Revista Chilena de Historia Natural
69: 589-604, 1996

The role of wave height, period, slope, tide range and embaymentisation in beach classifications: a review

El rol de la altura y período de la ola, pendiente, rango mareal y grado de protección en clasificaciones de playa: una revisión

ANDREW D. SHORT

Coastal Studies Unit, Department of Geography,
University of Sydney Sydney, NSW 2006, Australia
E-mail: A.Short@csu.usyd.edu.au

ABSTRACT

This paper reviews recent developments in the classification of beach systems and in particular the contribution of wave height and period, sand size, beach slope, tide range and embaymentisation to beach type and morphodynamics. The review begins with the micro-tidal, single bar, beach model of Wright and Short (1984) which is solely dependent on wave height, period and grain size (sediment fall velocity). More recent research has modified this model to accommodate a wider range of beach environments including multiple bars, high tide ranges and embayed beaches. In multi-bar beach systems beach slope and wave period are critical to determining bar number. In areas of increasing tide range the ratio of tide range to wave height, the relative tide range, can be used to classify tide dominated beach types and the transition to tide flats. When beaches are bounded by headlands or structures, the ratio of the shoreline to embayment chord length, can be used of classify three beach systems ranging from normal to topographically dominated beaches. The original single bar beach model, together with these modifications now make it possible to classify all open coast beach systems, and to predict beach type based on the relevant wave, sand, slope, tide and embayment parameters.

Key words: Sandy beaches, waves, tides, sediment, embayment.

RESUMEN

Se revisan los desarrollos recientes en la clasificación de los sistemas de playas y la contribución de la altura y período de las olas, tamaño de la partícula, pendiente, rango mareal y protección al tipo de playa y morfodinámica. La revisión comienza con el modelo de playa micromareal con barra única de Wright and Short (1984) el cual depende sólo de la altura y período de la ola y tamaño del grano (velocidad de sedimentación). Investigaciones más recientes han modificado este modelo a fin de acomodar un rango más amplio de playas incluyendo barras múltiples, rangos mareales altos y playas protegidas (en bahías). En playas con barras múltiples la pendiente y el período de la ola son críticos en la determinación del número de barras. En áreas con mayor rango mareal la proporción rango mareal: altura de la ola (rango mareal relativo) puede ser usada para clasificar playas dominadas por mareas y áreas transicionales a planicies mareales. Cuando las playas están limitadas por promontorios o estructuras, la proporción línea de costa: longitud de la cuerda de la bahía puede ser usada para clasificar tres sistemas de playas, desde normales a aquellas dominadas por la topografía. El modelo original de playa con barra única, junto con estas modificaciones, hacen ahora posible clasificar todas las playas expuestas y predecir el tipo de playa basado en olas relevantes, arena, pendiente mareas y parámetros relacionados a protección topográfica.

Palabras clave: Playas arenosas, olas, mareas.

INTRODUCTION

Sandy beaches are accumulations of sand lying between modal wave base and the swash limit. They are deposited primarily by waves, but also influenced by tides and topography. Their morphology and dynamics should therefore be a function of their sand size, the breaker wave climate, including height and period, tide range, and major topographic features. Each of these variables, however, has considerable spatial and temporal variation, resulting in a range of beach types. At the level of an individual beach where sediment size may be assumed constant, temporal changes in wave height

(Received 1 January 1995; accepted 28 July 1996)

and period and lunar tidal cycles induce beach response and change. At a regional level, changes in both sediment and breaker wave height induce further spatial and temporal changes, while at a global level a wide range of variable combinations and beach response occurs. All these beaches will, however, possess three dynamic zones - a zone of wave shoaling seaward of the breaker point, a surf zone of breaking waves, and a swash zone of final wave dissipation on the subaerial beach. The nature and extent of each of these zones will ultimately determine the beach morphodynamics. The width of the shoaling, surf and swash zones will depend on wave height and beach gradient (a function of sediment size and wave height), while tide range will determine the vertical stability or daily movement of all three zones.

The aim of this review is to examine the major parameters that determine the shape and nature of beach and surf zone morphodynamics, using readily obtainable variables of breaker wave height, wave period, tide range, sediment size, beach slope and embayment shape. The review will first examine beach morphodynamics in areas of micro-tidal range (< 2m), where the swash, surf and shoaling zones are assumed to be stationary. Second, it will look at the influence of decreasing beach gradient (primarily caused by decreasing grain size) which can lead to the formation of multiple bars in micro-tidal environments. Third, it will extend the micro-tidal model into areas of increasing tide range when all three zones are daily translated to and fro across the inter- and sub-tidal beach. Finally it will incorporate the additional variables of embayment length and chord to examine the role of embayments (headlands, groynes, etc) in influencing beach morphodynamics.

Micro-tidal single bar beaches

Micro-tidal beach systems are assumed to be wave dominated, with a low tide range that has a minor to negligible role in determining beach morphology. Tide is therefore largely ignored in assessing general beach morphodynamics. The three zones of shoaling, surf and swash are therefore assumed to be stationary.

Wright & Short (1984) used the dimensionless fall velocity (Ω, Gourlay 1968) to quantify single bar, micro-tidal beaches and to classify three distinctive beach types, where

$$\Omega = Hb / Ws\, T$$

where Hb is breaker wave height (m), Ws is sediment fall velocity (m/sec) and T is wave period (sec). The three beach types consist of two end members, dissipative and reflective, linked by an intermediate state.

Dissipative beaches (Figures 1 and 2) occur where $\Omega > 6$ and are characterised by fine sand, high wave energy, and preferably short wave periods. For this reason, on open swell coasts, they are only found in areas of fine to very fine sand with persistent high swell (> 2 m), such as parts of the southern Australian (Wright et al. 1982), south African (McLachlan et al. 1993) and east and west South American coasts (Suhayda et al. 1975).They are more common in storm dominated sea environments, where high, but short period storm waves act on a fine sand beach, such as parts of the North Sea (Short 1992), Arctic Ocean (Short 1975), Baltic (Aagaard 1990) and Mediterranean (Bowman & Goldsmith 1983). They also occur in some large lakes (Aagaard & Greenwood 1995) and coastal bays (Short 1996). In between the storms the dissipative morphology usually remains inactive under calms and low waves.

