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Beach cut in relation to net offshore bar migration

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ABSTRACT

This paper investigates the relationship between beach cut and the process of net offshore bar migration using a 3.4 yr morphological data-set collected at Wanganui, New Zealand. During the study period the following four types of beach cut occurred: four episodes of laterally-extensive erosion: three episodes of rip-embayment erosion; three episodes of overwash-channel erosion, and six episodes of berm-front erosion. Each type of erosion had distinctive physical and temporal dimensions, and characteristic morphological and energy associations. Furthermore, each type of erosion occurred systematically during a particular time within the inter-generation period of the NOM cycle. Overwash channel and berm-front erosion occurred earlier in the period, under double bars and intermediate morphologies, i.e. 2D to 3D. Rip embayment erosion occurred during the earlier/middle part of the inter-generation period, under double bars and strongly 3D morphology, while laterally extensive erosion occurred later in the period under single bars and more linear (2D) morphology. While wave energy conditions also varied systematically during inter-generation periods, morphological control nevertheless appears to be of fundamental importance.

ADITIONAL INDEX WORDS: beach erosion, inner bar, outer bar, surf zone, NOM, Wanganui, New Zealand

INTRODUCTION

Exposed sand-dominated beaches are often subject to wave-induced erosion during higher energy conditions. In the most severe cases, erosion may extend into the foredune with consequence for engineering structures, beach-front property and dune stability. While coastal research has often focused on shorter-term beach/dune/energy interactions, e.g. see Basco and Shin, 1996; Zheng and Dean 1996, longer-term controls are also important, e.g. see Psuty et al., 1988; Dolan et al., 1991.

Recently, Guillen et al. (1999) identified laterally extensive episodes of dune-toe erosion and accretion along the coast of Holland, and found that the return period of these oscillations (several years) correlate with the offshore migration return period of subtidal sand-bars. This repetitive, or cyclic, bar migration process is referred to as net offshore bar migration (NOM). It consists of a bar forming on the lower foreshore, systematically migrating seaward across the surf zone, and finally degenerating and disappearing several years later in the outer surf zone. This process has been documented for several multi-bar coasts throughout the world (see Shand and Bailey, 1999, for review).

An investigation by Shand and Shepherd (2003) into backshore erosion at Wanganui on the southwest coast of the New Zealand North Island, found that such laterally extensive erosion occurs prior to the generation of a new bar within the NOM cycle. At this time, the number of bars in the cross-shore direction is reduced, the inter-tidal beach has greater width and more uniform (or dissipative) morphology, and the inner bar has a linear, or 2-dimensional (2D), form.

This paper is an extension of the work of Shand and Shepherd (2003). In particular, it analyses all episodes of erosion, i.e. both backshore erosion and also upper beach erosion, which are evident within the same 3.4 yr record of morphological data used by Shand and Shepherd (2003). In addition, it considers the nature and role of the associated energy conditions.

FIELD SITE

The field site is ~1.5 km from the Wanganui Rivermouth on the southwestern coast of the New Zealand North Island (Fig 1). The nearshore is characterised by fine sand (2 to 3 phi), has a cross-shore slope of ~0.0092 and width of ~530 m. Two subtidal sand-bars are usually present; these bars undergo net offshore migration with the mean life-cycle of a bar being ~3 yrs (Shand et al., 1999). The foreshore is characterised by medium sand (1.7 phi), has an average cross-shore slope of ~0.055 and an average width of ~85 m. About 30% of the time a small amplitude (swash) bar is present on the lower foreshore. The foredune is characterised by fine sand (2.2 phi), is ~5 m high, has a seaward slope of ~0.176 (10 deg) and the vegetation-front is encroaching seaward at ~1 m/yr. The backshore area, i.e. that area between the foreshore and the foredune, is ~10 m wide.

