BEACH RESPONSE TO VARIATIONS IN BREAKER HEIGHT

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ABSTRACT

The breaker wave height required to produce a particular beach-surfzone morphology is examined for micro-tidal, medium to fine sand beaches. Waves >2.5m produce dissipative beach systems with wide surfzones and shore parallel bar/s and channel/s. Breakers between 1 and 2.5m result in rip circulation and associated rhythmic morphology (crescentic bars, rip channels, megacusps, etc). Low waves (<1m) form steep, barless reflective beaches with characteristic cusps/berm. To gauge the stability/mobility of each of these beach types the range of beach profile changes associated with each is presented, for both the time and space domain. Modally dissipative beaches where breakers consistently exceed 2.5m undergo minor changes in profile and are consequently stable both temporally and spatially. Modally rhythmic beaches have a variable moderate energy wave climate are highly unstable both over time and alongshore. Modally reflective beaches with their low waves are relatively stable. Beaches which experience a highly variable wave climate over time exhibit all three types and are consequently highly unstable. The environmental parameters useful for quantifying these beach types and associated profile changes, and the implications of these results are discussed.

INTRODUCTION

Two dimensional beach response to eroding and accreting wave conditions has been well documented both in the laboratory and in the field. High storm waves or steep waves lead to a lowering of the beach profile resulting in beach cut and seaward transport of beach materials into the surfzone and nearshore. Low swell or long waves result in a steepening of the profile by onshore sediment movement and beach fill. Between these two extremes, systematic mesoscale patterns of beach-surfzone response have been observed. The nature of the beach morphology and associated surfzone dynamics (i.e. beach morphodynamics) under a range of wave conditions is described by Short 1979 a and b, and Wright, et al., 1979. In particular Short 1979a associates sequences of beach response with rising and falling wave conditions.

In this paper the absolute level of breaker wave height required to achieve a given level or type of beach morphological response is examined. Short's 1979a ten beach-stage classification is used to quantify beach response within three broad categories of beach type: low wave energy - reflective beaches, moderate energy - rhythmic beaches, and high energy - dissipative beaches. This paper is therefore concerned with the actual breaker height required to produce a given level of beach surfzone morphodynamic response; and the characteristic temporal and spatial changes in beach profile and on-offshore sediment transport that are associated with the three beach types. The temporal changes are associated with variations in breaker wave height over time and the resultant movements in on-offshore sand transport and consequent changes in beach profile. For a particular wave-beach environment the most frequently occurring or characteristic beach profile or morphologic configuration is called the modal beach type. The degree of departure from the modal type is dependent on the variation in the breaker wave climate. Spatial changes are concerned with alongshore variation in beach profile at any point in time. The variability within both temporal and spatial suites of beach profiles is used to quantify beach stability/mobility.

DATA BASE

The correlation between breaker height and beach stage is based on 1174 daily observations of both parameters at Narrabeen Beach, N.S.W., a medium to fine sand (mean grain diameter 0.3 to 0.4 mm), single barred beach in a moderate to high energy wave environment (east coast swell, Davies 1980). Modal wave period in the study area ranges from 10 to 12 seconds. The procedure for recording the observations is discussed by Short 1978b. The daily observations are supplemented by field investigations of beaches composed of very fine to coarse sand in wave environments ranging from low to very high energy (west coast swell) around the 6,000 km of the south and east coasts of Australia (Short, 1978) (see Fig.1) and elsewhere (Short, 1979a).

The main field sites are in microtidal environments and in coastal segments where littoral drift is negligible. The prime concern of this paper is the effect of breaker

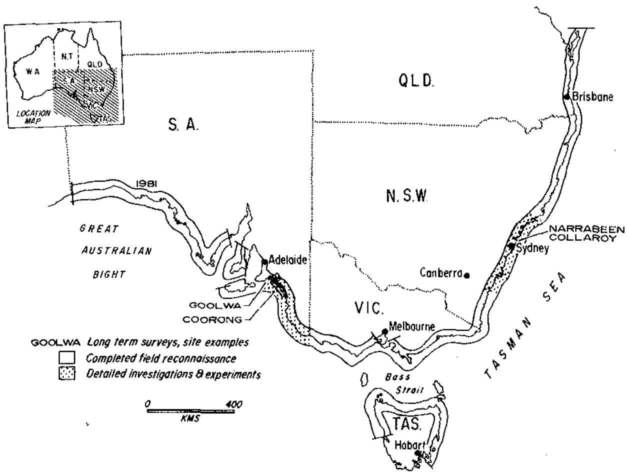

Figure 1: The southeast of Australia showing the main field sites discussed and area of field investigations.

height in influencing on-offshore sediment transport and morphologies in the absence of littoral drift and large tides.