Dissipative beaches are characterised by a wide, low gradient swash zone, a wide surf zone, containing two (swell coast) to five (sea coast) subdued shore parallel bars and troughs, extending up to hundreds of meters seaward. Their dynamics is driven by spilling breakers, which dissipate their energy across the wide surf zone. In doing so the incident wave energy in increasingly transferred to infragravity frequencies which manifests itself as wave set-up and set-down at the shoreline. Surf zone circulation is predominantly at low infragravity frequencies, and is vertically segregated with onshore flows toward the surface, and seaward toward the bed (Wright et al. 1982). The bar/s location is a function of standing waves (Short 1975), which are a product of the group bound long waves

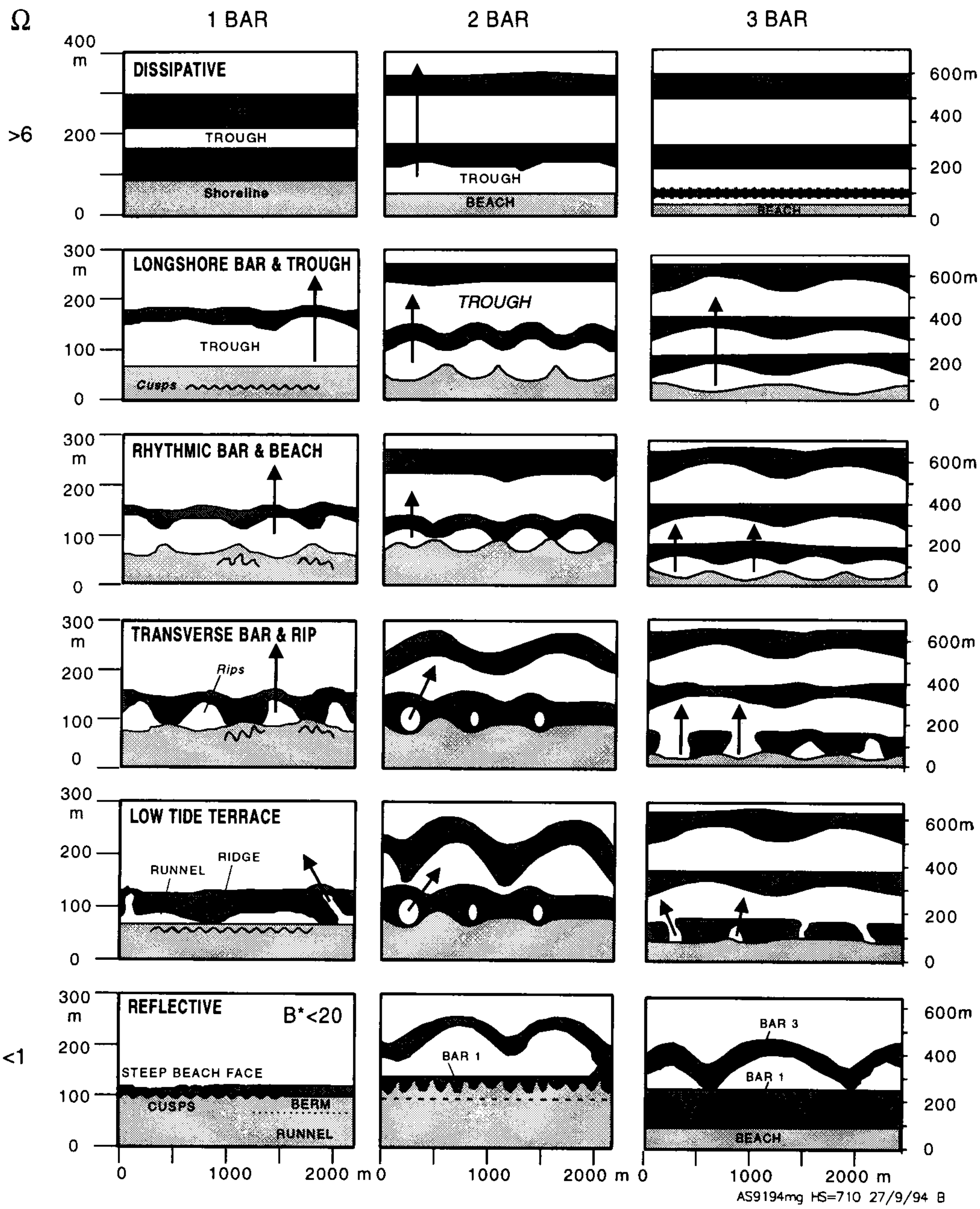


Fig. 1: Beach types observed in one, two and three bar beach systems. The single bar systems contains the six beach types described by Wright & Short 1984. In the double and multi-bar systems, rip presence and spacing, and the sequencing of hierarchical bar types will vary depending on formative mechanisms and the degree of bar activity/inactivity. Arrows indicate active rips. (Modified from Short & Aagaard 1993).

Tipos de playas que ocurren en sistemas de playas con una, dos y tres barras. Los sistemas con una barra contienen los seis tipos de playas descritos por Wright & Short 1984. En los sistemas con barras dobles o múltiples, la presencia de resacas y espaciamiento y la secuencia de tipos jerárquicos de barras variará según los mecanismos de formación y el grado de actividad/inactividad de las barras. Las flechas indican corrientes activas de resaca. (Modificado de Short & Aagaard 1993).

associated with wave groupiness (Aagaard 1990), which in turn can be amplified by the shoreward growth of infragravity energy produced by the incident waves.

Rip dominated intermediate beaches occur when 1 > Ω > 6, which is produced by moderate to high waves, fine to medium sand, and longer wave periods (Figure 2).