The mean neap tide range is 0.8 m and the mean spring tide range is 2.4 m. The mean deepwater significant wave height is 1.3 m and the 5% excedence value is 2.5 m. The mean wave period is 10.1 s (range 3.5 s to19 s) with sea wave conditions occurring for ~75% of

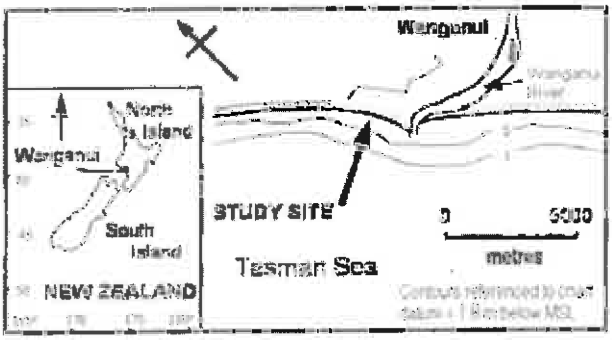

Figure 1 Location map of the Wanganui study site

the time and swell waves for the remaining time. Approximately forty two percent of waves approach from the west, ~24% from the south and ~34% lie within one degree of shore-normal. The prevailing WNW wind approaches the coast at ~35 deg from the shoreline, and the wind speed 5% excedence value is 12.4 m/s. The mean value for longshore currents within the inner surf zone is 0.42 m/s and the 5% excedence value is 1.01 m/s. Wave height, wind strength and the magnitude of longshore currents are all positively correlated, as are the direction of these process variables (Shand et al., 2001).

METHODS

Episodes of backshore erosion were identified on morphological maps which cover several hundred metres of coast; examples are shown in Fig 2: The maps were produced from high resolution ground surveys carried out at fortnightly intervals between August 1991 and March 1995. Errors, based on 95% confidence intervals, are estimated to be 5 m in the cross-shore direction and 10 m in the longshore direction. To detect morphological variation, a 300 m long study area was used. The morphological maps were also used to determine the (average) cross-shore location for the low tide step; this location was used as a proxy for the seaward boundary of the foreshore. In addition, plan-view morphological configurations of the beach and inner bar system were derived from the maps.

Cycles of NOM were identified from time-series of cross-shore bar location derived from 4 min time-exposure photographs. The photographs were taken at monthly intervals from on top of a 42 m high cliff located some 1600 m northwest of the study site. Each photo was digitised, rectified to ground co-ordinates and the coastline straightened to facilitate subsequent analysis. Intensity values were then averaged over the 300 m long study area, and intensity maxima used to represent bar-crests. These techniques are described in Bailey and Shand (1996), and Shand (2003). Errors are estimated to be ~15 to 20 m in the cross-shore direction and ~75 m in the longshore direction. The somewhat large longshore value reflects the distance from the camera. Such an error is acceptable for the present study, however, given the need to determine longer term systematic cross-shore bar migration rather than the analysis of inter-survey bar migrations.

Wave data were based on daily observations at the seawardmost break-point using the pole and horizon method described by Patterson and Blair (1983). Such measurements have been shown to provide a reliable estimate of relative wave height. In the Wanganui case, the pole and horizon data were found to approximate deepwater significant wave height.

RESULTS

Characteristics of beach cut

Sixteen episodes of beach cut occurred during the study period (Fig 3). Different types of cut were identified, and these were associated with three predominant beach morphologies. These erosion-types will now be described, together with corresponding erosion parameter values and energy associations. Note that when erosion extended beyond the 300 m long study area, the total length of cut was recorded.

Laterally extensive erosion occurred upon a featureless upper beach, relatively featureless lower beach (e.g. low tide terrace or broad ridge and mega-rippled runnel), and with 2D or weaker 3D inner bar morphology (e.g. longshore bar/trough or arrhythmic bar/trough). An example of laterally extensive erosion and such beach/inner bar morphologies is shown in Fig 2A. The erosion extended alongshore 300 to 650 m (Table 1), and in all four cases erosion reached the backshore region. Other parameter values in Table 1 show that this type of beach cut had the greatest-equal scarp height (mean = 1.5 m) and the longest persistence (mean = 13.8 wk). Laterally extensive erosion required spring tides (mean range = 2.4 m), coupled with the highest storm-wave conditions (mean = 3.1 m) of all erosion types. Laterally extensive erosion appears to be equivalent to Wright's (1980) *mode 2* beach cut.