BREAKER WAVE HEIGHT AND BEACH STAGE

The relationship between breaker height and beach response is presented in Figure 2a and 2b. In each figure the probability of occurrence of each beach-stage is plotted for the given level of breaker height (in 0.5m intervals) during falling (Fig. 2a) and rising (Fig. 2b) wave conditions. Falling wave height is associated with onshore sand transport, beach accretion and movement from the dissipative beach-stage 6 through the rhythmic stages 5,4 and 3 to the reflective stages 2 and 1. Rising wave height on the other hand is associated with offshore sand transport and movement through the erosional beach cycle from the reflective beach stages 1 and 2 through the channel forming and rip dominating stages 3′, 4′ to the dissipative stages 5′ and 6.

Falling Wave Height

Figure 2a illustrates the beach-stage distribution associated with discrete levels of falling wave height

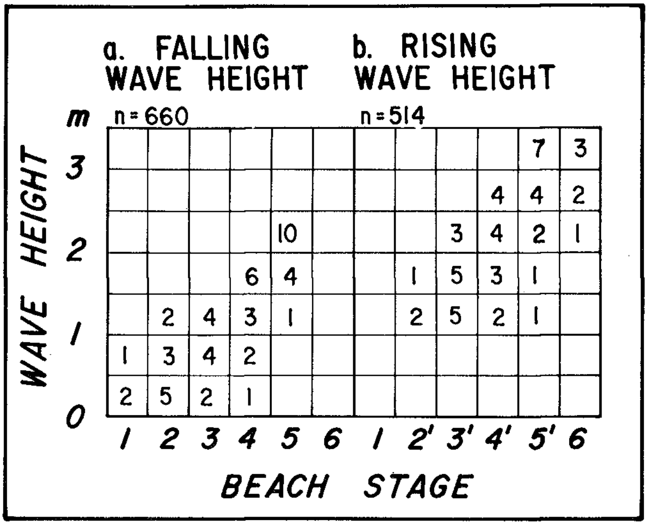

Figure 2: Plot of the probability of occurrence (out of 10) of each beach-stage for a given level of breaker wave height, under falling wave and rising waves.

under falling wave conditions. In an idealised situation as waves decrease from >3.5 m (beach-stage 6) they must drop to 2-2.5m before onshore sand movement combined with low frequency edge waves (Wright et al, 1979) produce the crescentic bars of stage 5. The crescentic bars dominate until waves fall to 1-1.5m. At this level stage 4 dominates with well developed crescentic bars and adjacent shoreline megacusps. The 1-1.5m waves encourage channel infilling and movement to stage 3 which at 0.5-1m completes infilling resulting in bar welding to the beach face. Subaerial deposition of beach cusps on a reflective beach face (beach-stage 2) dominates the lowest wave height (0-0.5m) eventually leading to a formation of a highly reflective beach berm (beach-stage 1).

Rising Wave Height

Figure 2b plots the beach-stage distribution for levels of rising wave height (0-0.5 to >3.5m). Beach erosion begins when breakers exceed 1m with waves 1-1.5m high leading rapidly through beach-stage 2′ to 3′ (incipient channel formation across the newly formed bar). The channel excavation continues as waves rise to 1.5-2m. Only when waves reach 2-2.5m do the individual incipient rip channels begin to coalesce alongshore forming beach-stage 4′ (continuous channel). Higher waves (2.5-3m and 3-3.5m) and substantially higher wave energy is required to excavate the continuous longshore channel that feeds the rips of beach-stage 5′. Very high waves >3.5m and extreme energy conditions are required to produce the fully dissipative beach-stage 6 with its shore normal low frequency return flow and parallel bar-channel morphology. At Narrabeen Beach the observations of this stage are insufficient to provide a reliable distribution against wave height. However observations on higher energy beaches elsewhere in southeast Australia indicate that waves 3.5 to 4m are required to achieve this most dissipative stage.

The above results are concerned solely with the beach response to levels of breaker height. The spread of the distribution either side of the modal beach response represents a parameter not considered in this summary, that is, the inherent lag in beach morphology as it responds to the more rapid changes in wave height. Whereas substantial changes in wave height may occur on the order of 1 to 10 hours, beach morphology has a lag on the order of 10 to 100 hours. The modal beach stages of Figures 2a and 2b represent the beach stage reached when waves have operated at a particular height for a time period sufficient for the beach morphology to fully respond to the ambient conditions.

