the constancy of spacing was best on the

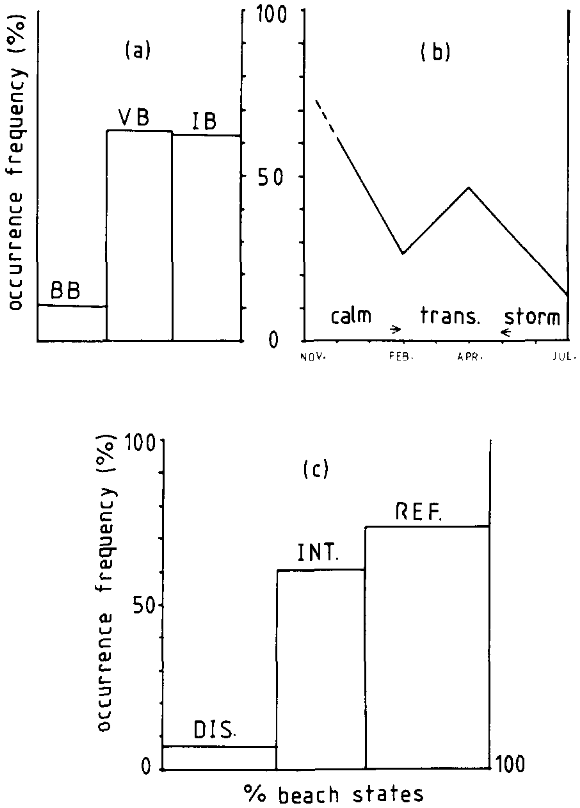

Fig.3. Cusp occurrence: (a) on Badagry Beach (*BB*), Victoria Beach (*VB*) and Ibeno Beach (*IB*) in December, 1984; (b) in relation to the coastal conditions at Ibeno Beach; and (c) as a function of spatial distribution in modal beach states at Ibeno Beach.

coarsest beach of Badagry which had a variation of 3–4% from the mean spacing. The fine-grained beach of Ibeno showed the poorest regularity in spacing, the variation from the mean being 34%. Victoria Beach, comprising mostly sand in the medium grade, indicated a spacing variation of 13% from the mean.

TABLE 1

Cusp spacing for the beaches of Badagry and Victoria (December, 1984)

	Badagry cusps		Victoria cusps	
	upper	lower	upper	lower
mean (m)	33.1	21.6	63.3	43.5
range (m)	30–34	21–22	47–76	34–50
standard deviation	1.46	0.55	11.28	5.69
% variation from mean	4.4	2.6	13.0	13.0

TABLE 2

Average cusp data for Ibeno Beach (November, 1984–July, 1985)

Months	Mean (m)	Standard deviation	Variation from mean (%)
November	33.1	4.18	12.6
December	33.0	11.3	34.2
February	26.4	3.97	15.0
March	26.6	5.55	20.9
April	37.0	9.15	24.7
June	31.5	9.34	29.6
July	32.4	5.16	27.9

Earlier studies of beach cusp characteristics have often overlooked the effects of beach and surf-zone morphodynamics. In this report, morphodynamics is considered in the perspective discussed in studies of Short (1979a, b), Wright et al. (1982) and Wright and Short (1984). On Ibeno Beach, mean cusp spacing showed a tendency to increase with increased reflectivity of beach-state. The dissipative segment showed a mean spacing of 34.7 m as against 37.3 m on the reflective segment. The intermediate beach-state on the other hand revealed a mean spacing of 36.9 m (Fig.4).

Thus, compared with the dissipative beach segment, the disparity in spacing of cusps is less significant for the intermediate and reflective beach segments. However, the regularity in cusp spacing was best on the reflective beach segment and worst on the dissipative. Furthermore, as shown in Fig.3c, cusps were

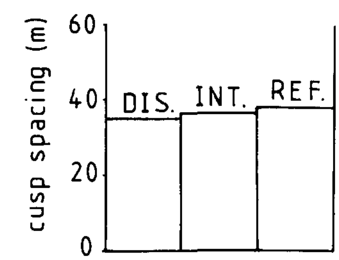

Fig.4. Mean spacing of cusps in relation to beach states at Ibeno Beach.

most widespread or stable in occurrence on the reflective segment whereas they were transient on the dissipative segment. The persistency of cusps on reflective foreshores has been reported by Inman and Guza (1982).