Table 1: Descriptive statistics for erosion dimensions, persistence and energy associations with respect to different types of beach cut.

Type of cut		Length (m)	Height (m)	Duration (wks)	Tidal rng (m)	Wave ht (m)
Laterally Extensive	*Mean*	430	1.5	13.8	2.4	3.15
	Range	300 - 650	1 - 2	1 - 40	2.2 – 2.8	2.4 – 3.8
Rip Embayment	*Mean*	120	1.5	5.3	2.4	2.2
	Range	100 - 160	1 - 2	4 - 8	2.2 – 2.8	1.8 – 2.9
Overwash Channel	*Mean*	77	1.0	2.7	2.0	2.8
	Range	40 - 100	0.5 – 1.5	2 - 3	1.8 – 2.2	2.7 – 2.8
Berm-front	*Mean*	17.5	0.63	1.7	1.2	2.05
	Range	10 - 30	0.25 – 1.0	1 - 4	0.8 – 2.6	1.6 – 3.1

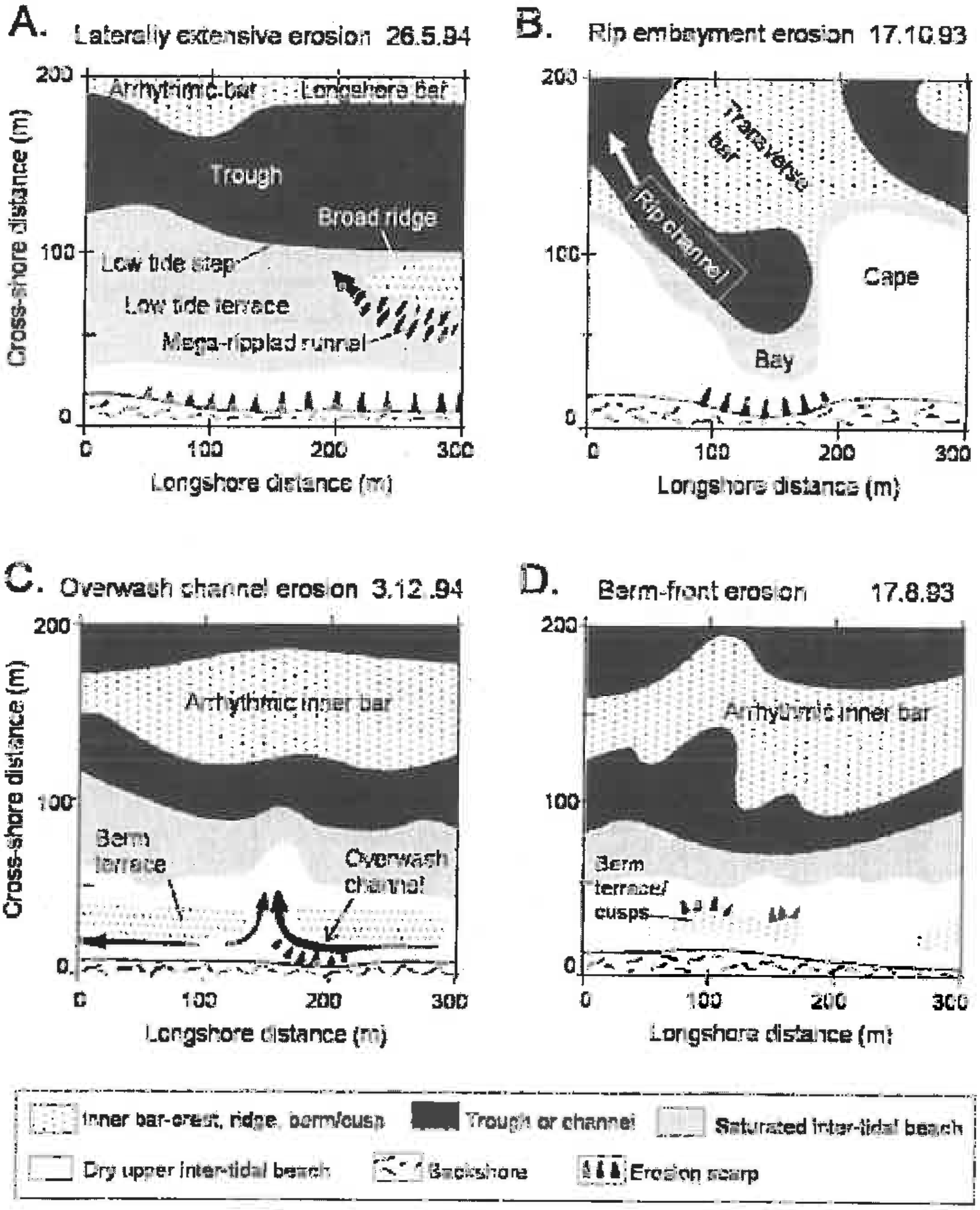

Figure 2 Examples of morphological maps used to identify erosion, low tide step and morphological configuration. A different type of erosion is depicted in each map.

Rip embayment erosion occurred with an either featureless or berm-terraced upper beach, a strongly 3-dimenional lower beach (e.g. cape and bays), and strongly 3D inner bar morphology (e.g. transverse bar/rips). An example of rip embayment erosion and such beach/inner bar morphologies is shown in Fig 2B. In this situation, and in the following types of erosion, some cusping of the berm may have occurred. In the three observed cases of rip embayment erosion, beach cut occurred at the head of a rip-associated bay (rip embayment) and extended into the backshore. Such erosion had significantly shorter (alongshore) length than laterally extensive erosion (mean = 120 m c.f. 430 m, Table 1), had equal scarp height (mean = 1.5 m), but a lower, although not