The results are further summarised in Figure 3a and which plots the location of the modal beach-stage for rising and falling wave conditions. It illustrates the levels of breaker height required to generate movement to various stages in the erosional (rising) or accretional (falling) wave-beach cycles. Figure 3b illustrates all possible linkages through and between the beach-stage cycle. By comparing figure 3a and 3b a fuller understanding of natural beach response can be extracted. A movement to any beach-stage must be in the direction of the arrows in figure 3b. Therefore, for example, to achieve stage 4, stages 4′ or 5 must first be reached. In figure 3a if conditions oscillated between 0-1.5m the corresponding beach stages would be 2′ and 3′ on the erosional phase and 2, 3 and 1 on accretion, stage 4 could not be produced, because the prerequisite stage 4′ or 5 require waves greater than 2m.

Modal Breaker Height and Beach Type

The Narrabeen field site experiences the entire spectrum of beach response from reflective to dissipative beach-stages. This is a consequence of the range in breaker height at the coast and the medium to fine beach

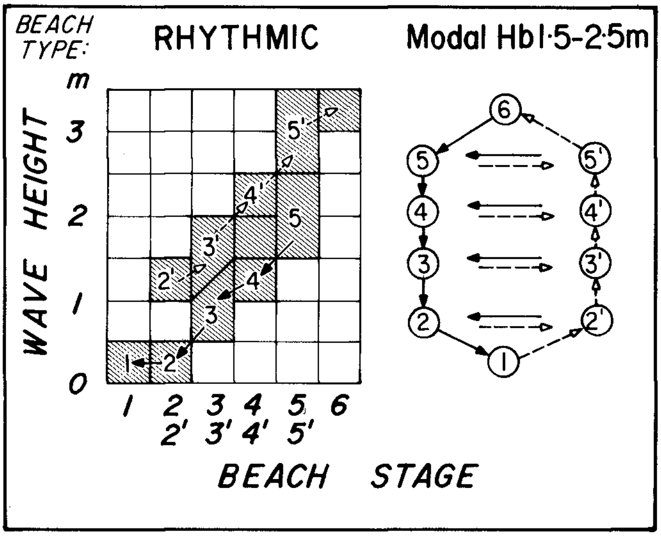

Figure 3: Location of the modal beach-stage (shaded) for levels of breaker wave height under rising and falling wave conditions. On right are the linkages between the ten beach-stages. Solid lines indicate falling wave height and movement to accretionary stages, dashed lines rising wave height and movement to erosional stages. Movement between and amongst the stages can only be in the direction of the arrows.

sand. However, over shorter time periods and in many locations wave height does not vary so considerably and as a consequence the beach oscillates around a modal type. Basically three modes of wave-beach interaction have been described in the literature - reflective, rhythmic and dissipative. Table 1 lists their origin and characteristics. The breaker height required to generate a modal reflective, rhythmic or dissipative beach (on medium to find sand beaches) can readily be determined from Figure 2b.

Reflective beaches are associated with waves less that 1m in height. They are characterised by beach-stages 1 (berm) and 2 (cusps), with a relatively steep beach face, waves breaking on a coarse grained low tide step and barless surfzone (though 'relic' outer bars may exist further offshore).

Table 1 - MODES OF WAVE - BEACH INTERACTION

Wave Energy (Breaker Height)	Surf Zone Dynamics[1]	Beach-Surfzone Morphology	Reference - terminology
High (>2.5m)	Dissipative	Shore parallel bars, channels mega-rips predominantely shore normal circulation	Sasaki - Ingragravity (>2.5m) Short - Beach-stages 6, 5′ Wright, et al - Beach Type 1, 2
Moderate (1-2.5m)	Rhythmic	Rips crescentic bars megacusps, etc. rip circulation	Sasaki - Instability Short - Beach-stages 5,4,4′,3,3′ Wright, et al.- Beach type 3,4,5
Low (<1m)	Reflective	Barless steep beach-face cusps, berm, wave reflection	Sasaki - Edge Wave Short - Beach-stages 2,2′,1 Wright et al. - Beach type 6

1. Guza and Inman′s (1975) terms, dissipative and reflective are used to describe the high and low energy surf dynamics, while Homa-ma and Sonu (1962) term rhythmic is attached to the intermediate moderate energy beaches.

Rhythmic beaches require breakers 1 to 2.5m high to maintain their classic rip circulation. Crescentic/transverse bars, rip feeder and rip channels, and megacusps produce the characteristic 'rhythmic' longshore variation in beach and surfzone morphologies.