The generally higher regularity in cusp spacing evident on the microtidal (reflective) beaches and their counterpart at Ibeno are in consonance with the observations of Short (1979a), Sallenger (1979) and Seymour and Aubrey (1985). In essence, they consider the regularity of cusp spacing to be a major attribute of cusps formed by swash associated with subharmonic edge wave. The latter was most easily excited under reflective conditions. Similarly, Short (1979a) noted that cusps tended to be rare under dissipative conditions, the latter being prevalent at low tide.

Cusp length (the horizontal distance along the horn surface) was found to be longer on the lower-level cusps compared with the upper-level series. On Badagry Beach, the lower cusps were on the average about 10 m long as against 5 m for the upper cusps. The upper and lower series of cusps at Victoria Beach had a range of 7–10 m as against a cusp length of 12–19 m evident at Ibeno. Moreover, while the upper-level cusps revealed the apex of their horns to be rounded, the lower-level cusps and those at Ibeno depicted an acute shape.

From existing data, cusp length was found to reveal a closer relationship with swash length than with cusp spacing. Swash length varied between 5–19 m on the steep microtidal beaches as against 13–32 m on Ibeno.

Cusp relief (elevation between the highest point on the horn and the lowest point on the bay) was found to vary most on the Victoria Beach and least on Ibeno. On the former, relief was between 0.8 and 1.3 m against a range of 0.3–0.5 m at Ibeno. Badagry Beach showed a relief ranging between 0.5–0.8 m. The generally higher cusp relief on coarse-grained beaches has been well documented and discussed by Mii (1958).

Continuous measurements of beach slope at the mid-tide level reveal that cusps were consistently absent at Ibeno on beach segments with slopes of 3° or less. The critical slope values for extinction of the lower-level cusps on the beaches of Badagry and Victoria were 13° and 15°, respectively. Furthermore, with the exception of Badagry Beach, where contrast between the slope of the bay and the horn was not remarkable, the other beaches indicated a steepening of the horn relative to the cusp bay. The slope of cusp horn varied from 4°–7° on Ibeno and 14°–22° on Victoria; the cusp bay had slope values of 2°–5° and 5°–10°, respectively.

(b) Textural characteristics

A summary of textural characteristics of cusps from the three beaches is given in Table 3. Mean grain size was finer on the bays than the adjacent horns of cusps from the studied beaches. This observation has been widely reported in the literature. However, Ibeno Beach exhibited the least variation of 22% in mean grain size of surface sediments comprising the horns and bays of cusps. The largest disparity in mean size of cusp sediments was found at Badagry Beach. The variation in the latter beach was 43% as against 37% on Victoria Beach.

Sorting of sediments on all the beaches was better on the horns of cusps compared with the bays. However, unlike at Ibeno, the microtidal beaches showed elevated values of kurtosis on cusp bays. On the Victoria Beach, the horn sediments were platykurtic while those of the bays varied from platykurtic to leptokurtic. Both bay and horn sediments at Badagry Beach exhibited a tendency towards mesokurtic. Horn sediments at Ibeno Beach were predominantly leptokurtic as against a variation of platykurtic to very leptokurtic evident on the bays.

There was no distinct contrast between skewness of horn and bay sediments from Victoria Beach; both showed a strongly fine-skewed tendency. Bay sediments on Badagry Beach had a nearly symmetrical skewness as against a range of nearly symmetrical to strongly fine skewness depicted by the horns.