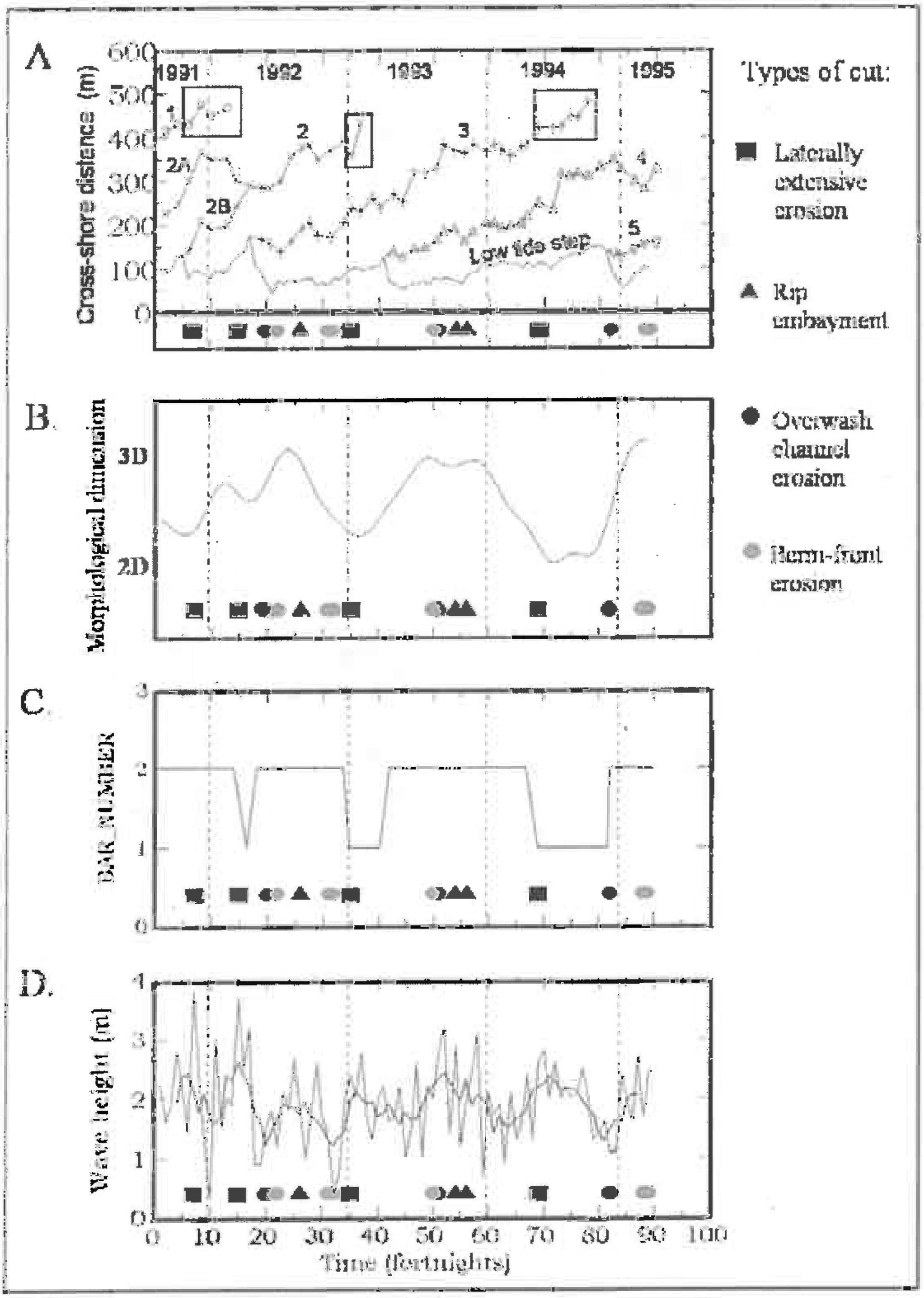

Figure 3 Comparisons of beach cut with cross-shore migration of bar-crests and the low tide step (A), relative morphological dimension (B), bar number (C) and daily wave height during the study period (D). Filtered wave height is depicted by the bolder line in D. The rectangles in A locate highly degenerated outer bar-crests; these bars were excluded when determining the bar numbers in B. All terms are described in text.

statistically different, persistence (mean = 5.3 wks c.f. 13.8 wks). Statistical significance was determined using two sample t-tests and a 20% threshold. As with laterally extensive erosion, rip embayment erosion also required spring tides (mean range = 2.4 m), but significantly lower wave height (mean = 2.2 m). Rip-embayment erosion appears to be equivalent to Wright's (1980) *mode 3* beach cut.

Both *overwash-channel erosion* and *berm-front erosion* occurred with a bermed upper beach, featureless lower beach (e.g. low tide terrace) and 3D inner bar configurations (e.g. arrhythmic bar/trough or transverse bar/rips). Examples of such erosion types, together with the associated morphologies, are provided in Fig 2C and D. In the three cases of overwash chanel erosion, scarping occurred on the landward side of the laterally orientated overwash channel, and in two of these cases, erosion extended into the backshore. In the six cases of berm-front erosion, the scarping occurred upon the terrace riser or berm-face.

Overwash channel and berm-front erosion were significantly different (less) from laterally extensive and rip embayment erosion in terms of length, height and escarpment duration. Furthermore, berm-front erosion parameters (Table 1) were significantly different (less) from overwash channel erosion, with a mean longshore distance of 17.5 m (c.f. 77 m). Berm-front erosion values were also less (but not significantly less) with respect to scarp height (mean = 0.63 m c.f. 1.0 m), and duration (mean = 1.7 c.f. 2.7 wks). Berm-front erosion occurred under conditions of significantly lower wave height (mean = 2.05 c.f. 2.8 m) and lower tidal range (mean = 1.2 m c.f. 2.0 m). A comparison of energy conditions for overwash channel and berm-front erosion with laterally extensive and rip embayment erosion, indicates that the former occur under significantly lower tidal range. It is noteworthy that overwash channel wave height (mean = 2.8 m) was significantly greater than rip embayment wave height (mean = 2.2 m). While berm-front erosion appears to be consistent with Wright's (1980) *mode 1* beach cut, overwash channel erosion was not accounted for in Wright's (1980) scheme.