Dissipative beaches occur when waves exceed 2.5m resulting in the formation of shore parallel channel/s and bar/s and predominately shore normal circulation (beach-stage 6). Beach-stage 5' characterises the dissipative extreme in shorter embayed beaches where the constraints imposed by headlands, etc. encourage megarips to persist even during very high wave conditions.

Temporal Variation in Beach Morphology

The foregoing is concerned with beach response to the absolute level of breaker height. To illustrate how natural beaches respond to variations in breaker height through time, ten years of daily wave data and four years of daily beach response for the Sydney region are summarised in Figure 4. The annual wave climate varies systemmatically through the year from periods of high to moderate to low waves with the beaches responding accordingly moving between dissipative, rhythmic and reflective beach types.

In a typical year beginning in December northeast seabreeze waves of moderate height (1-1.5m) cause minor beach scarping and erosion and a series of rips. During February and March, seabreezes persist but their effect is often overshadowed by the arrival of moderate to high 2-3m northeast and east swell generated by tropical cyclones. These waves cause moderate beach erosion, and the development of fewer but larger and more intense rip systems. If high waves persist, longshore channels and offshore bars eventually form. April and early May is a low energy transition period of beach accretion. May and particularly June and July are dominated by cycles of moderate to high (2-3m) southeast swell and storm waves resulting in moderate erosion. The beaches in this period are dissipative with major rip systems (spacing 500m) and in exposed portions longshore bars and channels. This period of erosion is followed by gradually decreasing southeast swell. The low waves (0.5-1.5m) produce onshore sediment transport and beach accretion at times moving the bar onto the beach as a series of cusps or a berm. By November the beaches are often in their most accreted and reflective form.

A further method of illustrating the range of Sydney

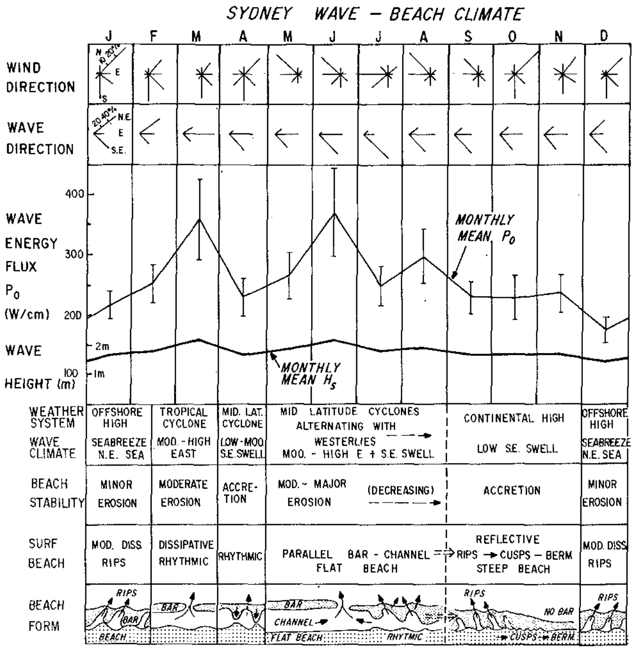

Figure 4: The annual Sydney wave climate and beach form. The wave height and energy is based on a nine years (1971-79) monthly mean of daily wave conditions (M.S.B. data). The stradling line and bars equal ± one standard deviation. The beach response through the year is reflected in the beach stability, surfzone type and beach form. The plan view of beach form illustrates the beach response typical open beach responding fully to the above conditions (from Short and Wright, in press).

beach types is the beach-stage curve (Short, 1979a) shown in Fig. 5. This plots the percent frequency of occurrence of the accretion and erosion beach-stages, along with the annual (combined) beach-stage curve. The curve identifies the modal rhythmic beach type for the Sydney coast. This is to be expected given Sydney's modal wave characteristics (H = 1.5-2m, T = 10 sec). Short 1979a presents hypothetical beach-stage curves for other higher and lower energy wave-beach systems.

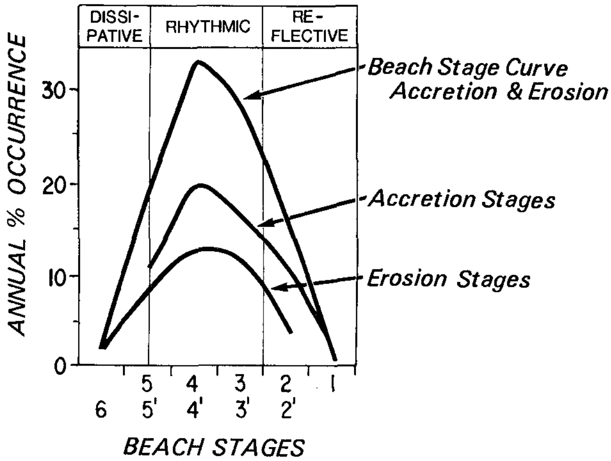

Figure 5: Beach-stage curves for Narrabeen beach plotting the percent frequency of occurrence of accretionary, erosional and combined beach-stages. Based on 950 daily observations.