TABLE 3

Summary of average surface textural characteristics of cusps on the studied beaches

	Badagry		Victoria		Ibeno	
	horn	bay	horn	bay	horn	bay
mean size (phi)	0.58	1.02	0.77	1.23	1.96	2.52
size range (phi)	0.28–1.02	0.85–1.22	0.30–1.13	1.0–1.57	0.70–2.42	2.22–2.93
% variation in sizes of horn and bay	43.1		37.4		22.2	
sorting	0.44	0.54	0.56	0.64	0.39	0.51
skewness	(−0.09)–0.65	(−0.09)–(−0.10)	0.16–0.69	0.00–2.97	(−0.75)–0.37	(−0.14)–0.87
kurtosis	0.91	0.98	0.80	1.06	1.38	1.25

At Ibeno, the bay sediments had a tendency towards strongly fine skewness whereas the horn sediments revealed a strongly coarse skewness to strongly fine skewness.

Comparison of surface and sub-surface (3–10 cm) grain-size data of cusps showed an upward-sequence of fining and improvement in sorting on the Victoria Beach. Kurtosis and skewness did not yield any obvious trend. Cusps on the Badagry Beach showed a coarsening-upward sequence on the horns as against the bays with a fining sequence. Sorting, however, deteriorated with depth on the bays as against a slight improvement on the horns. No distinction was evident in skewness and kurtosis of surface and sub-surface sediments. Ibeno Beach cusps revealed a consistent upward-coarsening tendency on both horns and bays. Such a pattern was not obvious on the Victoria Beach cusps. The sorting pattern on the two beaches were however identical. Skewness showed no definite trend on both horns and bays. On the other hand, kurtosis indicated a progressively higher value with depth on the two beaches.

Apart from the widely recognized surficial sediment characteristics of cusps, very few studies have focussed on sediment characteristics with depth. An earlier study by Chafetz and Kocurek (1981) indicated a tendency for accumulational cusps to exhibit an upward-coarsening sequence on the horns. The noted sequence was well depicted on the beaches of Badagry and Ibeno as previously discussed. The origin of the sequence and its absence from Victoria Beach cusps are not easily explained.

Results of permeability tests made at one metre intervals along the cusp length indicate remarkably higher rates on the horns compared with the bays for all the three beaches. Disparity in permeability between corresponding points on the bays and adjacent horns ranged from 14% at Badagry to between 16 and 64% at Victoria and 16% at Ibeno Beach. Further studies made at the latter beach in December, 1986 (Fig.5) revealed that besides the higher mean permeability rates on horns (7.4 cm^3 s^{-1}) than bays (6.2 cm^3 s^{-1}), permeability rates were less variable on horns. The standard deviation of 60 measurements was 0.55 for the horns and 1.0 for bays of cusps.

(c) Cusp formation and development

The precise origin of cusps on the studied beaches can not be conclusively asserted from the present investigation. This is attributed to the ephemeral nature of cusps on the microtidal beaches, the paucity of wave-state data and the inability to observe the sequence of events preceding the formation of cusps where none initially existed. Nevertheless, cusp development is primarily sustained by swash action.

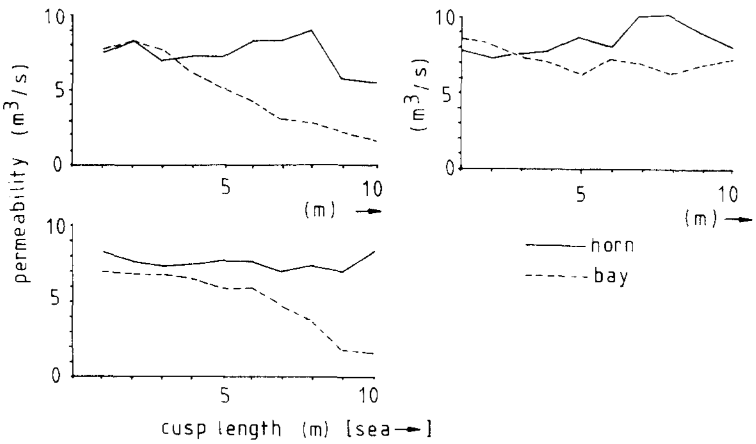

Fig.5. Permeability profiles of horns and bays of cusps on Ibeno Beach (December, 1986).

