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PROFILE CHARACTERISTICS OF SHINGLE BEACHES

by Robert Nicholls*

ABSTRACT

The shingle beaches in the eastern half of Christchurch Bay are discussed; as they have a range of profiles, typical of many of those found elsewhere in Southern Britain. The data comprises six monthly cross-sections, at 33 locations within the study area and much more frequent cross-sections at two contrasting intensive study areas (ISA) with, and without, a sand bar. A number of profile parameters are investigated including crest height, slope, volume, sweep zones and seasonal variability. The fundamental control of both the annual variation of wave power and occasional storm surges on profile development is apparent. Longshore morphodynamic and sedimentological changes and antecedent factors are also of significance. Important differences between the ISAs are noted, particularly with regard to cross-shore sediment transport. The difficulties of field measurements on shingle beaches are considered.

INTRODUCTION

Although on a worldwide basis most beaches are composed entirely of sand (0.063 to 2mm), there is a small, but significant proportion composed largely of pebbles and cobbles (4 to 256mm - henceforth termed shingle). They are found in many parts of the world, particularly in higher latitude countries, but are nowhere of more coastal engineering significance than in Britain (Carr, 1983a). It has long been recognised that shingle beaches have distinct characteristics from their sand counterparts such as steeper beach slopes (e.g. King, 1972; Komar, 1976; Carter, 1988). Their superior performance under wave action, for equivalent volumes of beach material, has made them attractive to the coastal engineer, particularly in Britain where the maintenance and nourishment of existing

*Institute of Marine Studies, Plymouth Polytechnic, Drake Circus, Plymouth PL4 8AA, U.K.

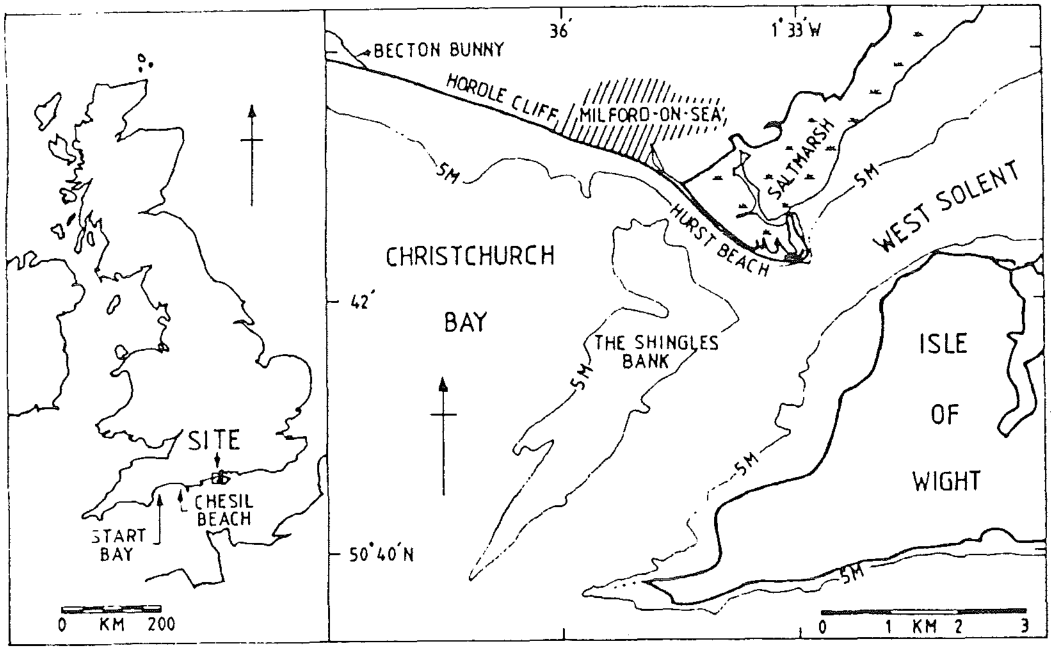

Figure 1. Location Plan. Crown Copyright. Reproduced from Admiralty Chart 2219 with the permission of the Controller of Her Majesty's Stationery Office.

shingle beaches (e.g. Foxley & Shave, 1983) and even the construction of artificial shingle beaches (e.g. Tyhurst, 1985) is receiving increasing interest.

This has raised important questions concerning short- and long-term profile development on shingle beaches in response to wave action. The behaviour of shingle, with subsidiary sand, is of particular interest as this represents the most common field situation in Britain. Unfortunately, there is a paucity of relevant scientific data. The extensive literature on sand beaches is not applicable because of factors such as permeability. Two-dimensional wave channel models are useful, but require field data for calibration. This paper reports the results of field measurements of shingle beach profiles in the eastern half of Christchurch Bay, between Becton Bunny and the Point of the Deep (Figs. 1, 2 and 3).

THE STUDY AREA

The beaches in the eastern half of Christchurch Bay are composed of shingle with a mean size in the range -2.5 to -5.5 phi, (6 to 45mm), with subsidiary fine to coarse sand (0.125 to 1mm) on the foreshore (Figs 1 and 2). The percentage of sand declines from 80% at Becton Bunny to 23% at the Point of the Deep. The offshore sediments are similar (Dyer, 1970). The net littoral drift is eastwards as indicated by Hurst Castle Spit (Nicholls & Webber, 1987a). The spit may be divided into two sections: (i) Hurst Beach, a transgressive shingle bank or storm beach between Saltgrass Lane and Hurst Point; and (ii) an accreting recurve between Hurst Point and the Point of the Deep (Fig. 3).