MODAL BEACH TYPES AND MORPHOLOGIES

Whereas the typical Sydney beach presented in Figures 4 and 5 can experience the entire spectrum of beach types, many beaches tend to remain at the dissipative or reflective extreme or oscillate within the rhythmic range. To examine how such beach morphologies vary over time in reference to modally high, low, or moderate waves three sets of field observations are presented for persistently dissipative, rhythmic and reflective beaches (see Figure 6).

To enable comparisons the data is presented both graphically as two-dimensional beach profiles or cross sections, and numerically using mean beach width (x_b), its standard deviation (σ_x) and coefficient of variation (σ_x/X_b). The standard deviation is a useful indicator of beach mobility and is in fact called the beach mobility index by Dolan et al., (1978). Further, the coefficient of variation is an indicator of backshore mobility and is here termed the backshore mobility index.

The nature of a beach's cross-sectional or profile variation is basically a function of the amount and form of sediment transfer within and between the subaerial beach, surfzone and nearshore. Where wave height is persistently

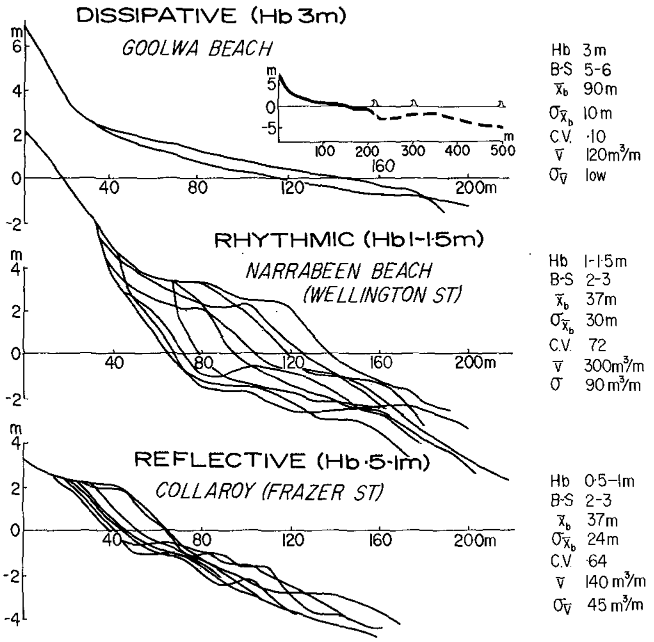

Figure 6: Variation in beach profile and morphometric parameters for a dissipative, rhythmic and reflective beach. Note the relative stability of the dissipative and reflective beach compared to the rhythmic beach. Narrabeen and Collaroy profiles selected from 3 years of monthly beach profiles. Goolwa profiles one year apart.

high (>2.5m) most sediment is carried seaward and stored in the surfzone and nearshore. Because of the time lag in moving sediment onshore from the outer bars bar/s and nearshore the beach face rarely accretes or experiences substantial changes in profile (Fig. 6). The beach is wide with a low gradient. Beach and backshore mobility is low because of the low sediment exchange. While a dissipative beach face represent an 'eroded' beach profile with minimum sand stored on the subaerial beach they are relatively stable features experiencing minor changes in beach profile. Erosion associated with dissipative beaches does not normally result from beach face retreat, rather low frequency wave set up tends to overrun the beach and attack the backshore directly, (as described by Wright, this vol.).

Rhythmic beaches exposed to waves of moderate height (1-2.5m) have the greatest potential for changes in beach form as a consequence of the variable wave climate and storage of sediment in the highly energetic surfzone. As wave height rises and falls, sediment is transported between the three storage zones. Beach volume is large as is the standard deviation reflecting the active sediment exchange between the beach, surfzone and nearshore (Fig. 6). Over time rhythmic beach form can shift from a flat eroded beach face, deep channel and offshore bar, through all the onshore bar migratory forms to a reflective beach. Beach and backshore mobility are both high, indicating a high potential for beach and backbeach erosion through sand removal particularly in rip embayments (see Short, 1979b and Wright, this vol.).