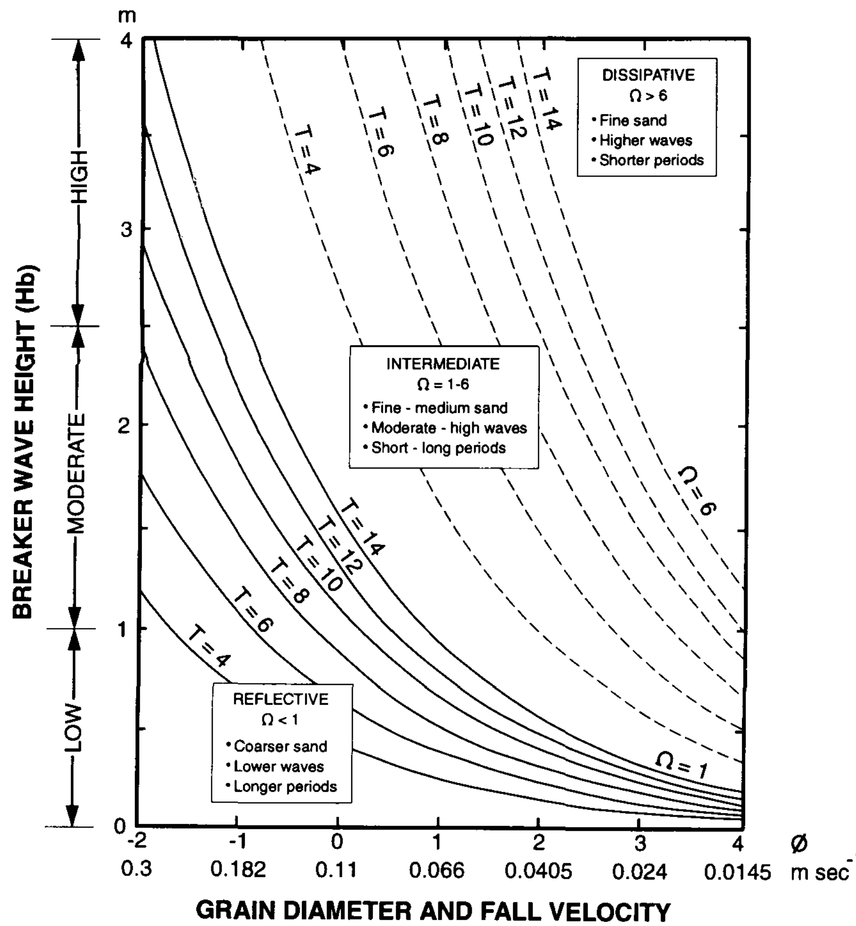


Fig. 2: A plot of breaker wave height versus sediment size, together with wave period that can be used to determine approximate W and beach type. To use the chart determine the breaker height, period and grain size/fall velocity (phi or cm/sec). Read off the wave height and grain size, then use the period to determine where the boundary of reflective/intermediate, or intermediate/dissipative beaches lie. Ω = 1 along solid T lines, and 6 along dashed T lines. Below the solid lines Ω < 1 the beach is reflective, above the dashed lines Ω > 6 the beach is dissipative, between the solid and dashed lines Ω is between 1 and 6 and the beach is intermediate. (Modified from Short 1986).

Gráfico de altura de la ola versus tamaño de sedimento; junto al período de la ola puede ser usado para la determinación aproximada de Ω y tipo de playa. Para usar el gráfico, determine la altura y período de la ola y tamaño/velocidad de sedimentación de la arena (phi o cm/sec). Lea altura de la ola y tamaño de la arena; luego use el período para determinar dónde se ubican los límites entre playas reflectivas e intermedias o entre intermedias y disipativas. Ω = 1 a lo largo de líneas continuas para el período y 6 a lo largo de líneas a trazo para el período. Bajo las líneas continuas de Ω < 1 la playa es reflectiva, sobre las líneas a trazo de Ω 6 la playa es disipativa. La playa es intermedia entre Ω 1 y 6 (líneas continuas y a trazos). (Modificado de Short 1986).

These are the most common beach type and occur both as single-barred intermediate beaches, and commonly as the lower energy inner bar or bars of multi-barred beaches. Their morphodynamics is characterised by regular longshore variations in surf zone morphology and dynamics. The morphology alternates longshore between shallower bars and deeper rip channels, while the surf zone circulation is cellular and horizontally segregated. Waves tend to break more on the bars with the water moving shoreward as wave bores. Water then moves sideways as rip feeder currents to collect in the rip embayments between the bars, and pulses seaward as narrow rip currents in the deeper rip channels.

There are four states of intermediate beaches (Figure 1). At the higher energy end is the longshore bar and trough state (LBT), which forms a transition from the dissipative beach type. The LBT, however, has a more pronounced bar and deeper trough. Waves break heavily on the outer bar and reform in the trough, reaching the shore as lower waves. Depending on the sand size the shoreline many be a low tide terrace to reflective, and is straight alongshore. Within the trough circulation is both vertically segregated (on-offshore) and horizontally segregated into cellular rip circulation. Rhythmic rip topography is, however, poorly developed.

The rhythmic bar and beach state (RBB) has well developed rip topography, with highly rhythmic or crescentic bars, separated by deep rip channels, feed by rip feeder channels which are part of a continuous though rhythmic longshore trough. The shoreline is rhythmic, with megacusps developing in the lee of the bars, and scour forming scarped embayments in lee of the rips. Cellular rip circulation dominates the surf zone.

The transverse bar and rip state (TBR) is similar to the RBB except the bars are attached to the megacusp horns, thereby fully segregating the rip feeder and rip channels, particularly at low tide, when rip currents will also intensify (Short & Hogan, 1994). The beach face is highly rhythmic. As the rip channels infills the low tide terrace state (LTT) is reached. This consists of a continuous bar attached to the beach and exposed at spring low tide, hence the name. It may the crossed by small transverse rips, feed by narrow feeder channels/runnels at the base of the beach. The shoreline straightens as the rips and embayments infill. At low tide waves plunge heavily on the outer terrace, while at high tide they may pass across the terrace unbroken to surge up the beach face producing a reflective high tide beach.

The low energy end member of the beach types is the reflective beach, which occurs when $\Omega < 1$. This requires medium to coarse sand, low wave energy and is favoured by long wave periods (Figure 2). It therefore commonly occurs on protected (low wave) swell coasts, and on all beaches composed of coarse sand and cobbles, no matter what the wave height. Reflective beaches consist of a relatively steep, swash dominated, beach face. If there is a mixture of sediment size, then the coarsest material accumulates at the base of the swash zone (at around low tide level) and forms a coarse steep step, up to several decimeters high. Immediately seaward of the step is a low gradient nearshore (wave shoaling) zone composed of finer sediment (Figure 1). There is no bar or surf zone, rather waves break by surging or collapsing over the step. The strong swash in turn builds the steep, high beach face.

The role of the three parameters Hb, T and grain size in influencing beach type is illustrated in Figure 2, which plots Hb versus grain size, with selected wave period lines. It is critical to understand that beach type and change is a function of all three parameters Hb, T and Ws. Dissipative beaches are favoured by high waves and fine sand, however with decreasing period they can occur in waves as low as 1 m. Likewise reflective beaches are favoured by low waves and coarse sand, however on long period swell coasts, and with coarse sand, beaches will stay reflective with waves up to 3 m. Figure 2 therefore indicates the sensitivity of each of the beach types to variation in the three parameters. It must be stressed, however, that Figure 2 merely predicts the beach type when it has fully responded to the conditions and reached an equilibrium state. In nature Wright et al. (1984, 1985) have shown that beach response lags behind changing wave conditions by days to weeks, and that the antecedent beach state will determine the amount of change required to reach an equilibrium situation. Consequently, as waves conditions rapidly change the impact of antecedent state, coupled with the inherent lagged response, means than beaches are often is disequilibrium with the prevailing wave conditions. This disequilibrium is manifest by beach change, either erosion, when attempting to respond to higher waves and become more dissipative, or accretion, when lower waves induce beach accretion and a more reflective profile.