Cusps from the investigated beaches provide evidence for both erosional and depositional origins. For instance, Smith and Dolan (1960) had maintained that cusps were essentially erosional in origin on the basis of the observed truncation of beach lamination. Lamination on the beaches of Victoria and Ibeno were indicated by contrast in mineralogy (dark versus light grains) whereas at Badagry, lamination was defined by variations in grain size.

Truncation of beach lamination was only evident from trenches made on bays of cusps. Horns of cusps typically revealed parallel lamination (Fig.6). In the former case, the lamination was inclined at an angle of 3°–10° in the seaward direction. It is worth mentioning that some investigators such as Williams (1973) have discountenanced the use of truncated laminae as evidence for erosional origin of cusps. This is because truncation of laminae

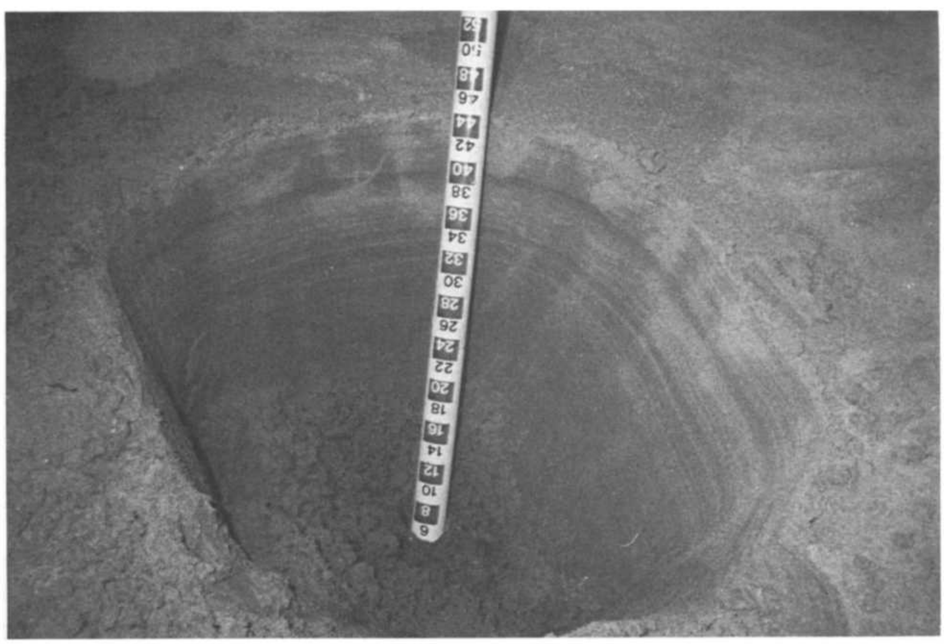

Fig.6. Parallel lamination of sub-surface of cusp horn at Ibeno Beach.

may be readily effected following the development of cusps by increased swash intensity or oblique waves transgressing the cusps.

Russell and McIntire (1965) proposed a depositional origin for cusps on the basis of the fact that the horns of cusps are consistently made up of coarser sediments and the bays of finer sediments. Such a relationship was typical of cusps from the studied beaches. Furthermore, in conformity with the upward-coarsening sequence found to be typical of beach cusp horns (Chafetz and Kocurek, 1981), the depositional origin may be ascribed to cusps formed on the beaches of Badagry and Ibeno where such a sequence was revealed.

The generally observed steepening of the beach profile associated with foreshore sedimentation provides another line of evidence in support of a depositional origin of cusps; the latter is the case if slopes are steeper on the horns compared with the bays. The cusps at Victoria and Ibeno indicated steeper slopes on horns than in bays; disparity in slope was not obvious on the beach of Badagry.

It is interesting to note that most of the proponents of edge-waves as the mechanism of cusp generation from an initial plane beach surface favour a depositional origin. Nevertheless, cusps on the studied beaches depicted similar swash patterns. Normally, wave swash spreads in such a manner that enhances intense backwash flow on the bays. Prior to swinging onto the bays, swash-entrained sediments were mostly deposited on the horns; the increased turbulence at the bays aggravates the erosion of its surface. Moreover, the delayed impact of the succeeding swash at the bays was also found to accentuate the accumulation of entrained sediments on the horns.