Low wave (< 1m) reflective beaches have low mobility and are relatively stable. Sediment exchange on reflective beaches (Fig.6) is between the steep cusped or bermed subaerial beach through a pivot point ($\sim$1m depth) to the attached low tide terrace. Because of their proximity the exchange is rapid. Reflective beaches are most susceptible to erosion (see Short 1979b and Wright, this vol.), however erosion is usually followed by rapid beach accretion. As Collaroy beach (Fig. 6) lies at the more energetic end of the reflective beach type (H = .5-1m) lower energy beaches will show even less mobility.

Figure 7 illustrates the range of temporal changes in beach profile for dissipative, rhythmic and reflective beaches in southeast Australia. The variation in profile elevation within the beach surfzone and nearshore has further implications for identifying areas of sediment storage and exchange. Table 2 indicates the relative importance of the beach, surfzone and nearshore as zones of active sediment storage.

Dissipative beaches represent an 'eroded' beach profile, and as such the 'eroded' material is stored in and particularly seaward of the surfzone. On the southeast Australian coast the active nearshore zone extends out to depths of at least 20m. Because of the depth and location of the potentially active sediment long periods (several weeks to months) of lower waves are required to move the sediment shoreward. On modally dissipative beaches such as Goolwa this rarely, if ever, occurs however in seasonally dissipative-reflective beaches as in Southern California this exchange is well documented (Aubrey, 1979). On N.S.W. dissipative beaches the inner bar occasionally attaches to the shore in late winter. The outer bar while moving

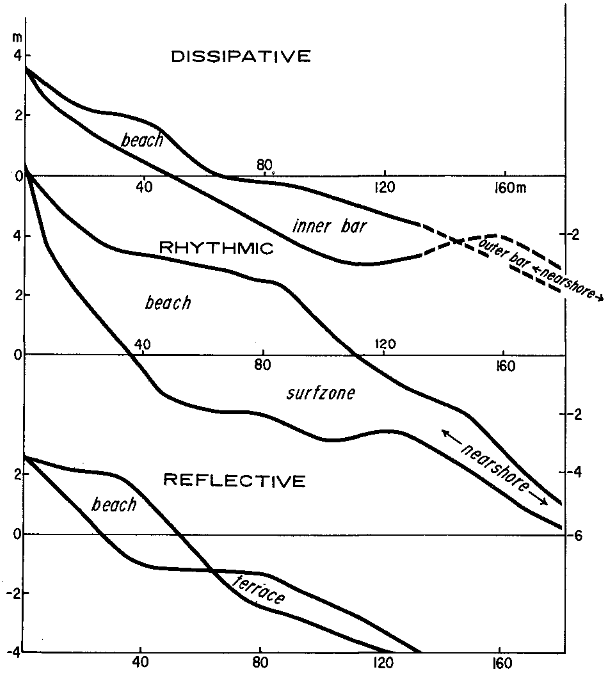

Figure 7: The active sweep zone for a dissipative, rhythmic and reflective beach based on 3 years of monthly beach profiles. Upper from Fens embayment, N.S.W. (data from P. Hesp), lower Narrabeen and/ Collaroy beaches.

Table 2

ZONES OF SEDIMENT STORAGE (%)

	SUBAERIAL	SURFZONE	NEARSHORE
REFLECTIVE	70	30	—
RHYTHMIC	40	40	20
DISSIPATIVE	10	20	70

inshore has not been observed attaching to the shore.

Rhythmic beaches can potentially store sand throughout the system, particularly in the beach and surfzone, and following high wave events in the nearshore. Sand stored in the energetic surfzone and perched on the subaerial beach can rapidly be moved between the two as wave conditions vary.

Reflective beaches store sand almost exclusively on the steep beach or following erosion in the low tide terrace. Exchange is rapid being accomplished in a matter of hours during erosion and a few days to weeks during accretion.

SPATIAL (ALONGSHORE) VARIATIONS IN BEACH TYPE MORPHOLOGIES

In addition to characteristic changes in beach profile through time, each beach type has a characteristic variation in beach profiles alongshore, at any point in time. Three examples from the same beaches are illustrated in figure 8.

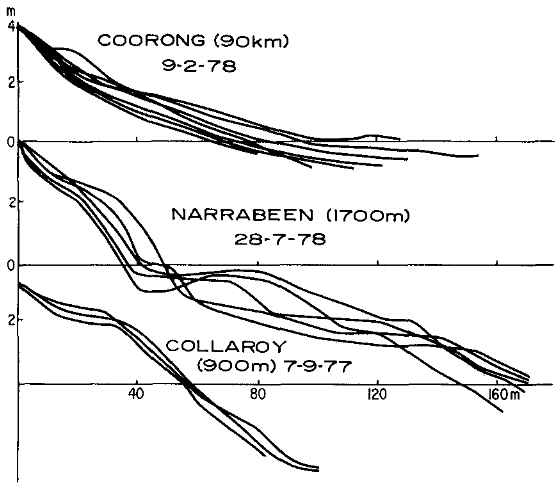

Figure 8: Alongshore changes in beach profiles on a dissipative, rhythmic and reflective beach.