Table 1 lists the modal Ω and wave height for the range of beach types observed on

TABLE 1

Beach type, Ω and wave height on Narrabeen Beach, Australia (Source: Wright et al. 1984 1985, Short 1993)

Tipo de playa, Ω y altura de la ola en Narrabeen Beach, Australia (Fuente de origen: Wright et al. 1984 1985, Short 1993)

Beach type/state	Ω mean*	Ω sd	Wave height (m)
Dissipative	> 5.5	–	> 2.5
Longshore bar & trough	4.70	0.93	2.0-2.5
Rhythmic bar & beach	3.50	0.76	1.5-2.0
Transverse bar & rip	3.15	0.64	1.0-1.5
Low tide terrace	2.40	0.19	0.5-1.0
Reflective	< 1.5	–	< 0.5

*mean Ws = 0.04 m/s; T = 10 s.

Narrabeen beach, Australia. However, the wave height in particular, should only be taken as a guide for beaches with similar wave period and sediment size.

This sequence of beach types was developed for essentially single bar beaches in micro-tidal environments and does not directly apply to multi-bar beaches and those in higher tide ranges, or in some estuarine environments. To incorporate these beach environments two additional parameters have been introduced, first beach gradient, and then tide range.

Micro-tidal, multi-bar beaches

Many micro-tidal beaches have more than one bar. Two bars are common on swell coasts (Short 1993), while in seas three to fives bars are more common (Short 1975, Aagaard 1990; Short & Aagaard 1992). In order to accommodate multi-bar beaches in a general sequence of beach types, two additions to the single bar model are required. First, the environmental conditions that favour multiple bars, (not covered in Figure 2), and second, the impact on beach/bar type and change in multi-bar systems.

Short & Aagaard (1993) developed the bar parameter (B*), to help explain the presence and number of bars in a wide range of micro-tidal beach environments, where:

$$B^* = x / g \tan\beta\, T^2$$

and x is the distance offshore (m) to where ß tends to zero, g is gravity (m/sec), and ß the beach-nearshore slope (degrees). They found that

- no bars (reflective beaches) occur where $B^* < 20$;
- one bar when B^* is 20 - 50,
- two bars when B^* is 50 - 100;
- three bars when B^* is 100 - 400;
- and four or more bars when $B^* > 400$

In other words, bar number increases as gradient and/or wave period decreases. This relationship is a product of the surf zone dynamics that controls bar formation and spacing. Infragravity standing waves will induce residual flows such that bars tend to form under the standing wave antinodes, while troughs will occur under the nodes (Short 1975).The spacing of the standing waves is positively related to wave period and inversely related beach gradient. In other words the bars are most likely to be formed where period is short, hence the bars are closely spaced and therefore in shallower water, and gradient low, hence the bars are closer to the surface. They are least likely to occur where wave period is long which produces more widely spaced bars, that extend into deeper water, and where gradients are steep and the water too deep for bar formation.

Figure 1 illustrates a generalised model of one, two and three bar beach systems. The two and three bar systems have several important characteristics not present on the single bar model. First, there is always a hierarchy of bar types, with the outer bar being the highest energy type, and the inner bar/s the lower energy type. This is a result of wave breaking leading to decreasing wave height across the bar system, which in turn reduced Ω, and thereby beach/bar type (Figure 2). Second, the outer bar/s may become inactive and stagnate, particularly in sea environments, as wave height decreases below a certain threshold (Aagaard 1989, Short 1992). Third, while most multi-bar beach types have a dissipative high energy end member, at the low energy end only the inner bar may become reflective. Rarely do the outer bar/s reach the beach owing to their inactivity during low waves.

In multi-bar systems, the inner bar can be assumed to behave like a lower energy single bar beach, moving through a range of usually lower energy beach types (TBR-LTT-R), while the outer bar/s usually remain dissipative, or at best move through the higher energy beach types (D-LBT-RBB). This outer bar movement is more likely to occur in swell environments, while stagnation is more likely in storm dominated sea environments, where calms may prevail between storms. Figure 3 illustrates the nature and frequency of occurrence of double bar systems along the open, swell dominated New South Wales coast. Note that the inner bar rarely moves beyond the TBR state, while the outer bar only reaches the TBR state 5% of the time. In addition movement horizontally across the chart indicates an inactive outer, but active inner bar, while movement down or diagonally across the chart indicates both bars are active and changing. The modal double bar situation for the NSW beaches are accommodated in the combination of outer LBT or RBB, and inner TBR or LTT, which account for 83% of the observations. Care must be taken is applying Figure 3 to other regions and environments, as changing wave and sediment combinations may produce additional bar combinations and certainly different frequencies of occurrence.