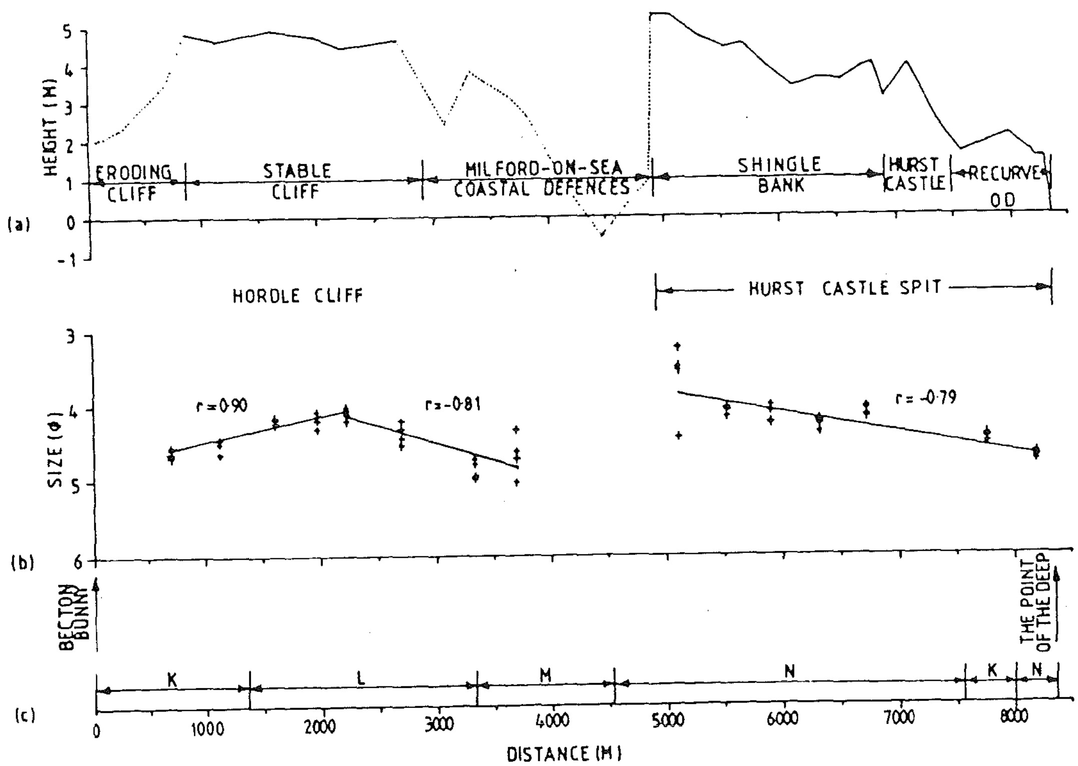

Figure 2. Selected beach characteristics between Becton Bunny and the Point of the Deep: (a) maximum beach elevation, May 1982; (b) mean grain size of the crest, November 1981; and (c) lower foreshore/offshore characteristics: K - lower foreshore sand beach; L - lower foreshore sand bar; M - nearshore sand bar; and N - no sand beach/bar.

The study area is exposed to waves generated in the Atlantic and the western English Channel. However, the Isle of Wight and the shallow shoal of the Shingles Bank, have a major effect on the energy and direction of waves impinging on the shoreline. The recurve is only exposed to waves generated within the small fetch of the West Solent (up to 22km)). In contrast to the British Isles generally, the tidal range is quite small, being 2.2m at springs. Storm surges can add up to 1m to water levels. There are fast tidal currents, attaining a maximum of 2.3m/s off Hurst Castle on mean spring tides.

Hurst Beach is being starved of shingle due to updrift coast protection at Milford-on-Sea and recently has experienced rapid recession of up to 3.5m/yr (Nicholls & Webber, 1987a; 1987b). In contrast, the wide shingle beach beneath Hordle Cliff (Hordle Beach) has been approximately stable and unlike Hurst Beach has an offshore sand bar (Fig. 2c). Thus, these two sites provide an interesting contrast and their behaviour was compared in detail.

METHOD

Thirty-three profiles with a spacing of 200 to 500m between the Point of the Deep and Becton Bunny (henceforth termed S1 to S33), were levelled at approximately six monthly intervals (Fig. 3). In addition, two intensive study areas (or ISA) comprising 11 profiles with a 15m spacing at Hurst Beach (henceforth called S89 to S99), and 3 profiles with a 25m spacing at Hordle Beach (henceforth called S29 to S29B), were levelled at approximately fortnightly intervals and after storms.

Profiles were measured in the following periods:

(a) S1 to S16, September 1980 to May 1982 - 4 surveys.

(b) S17 to S33, April 1981 to May 1982 - 3 surveys.

(c) Hurst Beach ISA, 16 March 1981 to 8 August 1982 - 36 surveys, usually at fortnightly or more frequent intervals between 16 March 1981 and 8 March 1981. Nine surveys were not completed because of factors such as limited daylight or weather conditions.

(d) Hordle Beach ISA, 13 September 1981 to 8 August 1982 - 23 surveys, usually at fortnightly or more frequent intervals between 13 September 1981 and 19 March 1982.

Visual wave observations were made on a daily basis at Milford-on-Sea, although there are substantial gaps in the record (Nicholls, 1985).

GENERAL PROFILE CHARACTERISTICS

The range of profiles are fairly typical of many of the shingle beaches in southern Britain (Fig. 4). A fine sand low tide beach or offshore bar may be present, particularly in the western part of the study area (Fig. 2c). This is considered as part of the offshore zone. The foreshore (average slope 5 to 13°) is backed by a supra-tidal beach face (average slope 7° to 20° and a beach crest or ridge (Fig. 4). One or more berms are usually present on the beach face. Landward of the crest there are two distinct morphologies (Fig. 4). Hordle Beach has accreted over the last 70 years (Nicholls & Webber, 1987a) and there are up to four 'fossil' shingle ridges beneath a stable cliff (e.g. Fig. 5d). At Hurst Beach, there is a landward slope (up to 13°) to a saltmarsh. The crest was a permanent feature at Hordle Beach and Hurst Castle Spit during the study period, attaining an elevation of up to 4.9m O.D., which is 3.8m above the highest tide (Fig. 2). Elsewhere, the crest is more ephemeral and prone to destruction during storms, as there is a lack of beach sediment. At the eastern end of the Milford-on-Sea coastal defences there is insufficient beach sediment to even develop a beach above high water (Fig. 2).

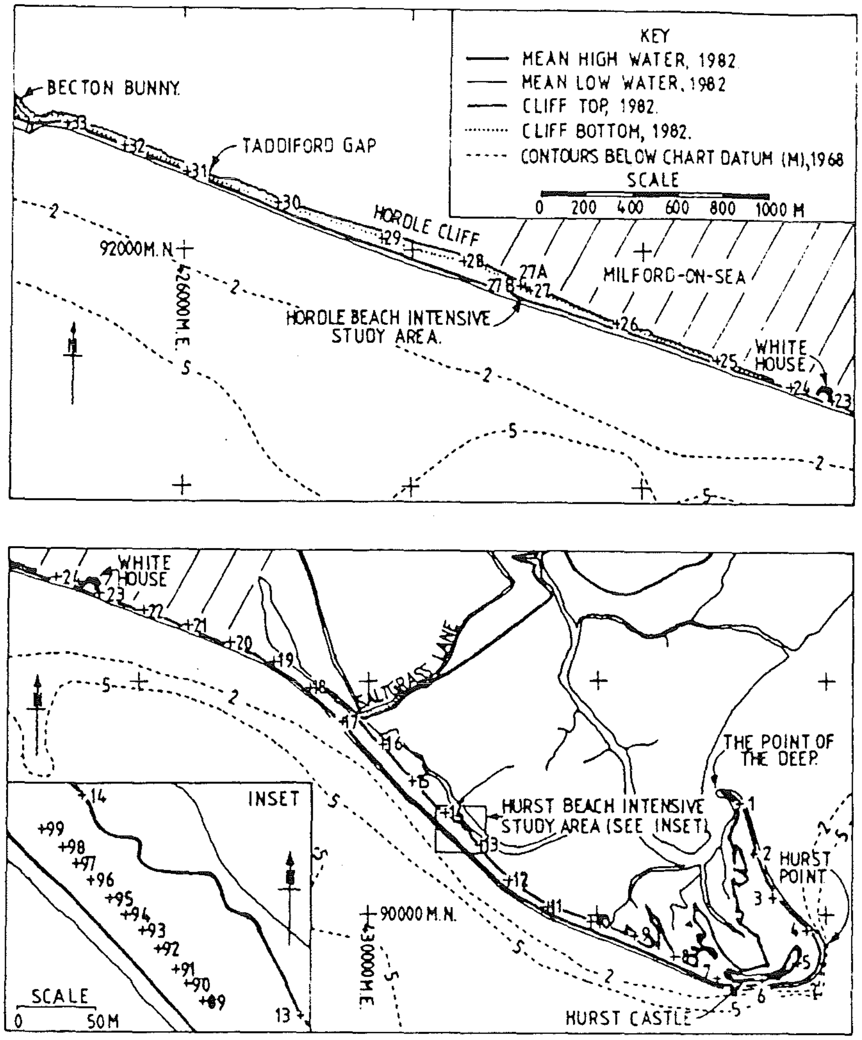

Figure 3. Location of beach profiles.