Dissipative beaches are characteristically uniform alongshore having a wide low gradient beach face, fronted by a wide deep channel/s and shore parallel offshore bar/s. Figure 8a a shows seven beach face profiles surveyed on the one day at 15 km intervals along 90km of the highly dissipative Coorong beach. All profiles have a concave subaerial beachface morphology. Each is low gradient with slight variations in gradient resulting from minor changes in grain size. Figure 9a illustrates that the shore parallel channels and bars of the surfzone possess the same conformity longshore. Therefore dissipative beaches exhibit extreme stability and uniformity alongshore.

Rhythmic beaches with their alternating bars and rip channels, megacusps, etc are as unstable spatially as they are temporally. Figures 8b and 9b illustrate this fact. The Narrabeen profiles show the alongshore variation from rip channels, to well developed bars and channels to a welded bar.

Reflective beaches are uniform alongshore except on a microscale when cusps are present. In plan form the continuous cusps or berm and barless surfzone results in lhe regular beach profiles illustrated in Figure 8c, and plan form as show in Figure 9c.

DISCUSSION

Given the seemingly endless variety of beaches around the globe and their ever-changing response to wave conditions it is essential that a logical genetic classification of natural beaches be developed, one that not only permits identification of beach type, but also contains a characteristic set of morphological response and dynamic interactions associated with each beach type.

The results presented here are an attempt to classify beaches into three basic types based on response to the level of breaker wave height for microtidal, medium to fine sand beaches. The characteristics associated with each beach type are tabulated for breaker wave height (Figure 3), two dimensional beach profile response over time (Figures 6 and 7), zones of sediment storage (Table 2), two dimensional alongshore variation in beach profile (Figure 8) and other morphometric parameters (Figure 6). More detailed discussion of beach-surfzone morphodynamics and modes of beach erosion are contained in Short 1979a and b, Short and Hesp (in press), Wright et al. 1979 and Wright (this vol.).

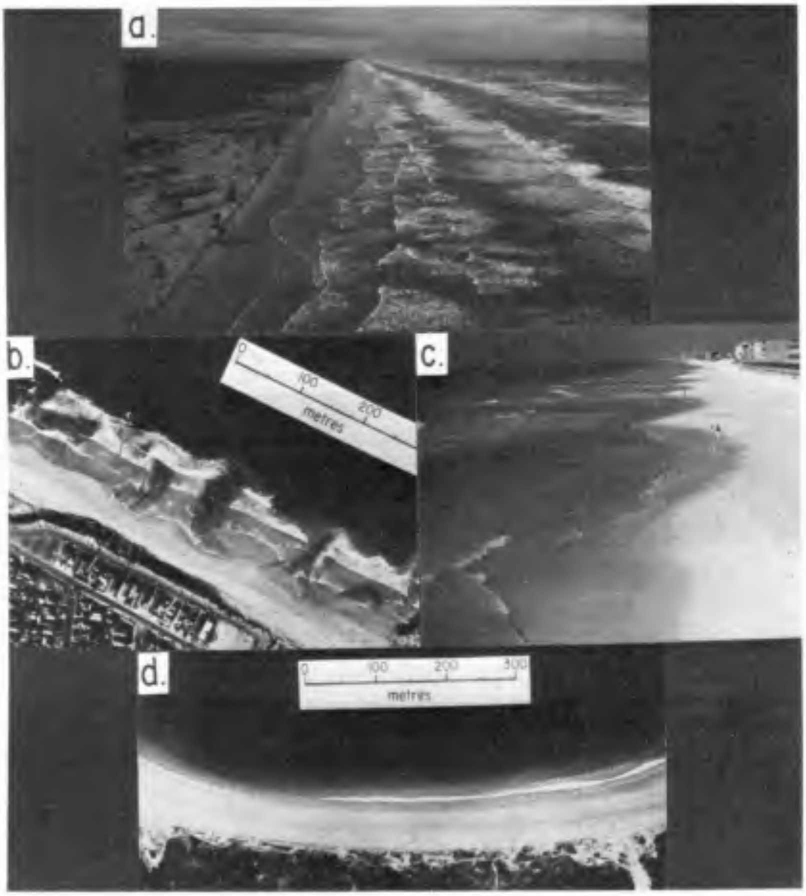

Figure 9: Examples of dissipative, rhythmic and reflective beaches. a. Aracaju, Sergipe (Brazil) note the longshore equilibrium in beach-surfzone form. b. Rhythmic beach-stage 3 at Cronulla Beach, N.S.W.; c. Rhythmic beach-stage 4→3 at Panama City Beach, Florida. d. Reflective beach at North Cronulla, N.S.W.