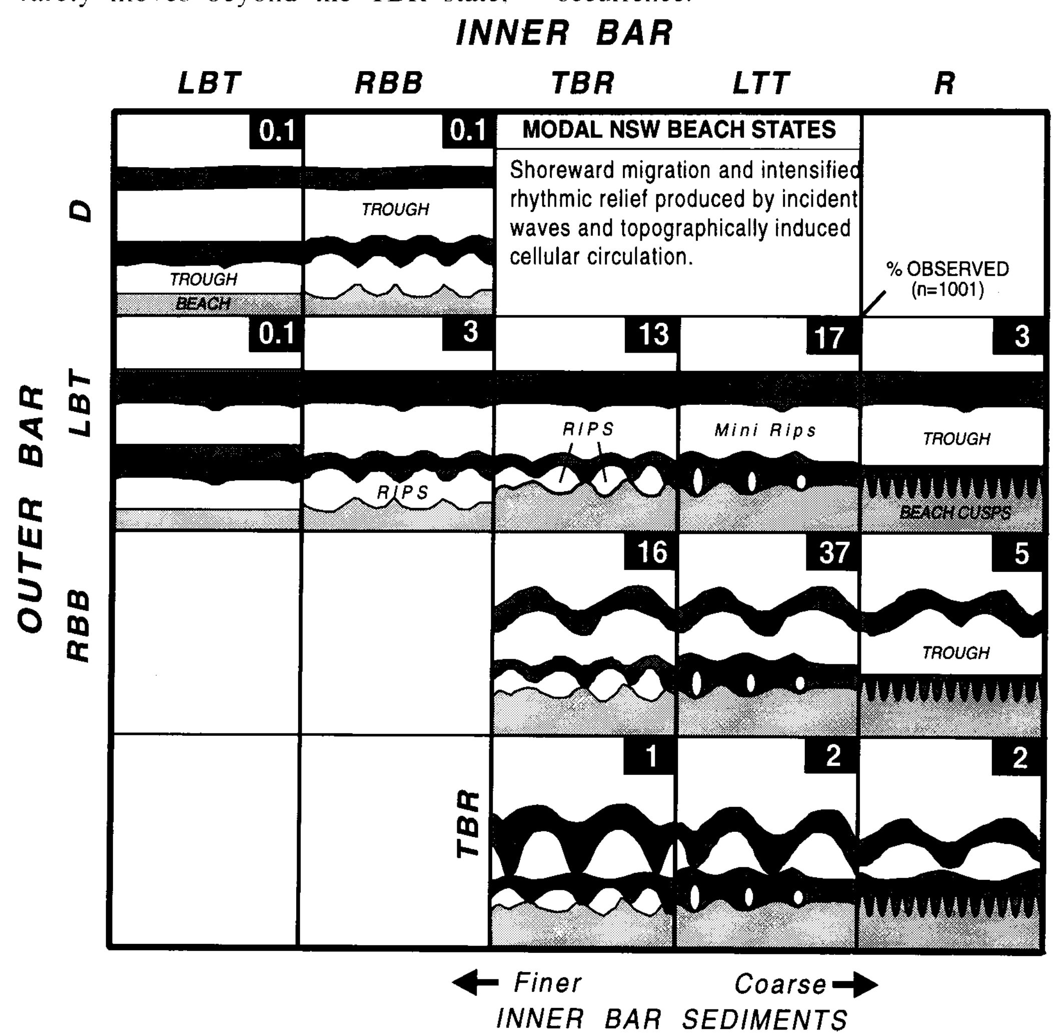


Fig. 3: Observed outer and inner bar combinations on the New South Wales coast. Number indicates frequency of occurrence, based on 1 001 observations. Modified from Short & Aagaard 1993.

Combinaciones observadas de barras externas e internas en la costa de New South Wales. Los números indican frecuencia de ocurrencia basados en 1 001 observaciones. Modified from Short & Aagaard 1993.

Impact of tide range

The single- and multi-bar beach models presented above do not consider tide range in their development. However, it has been long recognised that tide is important in influencing beach morphodynamics (Davis & Hayes 1984; Carter 1988; Short 1991). In order to accommodate increasing tide range, Masselink and Short (1993) introduced the relative tide range parameter

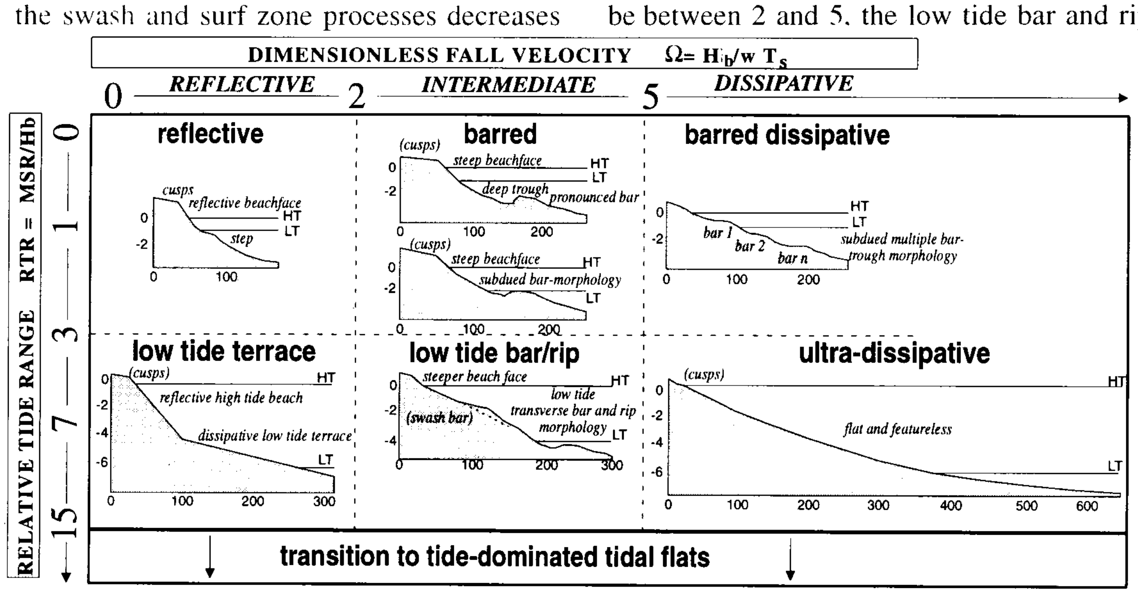
$$RTR = TR / Hb$$

where TR is mean spring tide range (m). By using both RTR and Ω they classified sand beaches into eight types. For simplicity these have been reduced to six in Figure 4.

When RTR < 3 the three single bar, micro-tidal beach types (reflective, intermediate and dissipative) of Wright & Short (1984) apply. These are identical to the single bar of Figure 1 described in the previous section. Landward of the breaker zone they are dominated by surf and swash zone processes. As tide range increases the impact of both the swash and surf zone processes decreases as shoaling waves increase in morphological dominance. The swash zone is restricted in impact to the high tide beach, while the surf zone is initially detached from the swash zone by an intertidal zone and located at the low tide level. With increasing tide dominance shoaling wave override the transient surf zone and dominate the inter- and subtidal morphology.

When RTR is between 3 and 15, the tide is 3 to 15 times the wave height. Three beach types can be identified, namely the reflective plus low tide terrace (RLT), the low tide bar and rip (LBR) and the ultradissipative (UD). When Ω < 2 and relatively low waves prevail, the beach face is steep and reflective, like its lower tide counterpart. However, the lower beach face, rather than a step, has a low tide terrace which may be continuous, or cut by rips. This is called the reflective plus low tide terrace type. Rips will only occur when the RTR < 7 and waves exceed 1 m. Also as RTR increases so to does the width of the low tide terrace.

As wave height increases causing Ω to be between 2 and 5, the low tide bar and rip



as9459mb HS=1 23/8/95 B A.Short Book Publication

Fig. 4: Conceptual beach model based on Ω and the relative tide range (RTR). When RTR < 3 and Ω < 2, the micro tidal beach types dominate. When RTR is between 3 and 15, tide range increasingly dominates the wide intertidal beach, with cusps restricted to high tide, and bars and rips, when present, to low tide. When RTR > 15 the transition to tidal flats is entered. (Modified from Masselink & Short 1993).