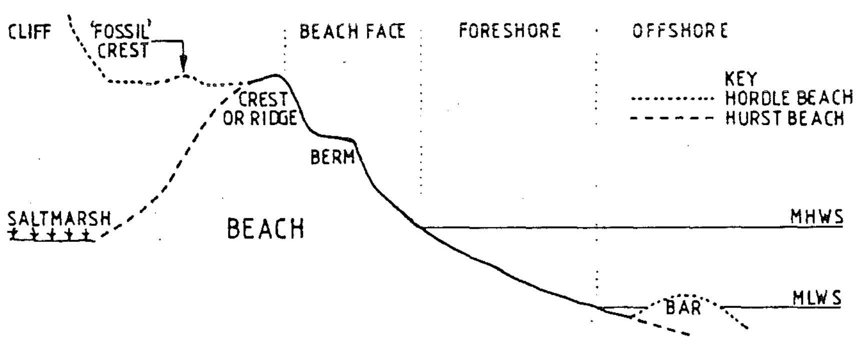

Figure 4. Typical cross-sections of the beaches at Hordle Beach and Hurst Beach.

Swash cusps are normally present west of Milford-on-Sea, regardless of the season. Waves usually break parallel with the shoreline at Hordle Beach, favouring their development (Inman & Guza, 1982) and up to three superimposed generations of such cusps have been observed on the same profile. In contrast, at Hurst Beach, cusps form less frequently and generally have a smaller amplitude than

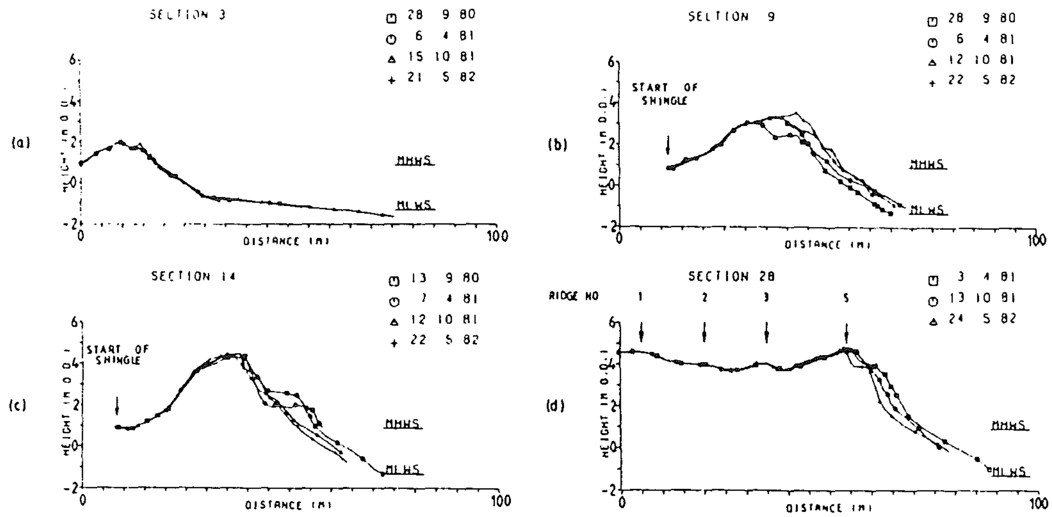

Figure 5. Sample beach profiles: (a) S3, (b) S9, (c) S14 and (d) S28.

the cusps at Hordle Beach. Two factors appear to be of significance: (i) the angle of wave approach is more oblique; and (ii) swell waves often break completely on the Shingles Bank.

Most of the beach profiles showed substantial changes during the study period (Fig. 5). The smallest changes occurred on the recurve of Hurst Castle Spit (S1, S2 and S3) which only experiences limited wave activity. Shingle was removed from S4 and S5 between September and November 1981, to nourish the beach in front of Hurst Castle (S6 and S7). S16 was also affected by coast protection works.

MOVEMENT OF MEAN HIGH WATER

There was a landward movement of mean high water (MHW) along most of the frontage in question (Fig. 6). On Hurst Beach, in 20 months, the maximum recession was 7.3m at S15, with 6.9m and 6.7m. recession at S13 and S7, respectively. However, there was significant local accretion of up to 5.1m at S9. Accretion also occurred at Hurst Point, while the recurve showed little net change. (The Point of the Deep accreted rapidly, although no accurate measurements are available). At Hordle Beach, in only 13½ months, the maximum recession was 3.3m at S29. The amount of recession diminished significantly towards the Milford-on-Sea coast defences.

At Hurst Beach the average recession rate of MHW for S16 to S6 (excluding S9 and S10) demonstrates that most recession occurred during the autumn and winter months;

Autumn 1980 to Spring 1981	2.3m
Spring 1981 to Autumn 1981	0.9m
Autumn 1981 to Spring 1982	2.0m

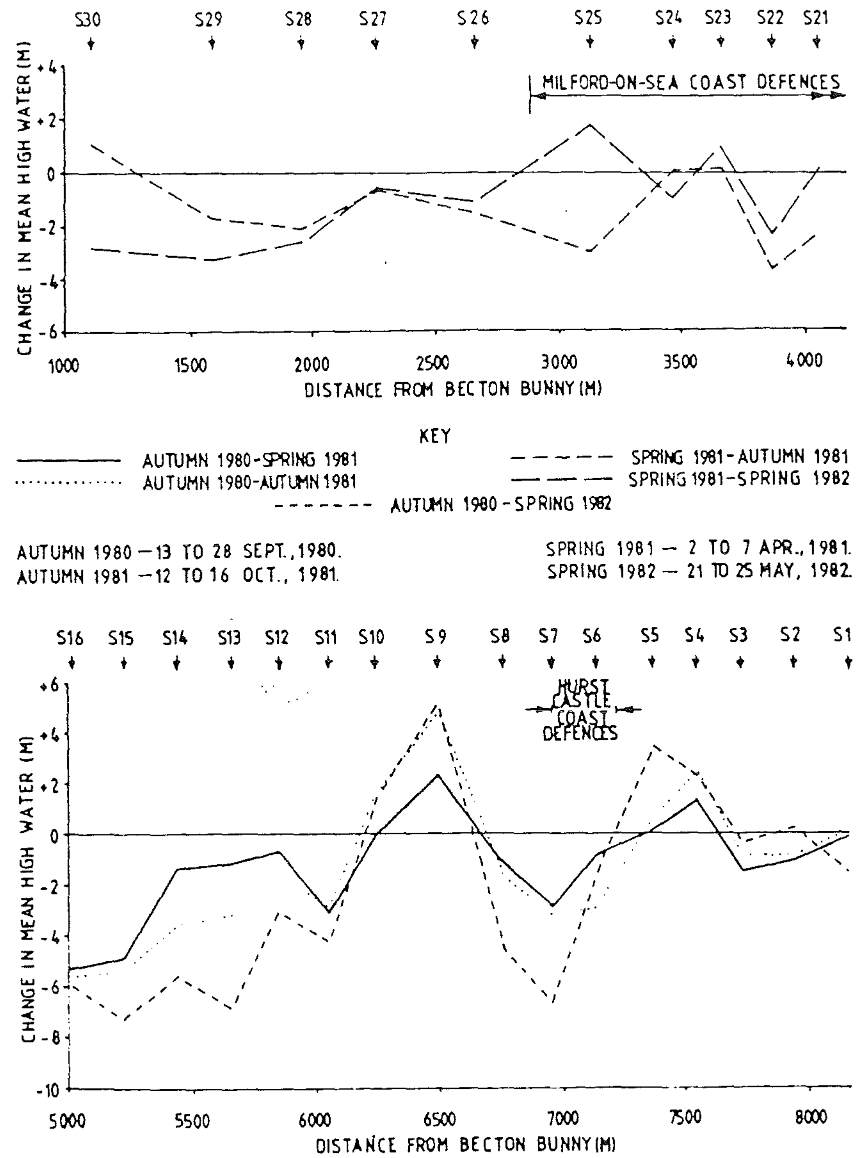

Figure 6. Movement of mean high water: a negative change indicates erosion and vice versa.