NOM-associations

Time-series for each subtidal sand-bar that existed during the study period are shown in Fig 3A. While only bar number 3 underwent a full NOM cycle during the 3.4 yr study, an underlying seaward migration trend still characterised the other four partially completed bar cycles. The merging of bars 2A and 2B early in the study is the result of bar switching, a morphological behaviour in which bars realign in the longshore direction (see Shand et al., 2001; Shand, 2003). Bar generation was defined to occur at the time pronounced bar/trough relief first developed. Each new bar was generated after the seawardmost bar had disappeared. The low tide step is also plotted in Fig 3A, and these data show the inter-tidal beach abruptly narrows following generation of a subtidal bar, and then, after an approximately stationary period, the beach systematically widens until the next bar is generated. During the study period there were four instances of bar formation within the inner surf zone, and four cases of bar degeneration within the outer surf zone.

A comparison of the different episodes of beach cut with the morphology depicted in Fig 3A, shows that laterally extensive erosion tended to occur later in the inter-generation period and in conjunction with beach widening. By contrast, all other types of erosion occurred earlier in the inter-generation period with overwash and berm-front erosion tending to occur closest to the time of bar generation.

The timing of beach cut episodes was compared with the configuration dimension of the inner bar (Fig 3B). This graph of (relative) dimensionality values indicates whether configuration change is tending 2D or 3D; these data were derived by smoothing numerical values assigned to the configuration sequence provided in Shand and Shepherd (2003). The results in Fig 3B show 3D-tending configurations predominate earlier in the inter-generation period, with a change to 2D-tending configurations later in the period. It is noteworthy that 2D morphologies often occurred, albeit briefly, when a new bar was generated. A comparison of the timing of erosion episodes with inner bar configurations indicates that the laterally extensive episodes coincide with the 2D-tending configurations later in the inter-generational period. By contrast, all other types of erosion coincide with the 3D-tending configurations earlier in the inter-generation period.

Timing of beach cut episodes was next compared with the number of bars in the cross-shore direction (bar number). The method used to determine bar number has been previously detailed in Shand and Shepherd (2003). Briefly, a highly degenerated outer bar, defined as having no landward trough, was not included in the bar number count as such a bar is less likely to be effective in causing significant wave energy dissipation, while an outer bar with pronounced relief was included in the count. The level of outer bar degeneration was identified using intensity patterns on rectified time-exposure images.

The bar number results (Fig 3C) show that two well developed subtidal bars occurred for 75% of the study period, while for the remaining 25% of the time only a single bar existed. The double bars occurred during four separate periods, with the single bars occurring during the three intervening periods. A comparison of bar number with the different episodes of beach cut shows that three of the four laterally extensive episodes corresponded with the presence of single bars. Furthermore, the landward bar during the remaining (first) laterally extensive episode was particularly small, having just been generated. By comparison, all other types of beach cut corresponded with double bars. The occurrence of the greatest erosion length under the least number of longshore bars, and the least change under the greatest number, is qualitatively consistent with other studies of beach-change (e.g. Kannan et al., 2003).

To test whether systematic variation in wave conditions corresponds with the different episodes of erosion, and hence plays a fundamental role in controlling the nature and timing of erosion events, maximum inter-survey wave heights corresponding to tidal range ≥ 2.2 m were derived (Fig 3D). The 2.2 m threshold was chosen as all episodes of laterally extensive erosion occurred when the tidal range was greater or equal to this value. A 5-point moving average filter was applied to the raw wave data to help identify systematic change.

The results in Fig 3D show wave height during spring tides had a quasi-regular fluctuation with an average periodicity of 26.4 wks (18 to 38 wks). While a period of higher waves did occur later in the inter-generation period and coincides with each episode of laterally extensive erosion, two of the six peaks (fortnights 20 – 30 and 50 – 60) occurred earlier in the cycle. These two peaks of higher wave energy (during spring tides) were associated with the episodes of rip embayment erosion. The episodes of overwash channel erosion and berm-front erosion were associated with either periods of lower energy, or change from periods of lower energy to periods of higher energy.