Modelo conceptual de playa basado en Ω y rango mareal relativo (RTR). Cuando RTR < 3 y Ω < 2, domina el tipo de playa micromareal. Cuando RTR está entre 3 y 15, el rango mareal domina en forma creciente la amplia playa intermareal, con cúspides restringidas a período de marea alta y barras y resacas (cuando presentes) durante la marea baja. Cuando RTR > 15 se entra a la transición hacia planicies de marea. (Modificado de Masselink & Short 1993).

type dominates. It consists of a steeper high tide reflective beach face, fronted by a wide low gradient intertidal zone, which may contain a low swash bar (ridge and runnel). Only at low tide does a bar form, and this may be a continuous attached bar cut by transverse rips or rhythmic with alternating bars and rips, the latter requiring higher waves. When RTR > 7 increasingly higher waves (> 2 m) are required to maintain the bar/rip type, otherwise it becomes ultra-dissipative.

When $\Omega > 5$ due to higher waves and/or finer sand, the entire inter- and sub-tidal profile become flat and relatively featureless, called ultra-dissipative (after McLachlan et al. 1993). Cusps may be present in the spring high tide zone, and very subdued swash bars may form the in intertidal zone, but the overall profile is a low gradient and concave, with no distinct bars or rips at low tide. As tide range increases, so to does the width of these beaches, which may reaches several hundred meters.

Another characteristic of beaches in areas of high tide range is often a distinct break in slope between the dry high tide beach, and permanently saturated lower tide beach. It is diagnostic of the reflective/low tide terrace beach, but becomes less prominent on more dissipative beaches. Where the high tide beaches is steep the break in slope is often sharp and marked by an abrupt change to finer sediment. At this point a low gradient low tide dissipative beach is formed. The elevation of the break in slope is related to grain size, increasing with finer sand and decreasing with coarser sand (Turner 1993). The break also usually coincides with the point of low tide water discharge from the beach, the effluent point.

When RTR > 15, beaches become increasingly tide dominated and begin to tend toward tidal flats. As beaches exist in all tide ranges, up to the maximum of 15 m, this implies that to have tidal flats, the increase in RTR beyond 15, must be induced by a substantial decrease in wave height. As tidal flats occur on all micro-tidal coasts, clearly it is the lower wave height, rather than high tide range, that is most critical in reaching this domain. Where some waves do prevail the beaches initially tend to have a steep high tide beach fronted by intertidal sand flats. As RTR >>15 then the domain of true tidal flats is approached with no high tide beach and low gradient intertidal flats that may contain increasing proportions of finer sediments (silts and mud).

The RTR parameter can also be used to classify wave dominated estuarine beaches. All the above types can be found in estuaries, but there are three problems in classifying and identifying these beaches in estuaries. First, is obtaining an accurate measure of dominant wave height. This is difficult in estuaries where calms usually prevail and episodic strong wind waves or even low ocean swell are likely to dominate any wave formed features. For much of the time the estuarine beaches may lie inactive, with the morphology or beach type being formed during the infrequent periods of higher wave activity. It is therefore essential to obtain a measure of the waves that form the beaches, not necessarily the prevailing lower waves. Second, during periods of higher estuarine waves, they may not have sufficient energy to develop the infragravity dominated circulation required to produce rhythmic topography, including bars, rips and cusps. Hence while the estuarine may develop the two dimensional profile of the above beach types, they may not have sufficient infragravity wave energy to develop three dimensional rhythmic features. Finally, in microtidal estuaries, small changes in wave height will produce a large change in RTR (Figure 5). Consequently rapid spatial changes in beach type may occur in micro-tidal estuaries due to longshore variation in formative wave height in a fixed tide range.

Overall, the impact of tide range is to increase the dominance of wave shoaling, particularly at the expense of the surf zone, and thereby restrict swash dominance to the narrow high tide zone. Hence, increasing tide range produces beaches with a steeper, swash-dominated high tide swash zone, usually composed of coarser sediment. The surf zone shifts with the tide, and can only imprint itself on the morphology at low tide, during the turn of the tide, otherwise not at all. The intertidal profile is low in gradient and concave up in profile. The exposed surface is a planer surface at low tide, but

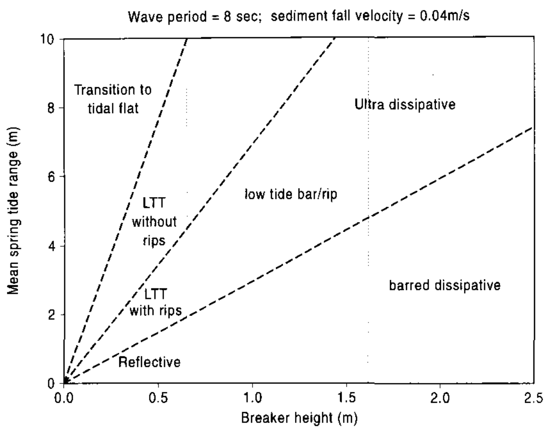


Fig. 5: This plot shows the location of the beach types presented in Figure 4, based on tide range and breaker wave height, in the case of a wave period of 8 sec, and grain size (Ws) of 0.04 m/sec. The boundaries are indicated by dotted lines, as their position will shift with changes in T and Ws. Note how, in areas of low waves or low tides, small changes in tide range and/or wave height will produce large shifts in beach type. (Modified from Masselink & Short 1993).

Localización de los tipos de playas presentados en la Fig. 4; gráfico basado en rango mareal y altura de la olas (período de la ola = 8 segundos, velocidad de sedimentación = 0.04 m/seg.). Los límites se señalan con líneas punteadas; sus posiciones variarán acorde los cambios de T y velocidad de sedimentación. Nótese, cómo en áreas con olas o mareas bajas, cambios pequeños en el rango mareal y/o altura de las olas producirán cambios significativos en el tipo de playa (Modificado de Masselink & Short 1993).

covered by shoaling wave ripples at high tide (Masselink, 1993).

Figure 5 illustrates the environmental range of macro- to micro-tidal beaches. It is interesting to note the convergence of the boundaries in areas on both low waves and low tide. This implies that 'macro-tidal' beach types can exist in areas of low tide range, if waves are low enough; and that small changes in wave height and tide range will have a pronounced impact on beach morphology in these low wave-tide environments, such as in estuaries. However, this impact is more likely to manifest itself spatially, rather than temporally, meaning that estuarine beaches are unlikely to experience rapid temporal change in response to changing wave conditions, rather they are episodically reworked by infrequent higher formative waves, and inactive in between. Longshore changes in the level of wave exposure, however, can and does lead to rapid spatial changes in beach and/or tidal flat morphology.

In summary, it is the relative range of the tide versus waves that is important in determining beach types. When RTR < 3 the wave dominated surf zone largely controls beach morphology, but as RTR increases, it is the wave dominated, wave shoaling zone, as it is transferred horizontally backwards and forwards across the sub- and intertidal zone, that increasingly dominates and determines beach and intertidal morphology.