MAXIMUM CREST HEIGHT

One of the most striking and important features of a shingle beach is the wave-deposited beach ridge or crest. The elevation of the crest depends primarily upon (i) the maximum run-up and (ii) sediment availability. If a crest is too low in relation to the run-up, then overtopping or overwashing may occur (see Nicholls & Webber, 1988). The highest beach crests occur on beaches exposed to oceanic fetches, e.g. 14m above mean sea level on South Island, New Zealand (Kirk, 1980) and 13.7m O.D. at Chesil Beach, Dorset, England (Carr, 1983b). Despite its impressive dimensions, even Chesil Beach is overtopped/overwashed on occasions (Carr, 1983b; Nicholls & Webber, 1988). In the following section only the fully-developed crests at Hordle Beach and Hurst Castle Spit are considered.

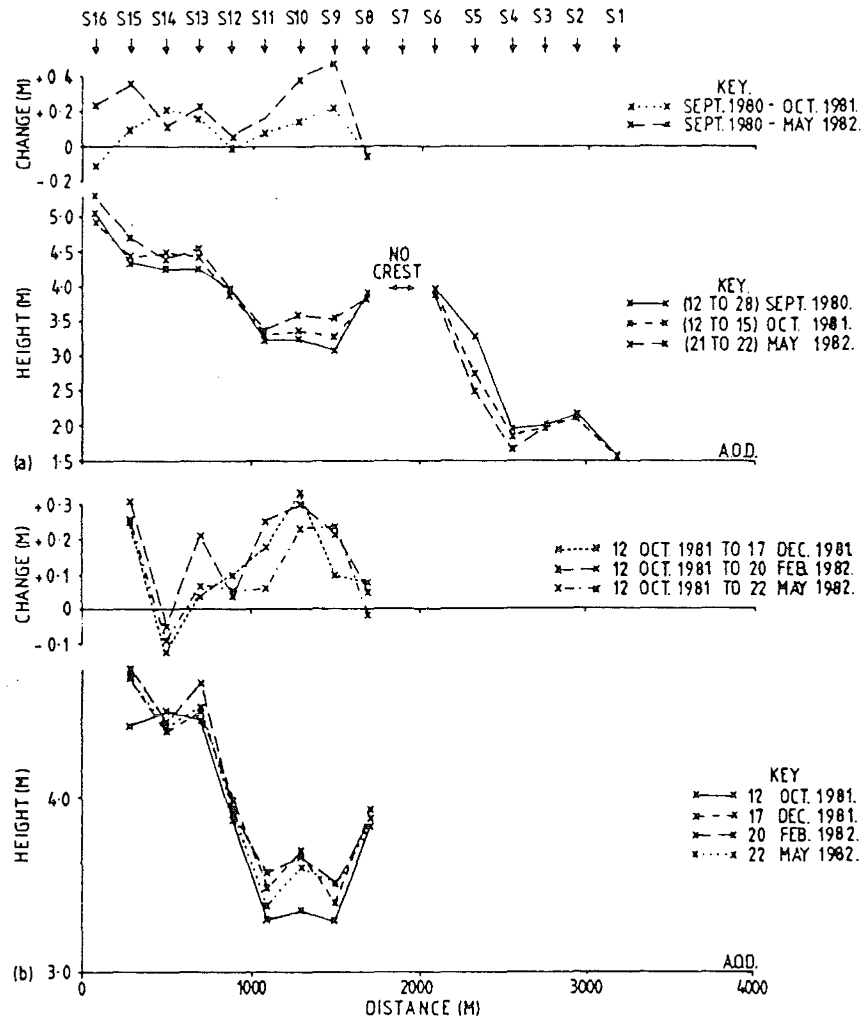

Figure 7. Longshore distribution and variation of the crestal elevation of Hurst Castle Spit. (a) September 1980 to May 1982. April 1981 data is excluded as it is very similar to October 1981. The changes at S4, S5 and S16 are largely artificial. (b) 12 October 1981 to 22 May 1982.

The highest crestal elevation on Hurst Castle Spit during the study period was 4.9m O.D. between S14 and S15 on 19 March 1982. However, this was a local maximum as the crest height varies by up to 0.3m over short longshore distances ($\leqslant$ 100m). Considering the crest heights measured at the beach profiles (Fig. 7a), there were two maxima along Hurst Beach of up to 4.7m O.D. at S14 and up to 4.0m O.D. at S6, separated by a minimum of, in round terms, about 3.5m O.D. in the vicinity of S9 to S11. (The crest at S16 was overwashed and then artificially reformed on several occasions during the study period and, therefore, is not considered). There is a major decline in crest height in the transition from Hurst Beach to the recurve from 4.0m O.D. at S6 to 2.0m O.D. at S4. This spatial variation reflects the longshore distribution of the maximum run-up, and illustrates the wave shadow of the Shingles Bank and the lower energy of the waves in the West Solent.

During the study period, all the crestal changes occurred during the autumn, winter or early spring months. Throat-confined overwashing only occurred in the vicinity of S16 and the crestal processes on Hurst Beach were dominated by overtopping and more limited crest-maintaining overwashing (sensu Nicholls & Webber, 1988). This caused limited landward recession of the crest together with a significant increase in its height at most profiles, the maximum vertical accretion being 0.45m at S9 (Fig. 7a). This appears to represent a recovery in crestal elevations following the overwashing of Hurst Beach during the autumn/winter of 1978/79 (Nicholls & Webber, 1988).

Most crestal changes in the period 12 October 1981 to 22 May 1982 occurred in a single event, this being a major storm surge on 13 December 1981 (Fig. 7b). The tidal elevation at Hurst Beach reached about 1.5m O.D. (0.6m above prediction), together with gale force south south-east to westerly winds. The maximum vertical accretion of the crest was 0.32m at S10. This demonstrates the important role of tidal elevation in crestal processes. On Hurst Beach, surges are of particular importance when compared to more exposed sites because, in addition to raising the still water level against the beach, they allow larger waves to pass over the Shingles Bank. In the study period, all the overtopping/overwashing events were associated with some surge component to the tidal elevation. Anthropogenic effects, most particularly pedestrian activity, redistributes freshly deposited crestal sediments removing any local surface undulations. Some of the minor fluctuations in crest height ($\leqslant$ 0.1m), e.g. 17 December 1981 to 20 February 1982 (Fig 7b) did not appear to be due to wave activity and may possibly be attributed to this mechanism.