ENVIRONMENTAL PARAMETERS

In order to explain beach type and beach morphological characteristics, this study has indicated that certain morphometric variables are particularly useful

Breaker wave height, together with period, determine the amount of wave energy available to do work across the nearshore and in the surf-swash zone. As shown in Figure 3 breaker wave height can be used as a simple rule to determine modal beach type, particularly when wave period is relatively constant.

Beach sand size, is equally important in controlling beach response. The foregoing results are based on observations on medium to fine sand beaches (mean diameter 0.2-0.4 mm). However as Short 1979b indicated that coarser sand-gravel beaches will result in more reflective beach types, even in moderate to high wave energy, and fine to very fine sand will lead to a wide shallow surfzone, more dissipative conditions and multiple bars even under moderate to low waves. The foregoing results refer only to high energy dissipative beaches.

The surf scaling parameter is a function of wave characteristics and beach slope and is also a useful measure of the degree of beach reflectivity or dissipativeness (see Wright et al. 1979).

The mean beach width is the basic measure for describing the beach profile and shoreline position. However in terms of application the standard deviation of mean beach width, called the beach mobility index, is an excellent index of the mobility or stability of a shoreline position. The backshore mobility index, is the coefficient of variation of mean beach width, and again is a very useful indicator of likelihood of backshore/foredune erosion.

Finally the mean beach volume and its standard deviation, here called the volume exchange are important indices of sediment location and transport within and across the beach-surfzone-nearshore (see Table 2).

IMPLICATIONS

The foregoing results are based on selected field sites in southeastern Australia. The frequency and duration of the observations have produced some findings that may have implications for beach investigations elsewhere.

1. The modal breaker wave climate (interacting with the local sediment type) will determine the modal beach type.

In medium to fine sand beaches modal waves less than 1m produce reflective beaches, between 1 and 2.5m rhythmic beaches, and greater than 2.5m dissipative beaches. Associated with each beach type is a characteristic beach - surfzone morphology and dynamics, modes of beach erosion (see Wright, this vol.) and zones of sediment storage.

2. In undertaking beach investigations the classification presented here provides a format for locating a particular beach type and planning survey and dynamic investigations based on the characteristics mentioned in (1) above. A program of study on a reflective beach will of necessity, be markedly different from one on a rhythmic or dissipative beach.

3. Beach nourishment programs are concerned primarily with nourishing the subaerial beach. However as Table 2 and Figures 6 and 7 indicate in all beach types a certain amount of this sand must be redistributed seaward. On dissipative beaches most sand placed on the subaerial beach can be expected to be redistributed seaward of the breakpoint. Understanding the beach type is important not only for determining how much sand might be required to nourish the system, but also when and where and at what beach stage would be most suitable to undertake the nourishment.

4. In extropolating results of beach investigations to other beaches and other coasts it is imperative that the beach type (and grain size) be considered. Findings on a coarse grained reflective beach may have little bearing on a fine grained dissipative beach. Beaches have a predictable range of morphodynamic variation, the spatial and temporal beach variability should be understood before between beach comparisons are made.

5. Beach erosion is of concern to all who investigate, work with and use the beach system. Wright (this vol.) discusses the three separate modes of erosion associated with reflective, rhythmic and dissipative beaches. The results presented here and elsewhere (Short 1979b, Short and Hesp, in press) support Wright's classification. Each mode of erosion possesses different morphological and dynamic characteristics, in turn leading to varying degrees of beach and backshore mobility. Therefore the contribution of each mode must be considered separately where designing a beach erosion program for a particular section of beach or beach type.

6. As stated in the Introduction the field sites investigated in this study experience negligible littoral drift. However in many area littoral drift is a major component of the beach system. Observations on the

northern New South Wales coast where littoral drift is significant show that the beach types and on-offshore characteristics still hold. However downdrift skewing of the mesoscale forms (bars, channels, rips, etc) does occur, as does significant net longshore sediment transport. Therefore in system experiencing littoral drift, the contribution of the mesoscale forms of on-offshore sediment exchange associated with dissipative, rhythmic and reflective beach types must be considered if accurate calculations of total transport are to be made.

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