Within the range of environmental conditions prevailing at the study sites, this investigation reveals that the formation of beach cusps was fundamentally controlled by the foreshore slope. Mii (1958) had earlier arrived at the same conclusion from studies conducted along the coast of Japan. The importance of beach slope in determining the occurrence of cusps is well documented in a number of theoretical and experimental studies such as by Guza and Inman (1975), Inman and Guza (1982), Takeda and Sunamura (1983) and Kaneko (1985). However, a corresponding field assessment of the beach slope effect on cusp formation is rare.

Furthermore, many of the predicted conditions for cusp occurrence or extinction, such as breaker type (Kaneko, 1985), are dependent on the foreshore slope. However, the occurrence of the upper level cusps on the microtidal beaches is indicative of the fact that, within certain limits, a compromise exists whereby steeper beaches require a correspondingly larger-than-normal wave-state for the generation of cusps. In contrast with the upper level cusps at Badagry Beach, those at Victoria appear to be erosional in origin. The latter is inferred from the numerous berm scarps associated with the cusps coupled with the poor periodicity of cusp spacing (standard deviation equals 11.28).

In general, a foreshore slope of abnormal (relative to the limits of the wave-state) steepness or flatness would render swash action ineffective during the process of cusp formation. Consequently, the rarity of the lower level cusps on the microtidal beaches and the intermittent extinction at Ibeno Beach are attributed to a foreshore slope exceeding the critical value for the microtidal beaches and, in the case of Ibeno, lower than 3°.

Conclusions

The present study of beach cusps on the Nigerian coast showed the following:

(1) In response to critical slope values, cusps were wide-spread on the fine-grained, mesotidal and modally dissipative beach of Ibeno when compared with the medium-to-coarse-grained, microtidal and reflective beaches of Victoria and Badagry. In addition, two different levels of cusps were typical of the reflective beaches as against a single level at Ibeno.

(2) Cusps on Ibeno Beach were most prevalent during calm coastal conditions with a diminishing tendency towards high energy

storm conditions. The observed temporal distribution of cusps may also have a direct bearing with the changing morphodynamic beach-state. High dissipative beach conditions are prevalent during stormy coastal conditions when beach and surf-zone profiles become flattened through seaward sediment transport by waves of high steepness. The reflective beach conditions, found most conducive for prevalence of cusps (Inman and Guza, 1982), are generally encountered during calm coastal conditions. Berm development and steeper beach and surf-zone profiles often observed during the latter condition are results of shoreward sediment transport by the prevailing swells.

(3) On the microtidal beaches, the lower-level cusps were transient in nature, had smaller spacing and higher regularity in spacing than the upper-level cusps. Generally, cusp spacing was most uniform on the coarsest beach of Badagry and least uniform on the finest beach of Ibeno.

(4) Cusp spacing showed an increasing tendency on foreshore segments of reflective beach-state. Spacing was smallest on dissipative segments.

(5) Cusp length was longer on the fine-grained beach while the reverse was the case for cusp relief.

(6) Measurements of foreshore slope at the mid-tide level indicate that, for the given range of wave-state, sediment characteristics, modal beach-state and tidal regime, cusps were consistently extinct on the mid-foreshores of Victoria and Badagry when the slope exceeded 15° and 13°, respectively. Similarly, no cusp was osberved on the mid-foreshore of Ibeno Beach having a slope of less than 3°.

(7) Textural characteristics of cusp horns and bays observed in this study revealed remarkable conformity with reports from elsewhere documented in the literature.

(8) Both erosional and depositional evidence abounds for the origin of cusps on all the beaches; however, the relative importance of these can not be fully ascertained from the present study. Nevertheless, existence and extinction of cusps on the beaches were fundamentally controlled by foreshore slope and swash action.

Finally, this study suggests that beach cusps may serve as a first-order signature of changing wave and beach conditions. Temporal changes in beach cusp dimensions and modelling in the perspective of Sunamura (1984) will receive future attention.

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