Since 1982, throat-confined overwashing of Hurst Beach has occurred, (Nicholls & Webber, 1988), and washover throats as low as 2m O.D. were formed. Thus, the maximum crest height of Hurst Beach shows significant spatial and temporal variability.

In contrast, the maximum crest height at Hordle Beach (Fig. 8) was: (a) more uniform in height and generally higher than Hurst Beach, ranging from 4.5m O.D. at S27, to 4.9m O.D. at S29; and (b) inactive during the study period, although it was undercut in places (eg. Fig. 5d). Visual wave observations suggest that the breaking wave heights at the Hordle Beach and Hurst Beach ISA's are similar for most conditions. However, the maximum run-up (measured approximately using the strand-line) is consistently lower at Hordle Beach than at Hurst Beach; e.g. after the major storm on 9 October 1981 and the storm surge of 13 December 1981 it was 3.37 and 4.17m O.D., respectively, at Hordle Beach and 4.32 and >4.5m O.D. (i.e. the crest was overwashed), respectively, at Hurst Beach. The lower run-up at Hordle Beach is due to the sand bar and generally shallow offshore gradients (Figs. 2 and 3) which cause waves to break further offshore than at Hurst Beach.

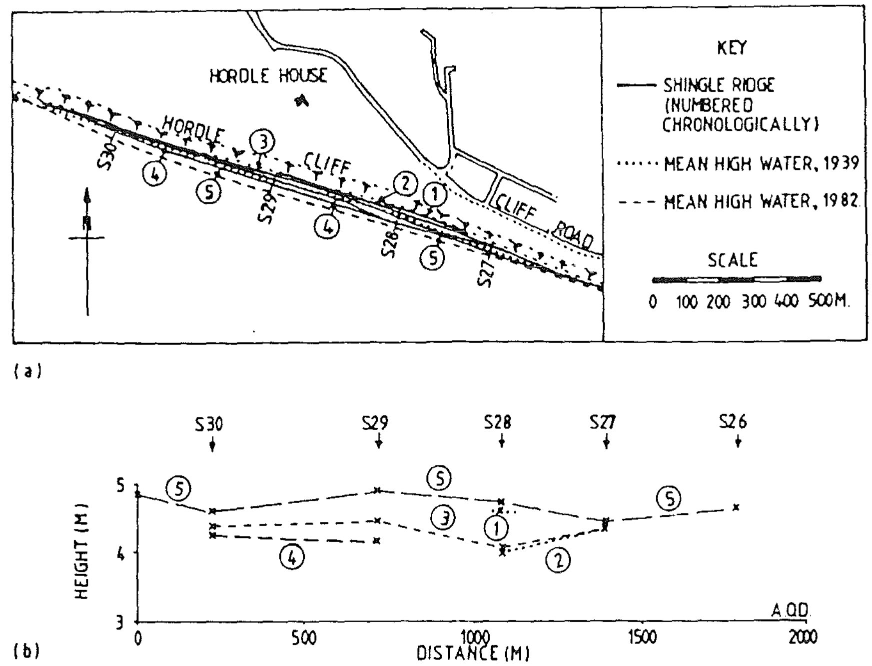

Figure 8.. The shingle ridges at Hordle Beach: (a) location; and (b) elevation on 24 May 1982.

The fossil beach ridges at Hordle Beach were up to 0.7m lower than the active ridge, although the oldest ridge was similar in height to the contemporary ridge. Unlike Hurst Beach, there is an excess of shingle at Hordle Beach, so the ridges can accrete vertically to the limit of run-up. Thus, this variability in height indicates significant temporal variability in maximum run-up. There are two possible explanations:

(i) changes to the sand bar and nearshore bathymetry off Hordle Beach and hence, the proportion of incident wave energy which reaches the shingle beach. Cartographic and chart analysis demonstrates that such changes have occurred (Nicholls, 1985);

ii) variability in the run-up of incident waves, e.g. the larger run-up of infrequent high energy swells will produce a higher crest than the run-up of the more typical storm wave/storm surge events.

The relative importance of these two hypotheses is not known. Whatever the cause, the ridges at Hordle Beach provide a record of the variability of maximum run-up at this site over a period of about 80 years.

BEACH SLOPE

The average beach slope of (i) the beach face (3.00 to 0.87m O.D.); and (ii) the foreshore (0.87 to -0.50m O.D.) were calculated for all the beach profiles. The boundaries were selected because:

(a) The beach face exceeded 3m O.D. on most profiles;

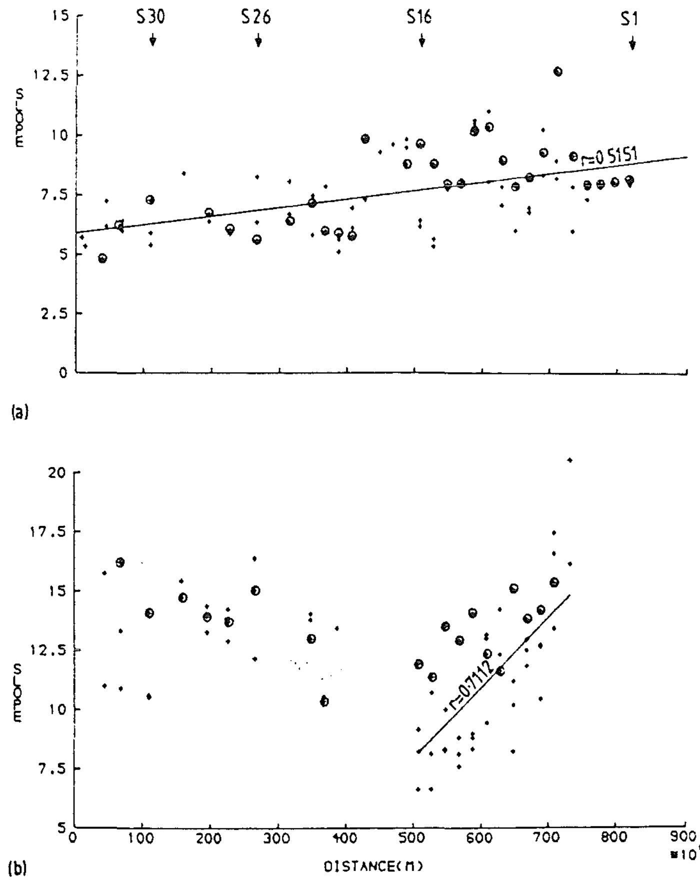

Figure 9. Beach slopes (in degrees) versus distance east of Becton Bunny during the period September 1980 to May 1982: (a) foreshore; and (b) beach face.

(b) The increase in slope from the foreshore to the beach face usually occurred near MHWS (0.87m O.D.) as the profiles were usually measured during spring tides.

Extrapolation was necessary to calculate some of the foreshore slopes; profiles were excluded if this exceeded 0.5m vertically. The foreshore has slopes in the range 4.8° to 12.7°, while the generally steeper beach face has slopes in the range 6.5° and 20.4° (Figs 9 and 10). Over short vertical distances, steeper slopes up to the angle of repose (≃35°) may occur and small (<0.1m) vertical beach scarps may be present for short periods on the foreshore (Nicholls & Webber, 1988).