The beach cut characteristics and relationships with NOM described above, together with considerations made in the following discussion, are synthesized diagrammatically in Fig 4.

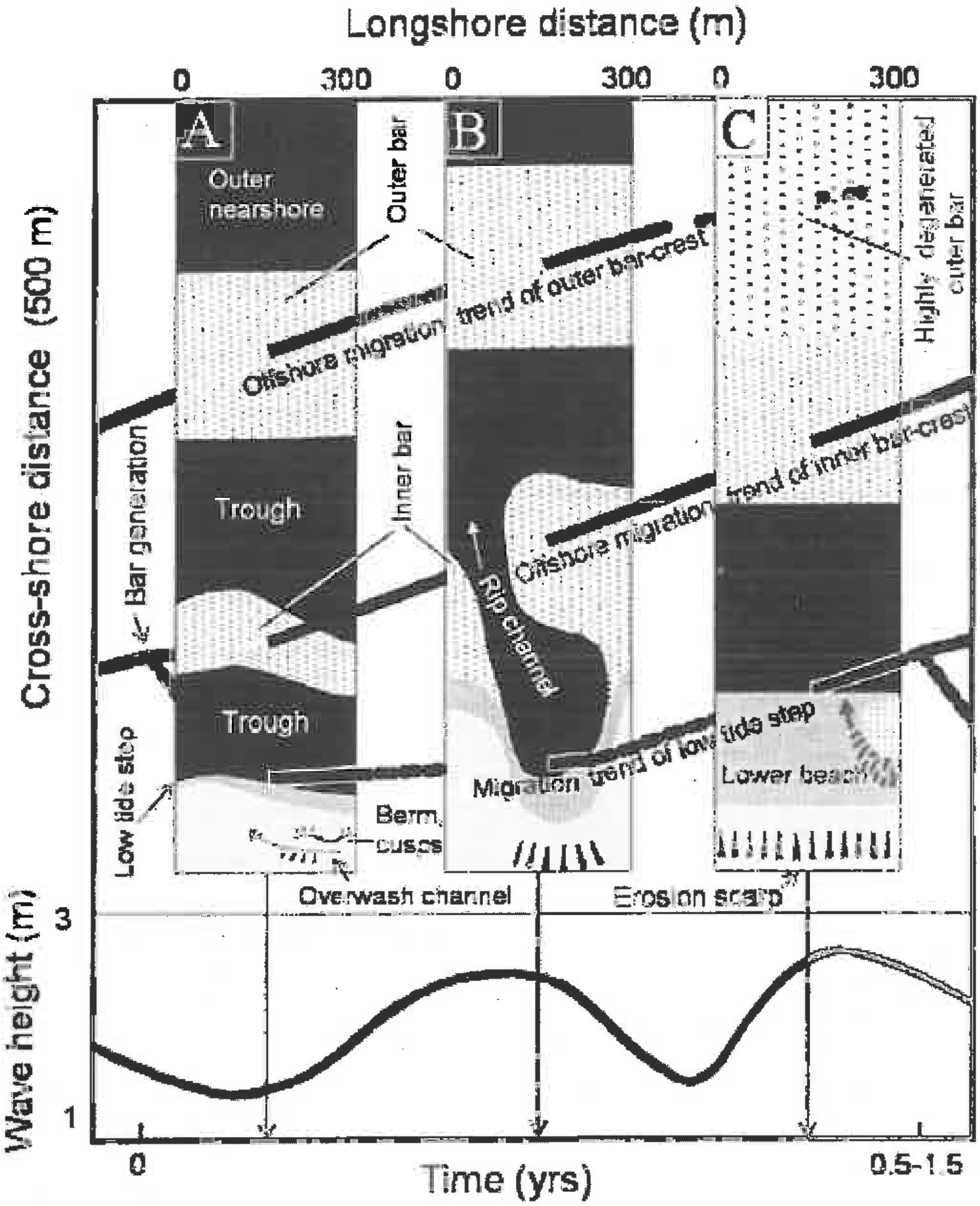

Figure 4 Conceptual model illustrating the relationships between types of beach cut and systematic variation in morphological configuration, cross-shore bar and step migration, and wave height, for the Wanganui study site. Panel A depicts overwash channel and berm-front erosion, panel B depicts rip embayment erosion and panel C depicts laterally extensive erosion.