Headland impacts (and megarips)

All the above apply to long beaches with no boundary effects. However, headlands, rocks, reef and structures will all impact the beach and surf zone through their influence on wave refraction and attenuation, and by limiting the development of longshore currents, rips and rip feeder currents. Martens et al. (in press) found that as wave height (Hb) increases and shoreline length (Sl) decreases, a critical threshold is reached where the single bar beach model is increasingly modified. On beaches with no headlands 'normal' surf zone circulation prevails. When headlands are present and are widely spaced and/or the beach receives low waves, the beach becomes sub-intermediate, as the headlands impact surf zone circulation only adjacent to the headlands, with normal circulation between. As wave height increases and/or the headland are closer together, the entire beach circulation may eventually becomes impacted by the headlands. At this stage topographically controlled cellular circulation, called megarips, prevail (Figure 6). Megarips are defined as large scale, topographically controlled rip systems (Short 1985). The degree of headland impact can be predicted using δ' where

$$\delta' = S_l^2/100Cl\ Hb$$

and S_l is the shoreline length between the headlands, and Cl is the chord length directly between headlands. The impact of δ' on beach circulation is indicated in Figure 7. When

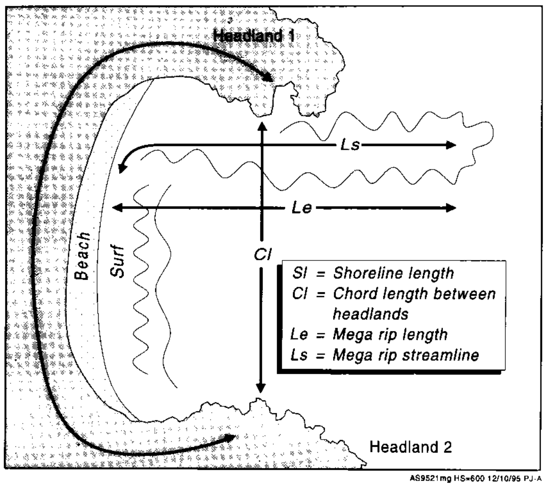


Fig. 6: Schematic diagram and parameterisation of an embayed megarip. (Modified from Martens et al. in press).

Diagrama esquemático y parametrización de una megarresaca incluida en una bahía (modificado de Marrtens et al., en prensa).

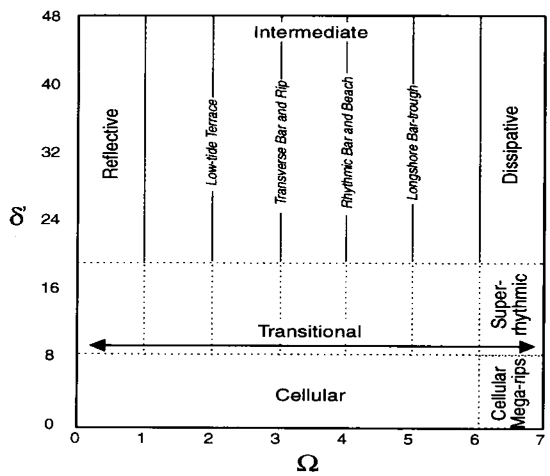


Fig. 7: The dimensionless fall velocity (Ω) is plotted against the dimensionless embayment scaling parameter (δ'). The micro-tidal beach model applies when δ' > 19. As δ' moves between 19 and 8 a transitional stage is reached as embayment ends begin to increasingly influence circulation, while when δ' < 8, the embayment size and shape dominates the entire surf zone circulation, usually producing megarips. (From Martens et al. in press).

Gráfico de relación entre el parámetro no dimensional de protección topográfica ("embayment scaling parameter") y la velocidad de sedimentación (parámetro adimensional) (Ω). Cuando los valores del primer parámetro son >19 se aplica el modelo de playa micromareal. A medida que los valores del mismo se mueven entre 19 y 8 se alcanza un estadio transicional, donde los extremos de la bahía empiezan a influenciar en forma creciente la circulación. Cuando el valor del parámetro de protección topográfica es < 8, el tamaño y forma de la bahía domina la circulación de toda la zona de rompiente, usualmente produciendo megarresacas. (De Martens et al., en prensa).

δ' > 19 normal beach circulation
δ' = 8 - 19 transitional circulation
δ' < 8 cellular beach circulation

Normal beach circulation is what is described above for micro- and macro-tidal beaches (Figures 1 and 4).

Transitional circulation occurs when the embayment size and shape begins to increasingly influence the surf zone circulation, by initially causing longshore currents to turn and flow seaward against each headland, while still maintaining some normal beach circulation away from the headlands.

Cellular circulation occurs when the topography (headlands) control the circulation within the entire embayment. Longshore flow dominate within the embayment, with strong, seaward flowing megarips occurring at one of both ends of the embayment, and in longer embayments also away from the headlands.

Figure 8 can be used as a guide to the combination of embayment dimensions and breaker wave height that produce transitional and cellular circulation, together with the approximate spacing for the megarips. Whereas small embayments (< 2 km) will shift to cellular circulation when waves exceed 3 m, long embayments(> 5 km) require waves to exceed 6 m to reach cellular circulation with rips spaced 2 km apart. The largest rip spacing observed on long straight beaches, is on the order of 3 km on the high energy Coorong coast of South Australia (Short 1985).

In addition to the above impacts, embayments and particularly the megarips they produce also influence beach erosion and the seaward extent of surf zone circulation. Whereas normal beach rips usually begin to dissipate seaward of the breaker zone, megarips have been measured to flow at high velocity (~ 2 m/s) up to 1 km seaward of the breakers. This has important implications for beach erosion, and seaward transport of sediments, nutrients and organisms. Basically because the cellular circulation is constrained by the headlands, in order to discharge water from the surf zone, rip velocities are higher, reaching 2 m/s and more. This in turn leads to greater beach erosion, with erosion greatest in lee of the rip

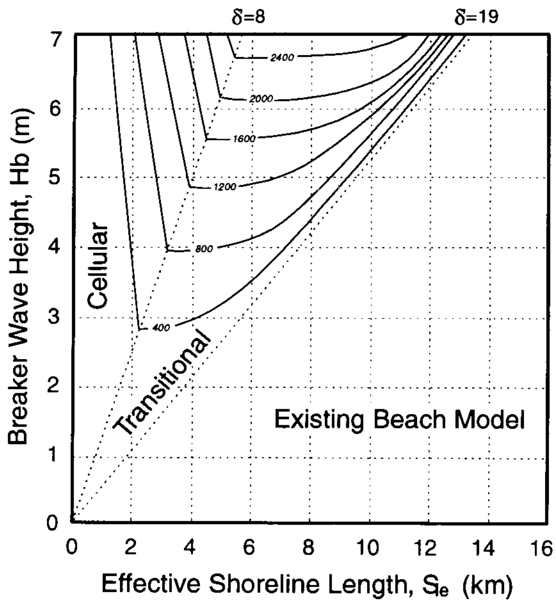


Fig. 8: Breaker wave height plotted against shoreline length to indicate both the range of the existing, transitional and cellular beach models (Fig. 5), and the predicted megarip shoreline spacing. The largest megarips are produced in the longer embayments by the higher waves, whereas small embayments will shift to cellular circulation under relatively small waves. (From Martens et al. in press).