The foreshore slope shows a significant correlation with distance (Table 1) and increased from Becton Bunny to the Point of the Deep (Fig. 9a). This appears to be primarily due to the longshore decrease in the proportion of sand in the foreshore sediments, as well as increasing offshore slopes. The foreshore was particularly steep at S11 and S12 (Fig 9a) where there is a bend in Hurst Beach, being steeper even than the beach face (Fig. 9b).

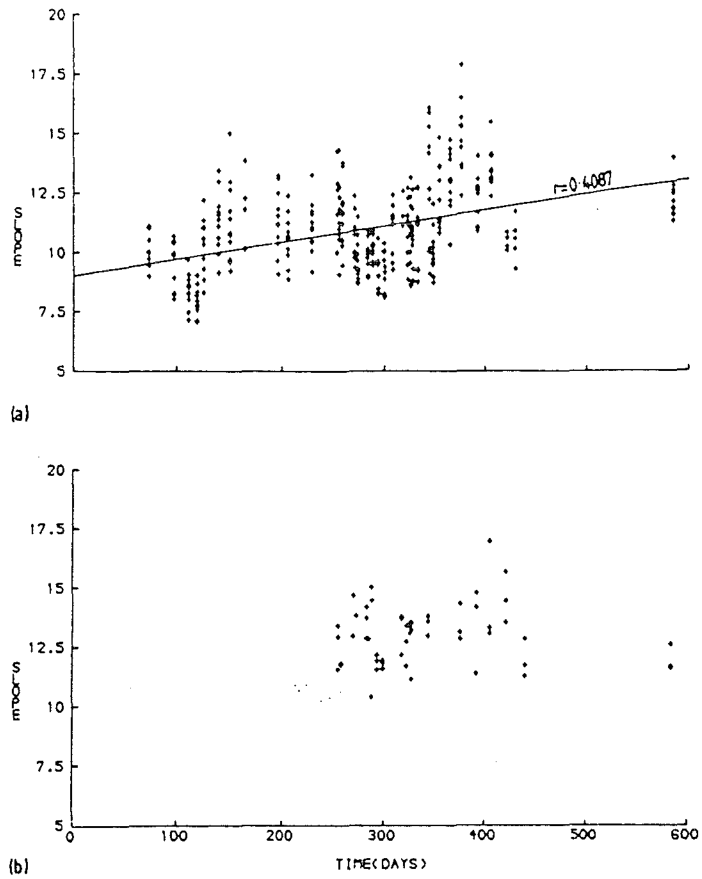

Figure 10. Beach face slopes (in degrees) versus time for the Intensive Study Areas at (a) Hurst Beach, and (b) Hordle Beach. Day 1 is 1 January 1981.

The longshore distribution of the beach face slope contained a distinct step in the values at Milford-on-Sea, although its magnitude declined with time and was negligible by the May 1982 survey (Fig. 9b). Between Becton Bunny and Milford-on-Sea, there is no longshore relationship, but along Hurst Beach, there is a significant increase in beach face slope (Table 2). This is probably due to a number of factors including: (i) a longshore increase in offshore slopes (Fig. 4); (ii) a longshore decrease in wave energy towards Hurst Castle (cf. King, 1972); and (iii) longshore changes in various sedimentological parameters. This latter factor is most difficult to assess. The surface beach face sediments are entirely shingle, but washover deposits containing subsiduary sand occur at depth (Nicholls, 1985). The proportion of sand within these deposits is thought to decline alongshore, in a similar manner to the sand within the foreshore sediments, improving the bulk sorting of the beach and hence increasing the beach face slope (cf. McLean & Kirk, 1969; Kirk, 1980).

The foreshore and beach face slopes along Hurst Beach both increased significantly with time (Tables 1 and 2) as might be expected with the rapid changes to MHW and crestal accretion already described. These results suggest increased coastal instability.

Table 1: Correlations of foreshore slope versus distance and time

	N	r	sig(%)
All Data (S1 to S33) v Distance	85	0.5151	99.9
Hurst Beach (S5 to S16) v Time	36	0.4592	99.5
Hurst Beach ISA (S89 to S99) v Time	208	-0.0829	-
Hordle Beach ISA (S27 to S27B) v Time	27	-0.5300	99.5

Table 2: Correlations of beach face slope versus distance and time

	N	r	sig(%)
All Data (S5 to S33) v Distance	72	-0.1513	-
Hurst Beach (S5 to S16) v Distance	46	0.7112	99.9
Hurst Beach (S6 to S16) v Time	44	0.5246	99.9
Hurst Beach ISA (S89 to S99) V Time	362	0.4087	99.9
Hordle Beach ISA (S27 to S27B) v Time	55	0.0351	-

Table 3: Beach slopes (in degrees) at the Hordle Beach and Hurst Beach ISAs between 13 September 1981 and 8 August 1982.

		N	Mean	Std. Dev.	Min.	Max.
Hordle Beach	Foreshore	26	6.78	0.75	5.53	8.37
	Beach Face	55	13.01	1.26	10.41	17.00
Hurst Beach	Foreshore	120	8.16	1.46	5.18	11.95
	Beach Face	223	11.16	1.81	8.04	17.81

Considering the ISAs (e.g. Fig. 10), at Hordle Beach the foreshore was less steep, while the beach face was more steep than at Hurst Beach (Table 3). Thus, there was a more marked break in slope at MHWS at Hordle Beach than at Hurst Beach (Fig. 12). Comparing individual surveys, there was considerable spatial variation (up to 7°) which demonstrates how much the profiles vary alongshore, although the temporal variation is approximately in phase indicating that the constituent profiles of each ISA behaved similarly. This was also the case when comparing the ISAs, although some deviation in behaviour is also noted e.g. between 16 September and 21 October 1981 (Days 259 to 294), the slope of the beach face exhibited a local maximum at Hordle Beach and a local minimum at Hurst Beach (Fig. 10). The temporal variation of the slopes was also larger in magnitude at Hurst Beach than at Hordle Beach, particularly on the foreshore (Table 3).

The beach face slope showed a significant increase with time at the Hurst Beach ISA for the entire dataset and most of the individual profiles (Table 2, Fig. 10a). This is similar to the trend discussed for Hurst Beach as a whole. However, the foreshore slope showed no significant change with time (Table 1). At the Hordle Beach ISA the foreshore slope decreased significantly with time (Table 1) while the beach face slope showed no significant change (Table 2).

VOLUMETRIC CHANGES

The beach volume of the entire study area and the ISAs was calculated for each set of profiles (Nicholls, 1985). Suitable lower boundaries were selected, usually at -1.0m O.D. On Hurst Beach, the settlement of the underlying saltmarsh surface due to the weight of the beach required a lower boundary of variable elevation.

Within the study area, the total volume of beach sediment above -1.0m O.D. is about $1.1 \times 10^6 m^3$, the bulk of which (89%) occurs at Hurst Castle Spit and Hordle Beach. This frontage only occupies 62% of the study area in terms of distance. The volume of beach sediment between Taddiford Gap and S26, i.e. Hordle Beach ($4.1 \times 10^5 m^3$), is approximately double that at Hurst Beach ($2.1 \times 10^5 m^3$), both in absolute and m^3/m terms.