DISCUSSION

Laterally extensive episodes of beach cut required substantially higher wave energy levels than did the other types, as such erosion not only occurred during the most energetic conditions, but coincided with a reduction in the number of subtidal bars from two to one later in the inter-generation period. With only a single bar, a higher proportion of incident wave energy would reach the shoreline and be available for erosion as up to 50% of storm-wave energy is dissipated when breaking occurs over an outer bar, e.g. see Keady and Coleman (1980). Furthermore, laterally extensive erosion tended to occur as soon as the bar number reduced, which suggests that the same storm responsible for subduing the outer bar may also linearise, and erode, the beach. It is also noted that the strong longshore currents which accompany storm wave conditions on this coast, probably enhance backshore/dune erosion by removing sediment which accumulates at the scarp-base following wave-undercut and slumping.

The importance of local morphological control during the laterally extensive erosion process is evident in that the relatively featureless/2D morphology which accompanies this type of scarping would facilitate widespread erosion. By contrast, the two periods of higher energy when laterally extensive erosion did not occur were characterised by 3D configurations which must limit the longshore extent of erosion.

While rip embayment erosion required similar tidal range to laterally extensive erosion, it required substantially less wave energy; this is apparent by the lower values in Table 1 coupled with energy loss associated with the increased bar number. However, rip embayment erosion caused similar severity in terms of scarp height and backshore incursion as laterally extensive erosion, which indicates that the locally pronounced 3D morphology associated with rip embayment erosion must significantly enhance wave-driven hydrodynamic processes and result in particularly strong radiation stress gradients.

The occurrence of overwash/berm-front erosion shortly after bar generation corresponds with the systematic change from 2D to 3D morphology during the earlier part of the inter-generation period. During this time, ridge and runnel development is common along the lower foreshore, with the ridge migrating landward to form a berm along the upper beach during post bar generation fair-weather conditions. Berm-front erosion occurs under moderate wave height and tidal range as these conditions allow for saturation, and hence slumping, of the terrace riser while minimising runup passing beyond the crest and smearing the erosion scarp. In contrast, the higher wave energy and tidal range associated with overwash erosion reflect the need for swash to pass over the berm-crest, pond at the rear of the structure, then flow laterally along the channel with sufficient speed to erode the (landward) beach. Observation showed that overwash channel erosion tended to coincide with destruction of the berm terrace.

CONCLUSIONS

During the study period the following four types of beach cut occurred: four episodes of laterally-extensive erosion; three episodes of rip-embayment erosion; three episodes of overwash-channel erosion, and six episodes of berm-front erosion. Laterally extensive erosion had the greatest longshore extent and occurred on a relatively featureless/2D morphology during extreme storm conditions and spring tides. Rip embayment erosion had moderate longshore extent and was confined to bay areas at the head of large rips under spring tides and moderate storm events. Overwash channel erosion and berm-front erosion occurred on the landward and seaward sides respectively of an upper beach ridge (berm terrace), with berm-front erosion having the shortest longshore extent, lowest height, shortest duration, lowest wave height and lowest tidal range of any erosion type.

Each type of erosion occurred systematically during a particular time within the inter-generation period of the NOM cycle. Overwash channel and berm-front erosion occurred earlier in the period, under double bars and intermediate morphologies, i.e. 2D to 3D. Rip embayment erosion occurred during the earlier/central part of the inter-generation period, under double bars and strongly 3D morphology, while laterally extensive erosion occurred later in the period under single bars and more linear morphology. While wave energy conditions also varied systematically during each inter-generation period, morphological control still appears to be of fundamental importance in determining erosion type. For example, while both laterally extensive and rip embayment erosion occurred during periods of higher energy, morphologies associated with each type of cut were quite different.

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