The cumulative changes in beach volume on Hurst Castle Spit show a loss of beach sediment (Table 4). These losses agree approximately with the predicted deficit to the sediment budget caused by the construction of coastal defences at Milford-on-Sea (Nicholls & Webber, 1987a). The

Table 4: Cumulative volume changes on Hurst Castle Spit (September 1980 to May 1982)

	Volume in m3			
	Sept 80	April 81	Oct 81	May 82
S7 to S1	0	-1,300	-2,500	- 1,900
Saltgrass Lane to S7	0	-9,000	-9,900	-14,600

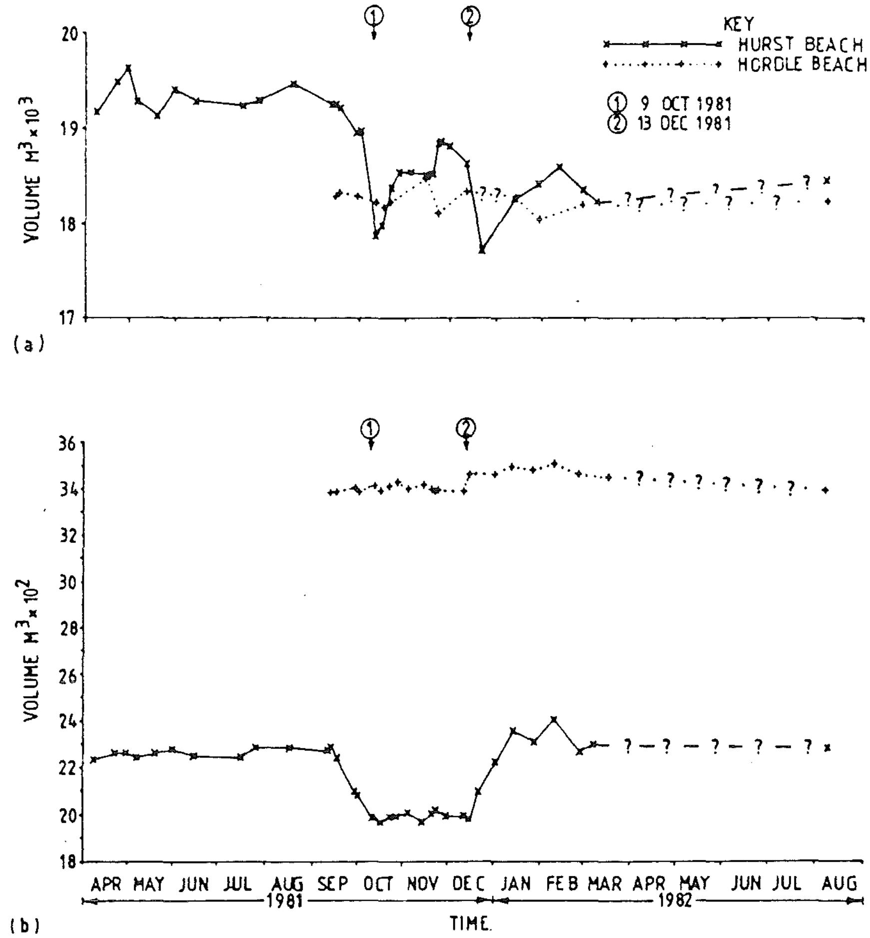

Figure 11. Volumetric fluctuations at the Intensive Study Areas (ISA) above a lower boundary of (a) - 1.0m O.D. at Hordle Beach and O.D. at Hurst Beach (i.e. total volume) and (b) 3m O.D. The Hurst Beach ISA is 165m long while the Hordle Cliff ISA is 75m long.

volumetric calculations also demonstrate that at least 9000m^3 of saltmarsh deposits were eroded from the foreshore of Hurst Beach. Such erosion is an integral part of the recession of Hurst Beach. Most volumetric changes occurred during the autumn/winter months, rather than the spring/summer months (Table 4).

The volumetric fluctuations of both ISAs, including the total volume, are shown in Fig. 11. The lower boundary at the Hordle Beach ISA, is -1.0m O.D. while at the Hurst Beach ISA it is O.D. There were significant volumetric fluctuations at Hurst Beach, most of these occurring in the autumn and winter months. In contrast, at Hordle Beach the volumetric fluctuations were much smaller (Table 5). This is surprising, particularly as the repeated destruction and construction of the large swash cusps would tend to overestimate volumetric fluctuations. The rapid volumetric losses to Hurst Beach during storms (up to 1100m^3 or 7m^3/m) predominantly represent cross-shore transport as much of the material is rapidly (in weeks) returned to the foreshore and

Table 5: Total range in volume in the period 16 September 1981 to 19 March 1982

Datum (m O.D.)	Hurst Beach ISA (m^3/m)	Hordle Beach ISA (m^3/m)
-1.0	-	4.2
0.0	9.1	-
3.0	2.6	1.7

beach face. Therefore, a rapid decrease in the volume of the beach results in accretion beneath O.D. and vice versa. This exchange includes the offshore zone under certain wave conditions. Two storms caused significant offshore sediment movement at Hurst Beach: these being on 9 October and 13 December 1981 (Fig. 11). The latter storm was associated with a major storm surge, but the tidal and wind conditions associated with the earlier storm occurred on other occasions during the survey period. Thus, it is unclear why it caused such large beach changes. In contrast, the 9 October storm caused negligible volumetric changes at Hordle Beach (Fig. 11a). (No comparative data is available for 13 December.) This important observation, combined with the low volumetric fluctuations throughout the study period, demonstrates that at Hordle Beach any sediment exchange across the -1.0m O.D. contour is limited and the bulk of the active shingle is confined to the foreshore and beach face. Thus, the profile dynamics are fundamentally different to those at Hurst Beach.

Not surprisingly, changes above 3.0m O.D. are less frequent and of smaller magnitude than those affecting the whole beach (Table 5). At Hordle Beach only one significant event occurred: accretion on 13 December 1981 (Fig. 11b). At Hurst Beach the upper beach was approximately stable during the spring and summer, but more variable in the autumn and winter. The storm surge on 13 December 1981 caused no net change, although this disguises a balance between beach face erosion and crestal accretion.

There was a net decline in the volume of the Hurst Beach ISA of about 700m^3 (or about 4m^3/m) between September 1981 and August 1982. The losses occurred between the O.D. and 3.0m O.D. contours as the net volumetric change above 3.0m O.D. was negligible (Fig. 11b). This is consistent with the increasing beach slopes already discussed.

The average sweep zones were calculated for the Hurst Beach and Hordle Beach ISAs using 17 common sets of profiles (Fig. 12). Summer conditions are under-represented, but as the largest volumetric changes occur in the autumn and winter months it is probably of little quantitative significance. The profiles were not extrapolated, so the total sweep zone

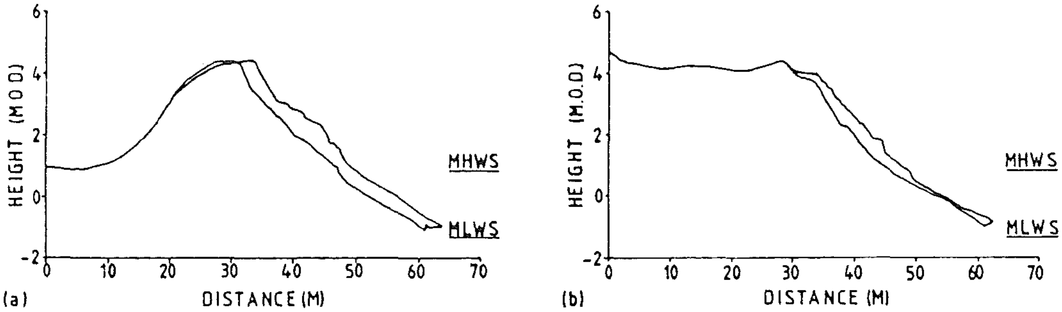

Figure 12. Sweep zones at (a) S99 and (b) S29.

Table 6: Average sweep zones at the ISAs between 13 September 1981 and 8 August 1982.

	Total Sweep Zone (m^2)	Sweep Zone above 1.0m O.D. (m^2)
Hurst Beach	21.52	15.80
Hordle Beach	13.0	9.84

and the sweep zone above 1.0m O.D. were both calculated (Table 6). In both cases a t-test showed that the average sweep zones at Hordle Beach are significantly smaller than at Hurst Beach (sig. 99.9%), although proportionally they are more similar than the volumetric fluctuations (Table 5). In particular, the magnitude of the sweep zones are most similar on the beach face (Fig. 12).

SEASONAL CHANGES

Shepard (1950) described a now classic seasonal cycle of beach changes in southern California, comprising erosion in the winter and accretion in the summer, and hence the terms 'winter' and 'summer' profiles entered the literature. It has subsequently been realised that these cycles are not universal as the seasonal pattern of wave activity shows great spatial variability (e.g. Komar, 1976). In fact, even Shepard (1950) notes beaches which did not conform to the general cycle, most particularly a relatively coarse-grained beach at Carmel. Carr, Blackley & King (1982) have demonstrated that Shepard's model is inappropriate for British waters. The autumn and winter months are characterised by greater profile variability than the summer months due to the greater wave energy, but not by distinctive profile types.

Similar conclusions have been reached for the beaches in Christchurch Bay. The monthly fluctuation of wave power in Poole and Christchurch Bays averaged over three years (1975 to 1977) shows a strong seasonal distribution; the year can be divided into two six month periods of relatively high wave power (October to March) and relatively low wave power (April to September) (Henderson, Donald & Webber, 1979). Only 20% of the annual wave power occurs in the latter period. Many of the profile characteristics already discussed also show the greatest changes/variability in the autumn and winter months. Recovery of the beach after storms (e.g. volumetric changes) is quite rapid over a timescale of days or weeks not seasons. The size of the active beach zone also shows seasonal fluctuations, being smallest in the spring and summer months. Crestal processes appear to be virtually impossible between May and August (inclusive), unless the crest has been reduced in height by overwashing, due to the low wave energy and the low probability of a significant surge.

Most profile types can be developed at any time of the year and the terms 'winter' and 'summer' profile are meaningless at this site. The only profile type confined to the 'high energy' months is the simple convex profile with no berm or cusps, as this only develops when the run-up reaches the top of the beach face. These profiles have a short life, of at most days, before onshore sediment transport produces a berm. The more typical beach profile with one or more berms, with or without swash cusps, may be present throughout the year.

DISCUSSION

The shingle beaches in the eastern half of Christchurch Bay show considerable spatial and temporal variability. These results demonstrate a lack of equilibrium and suggest that rapid coastal changes will continue. Most profile changes occur in the autumn and winter months when the wave power is greatest. Storm surges are significant, particularly with regard to changes on the upper part of the beach. Increases in still water level of varying timescales are known to promote offshore sediment transport (e.g. Komar & Holman, 1986), while the wave energy associated with surges in Christchurch Bay can be significant; e.g. 5% of the wave energy during 1976 occurred during a single surge on 14 October 1976, although it was a relatively calm year (Henderson *et al*, 1979).

The Hordle Beach ISA experiences less profile variability than the Hurst Beach ISA. The major reason appears to be that the offshore zone at Hordle Beach is much more dissipative than at Hurst Beach (cf. Wright & Short, 1984). This reduces the available wave energy on the shingle portion of the beach, particularly at low water when it can be zero. In addition, the volume of the Hurst Beach ISA was declining and the beach contours were receding, while at Hordle Beach they were both approximately stable. This net change will contribute to the difference in variability.

Thus, for similar wave conditions, shingle beaches fronted by a less steep sand foreshore or offshore zone are more stable than shingle beaches without such protection. Many of the shingle beaches in Britain are of the former type. The sand provides a seaward limit for the offshore transport of shingle which is often above low water (cf. Caldwell & Williams, 1986). In contrast, on unprotected shingle beaches exchanges of shingle between the beach face/foreshore and the offshore zone can occur under the appropriate wave conditions as demonstrated in Start Bay by Carr et al (1982) and on Hurst Beach by the volumetric calculations and also tracer studies (Nicholls & Webber, 1987c). The larger run-ups also necessitate relatively higher beach crests. Thus, a significantly larger volume of shingle is required to attain stability. In general, beach maintenance will be considerably easier on 'protected' shingle beaches than their unprotected counterparts.

All shingle beaches contain a subsiduary sand component, at depth, if not on the surface; even apparently pure shingle beaches such as Chesil Beach (Carr & Blackley, 1973). This subsiduary sand has a major influence on the beach permeability and hence slope, if sufficiently close to the surface (McLean & Kirk, 1969). Within the study area, the longshore decline in the proportion of sand between Becton Bunny and the Point of the Deep partly controls a longshore increase in the foreshore slope and the beach face slope on Hurst Beach. If the beach face shingle contains sufficient sand, beach scarping may occur; this essentially artificial situation having occurred during beach nourishment (Nicholls & Webber, 1988). The role of subsiduary sand within a shingle beach is not often considered, but clearly requires further investigation.

Hurst Beach is a rapidly eroding shingle bank with recession rates of up to 3.5m/yr between 1968 and 1982 (Nicholls & Webber, 1987a). During the study period, the foreshore and beach face contours at many of the profiles showed landward recession of a similar magnitude. However, the crest showed much less movement and the landward slopes of the bank were virtually stable (e.g. Fig. 5c), because the recession of the upper and landward portions of the beach occur spasmodically due to major overwashing events. The study period followed a major overwashing event of Hurst Beach on 13 February 1979 (Nicholls & Webber, 1988), which would have reduced the crestal elevations and beach slopes. Thus, the crestal accretion and increasing beach slopes measured during the study period represent the 'recovery' of the beach from the overwashing event. Wright & Short (1984) have emphasized the importance of antecedent conditions in beach morphodynamics. At Hurst Beach the overwashing/recovery cycle exerts an antecedent control on the profiles which is absent at Hordle Beach.

Finally, it is worth noting some of the problems of field studies on shingle beaches. The beach profiles at both intensive study areas showed considerable longshore variation. In future studies it is recommended that the beach be surveyed as a three-dimensional feature.

Storm-induced changes are difficult to measure as, after the storm abates, there is generally a delay before surveying, during which some recovery may occur. A new method for measuring the depth of disturbance on shingle beaches using segmented aluminium columns will also measure the maximum cut during storms (Nicholls, 1989). These difficulties may suggest that physical modelling of shingle beaches (e.g. Powell, 1988) is a better approach than field study. However, while model studies allow controlled experiments, it is vital that their results are calibrated against accurate field data (e.g. Nicholls & Webber, 1988). A more complete understanding of the dynamics of shingle beaches will best emerge by a combination of the two approaches.

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