Altura de la ola en la zona de rompiente versus longitud de la costa; se indican los rangos de los modelos existentes de playas, los de los transicionales y celulares (Fig. 5), además del espaciamiento a lo largo de la costa de las megarresacas predichas. Las megarresacas más grandes son originadas por las olas más altas en las bahías más largas, mientras que las bahías pequeñas mostrarán una circulación celular en condiciones de olas relativamente pequeñas (De Martens et al., en prensa).

(Short 1979). As the velocities are higher the rip currents can carry more material and coarser material, and as they penetrate further out to sea, they can carry this material a greater distance from the shore. The net result is more rapid and severe beach erosion on such beaches, with the eroded sediment taking longer to return to shore, commonly 2 to 5 years following severe erosion (Short et al 1995), and perhaps even lost from the system, to longshore or inner shelf deposits.

DISCUSSION

Sandy beaches exist in a wide range of coastal environments. Their grain size can range from fine sand to gravel, waves from calm to gigantic, and tide from zero to 15 m. All these beaches are, however, formed by the three wave processes of shoaling, breaking and swash, with the three waves zones increasingly shifted by increasing tide range. This paper has briefly reviewed the major parameters that contribute to beach shape and change. The role and range of each parameter is summarised in Table 2.

In micro-tidal systems only wave height, period and grain size are required to classify beach systems. These are incorporated in Ω to classify the three beach types -reflective, intermediate and dissipative (Table 2a). As tide range increases, it continuously shifts the position of the three wave zones, and thereby, modifies the beach morphodynamics. To incorporate tide the RTR utilises both spring tide range and wave height. This is used together with Ω to classify beaches by their RTR and Ω into the three micro-tidal plus three tide dominated beach systems. It can also be used to define the boundary between beaches and tidal flats (Table 2a).

On embayed beaches, less than a few kilometres long, the embayment size and shape will obstruct normal beach circulation. As embayment length decreases, and Hb increases, the embayment becomes too small to accommodate normal surf zone circulation and will shift to transitional and cellular circulation leading to megarip formation (Table 2b).

Finally, the seaward extent of these beaches and the number of bars is, however, dependent on additional variables, namely beach gradient (tan ß), and this can be incorporated in the bar parameter B^* to determine the number of bars, with the bar number increasing in micro-tidal systems as T and/or tan ß decrease (Table 2c).

The foregoing classification of beach types is required for a number of reasons. First it provides an understanding of the dominant processes acting on and controlling the morphodyanmics of the world's various beach systems, in all wave, tide and embayed locations. Secondly, as beach morphodynamics changes so too will the whole range of associated beach systems and sub-systems, including beach morphostratigaphy (eg. Greenwood & Davis 1984; Short 1984);

TABLE 2

Impact of salient environmental parameters on beach type (a), circulation (b) and bar number (c).
Shaded indicates area of tidal effects

Impacto de parámetros ambientales sobresalientes sobre tipo de playa (a), circulación (b) y número de barras (c). Sombreados indican áreas con efectos mareales

a. Tide range	Wave height Wave period Sediment			b. Embayment geometry	c. (Gradient)*
TR (m)	Hb (m) T (s) Ws (m/s)			Sl (m) Cl (m)	tan ß
RTR = TR/Hb	Ω = Hb/WsT			$\delta' = S_l^2/100\ C_l$ Hb	$B^* = Xs/\tan ß\ T_i^2$
		Beach type & abbreviation		circulation	bar number
< 3	$\Omega < 1$	reflective	R LTT	$\delta' > 19$ normal	< 2 0 = 0 bar
	Ω = 2 - 5	intermediate	TBR, RBB, LBT	δ'= 8-19 sub	20-50 = 1 bar
	$\Omega > 6$	dissipative	D	$\delta' < 8$ cellular	50-100 = 2 bars 100-400 = 3 bars > 400 = 4+ bars
= 3 - 7	$\Omega < 2$	reflective & LTT	RLT	$\delta' > 19$ normal	
	Ω = 2 - 5	LT bar & rips	LBR	δ' = 8-19 sub	
	$\Omega > 5$	ultradisssipative	UD	$\delta' < 8$ cellular	
= 7 -15	$\Omega < 2$	beach & LTT	BLT	$\delta' > 19$ normal	
	$\Omega > 2$	ultradissipative	UD	δ' = 8-19 sub	
				$\delta' < 8$ cellular	
> 15		> tidal flats	TF		

beach ecology (eg. McLachlan & Erasmus 1983; this volume); and beach erosion (eg. Wright 1980, Short 1985). These in turn will impact beach safety (eg. Short 1993; Short & Hogan 1995); long term barrier evolution (eg. Short & Hesp 1982); and beach management (Short & Hogan 1995).

It is therefore critical to understand the type and nature of beach systems wherever they occur. Each beach system is the product of a certain combination of waves, sediment and tide, and may also be influenced by the overall gradient and topography, if present (such as headlands, reefs, rivers). The character of a beach is often predetermined or inherited from the available sediment, prevailing tide range and the wave climate. As tides and sediment can be assumed constant within an individual beach, then temporal beach changes are largely driven by changing wave conditions. At a regional level beach systems will not only vary temporally in response to waves, but also spatially in response to regional changes in sediment size, gradient and headlands.

To illustrate the temporal variation in beach type Short (1979) introduced the beach state curve, that simply plots the frequency of occurrence of beach types on a particular beach. Short & Wright (1984) elaborated on this by expanding the concept to a range of beaches around the south east Australian coast. The results shown in Figure 9, indicate both temporal change in a range of microtidal beach types (reflective to dissipative) based on changes in wave height, together with the change in beach type between various beaches. Finally, Short (1993) in a survey of all 721 NSW beaches was able to classify all beaches as to their modal beach type and bar number (Figure 10). In this way individual and regional beach characteristics can be presented in a simple and standardised format.

Beaches can and do change dramatically both in space and in time. All of these

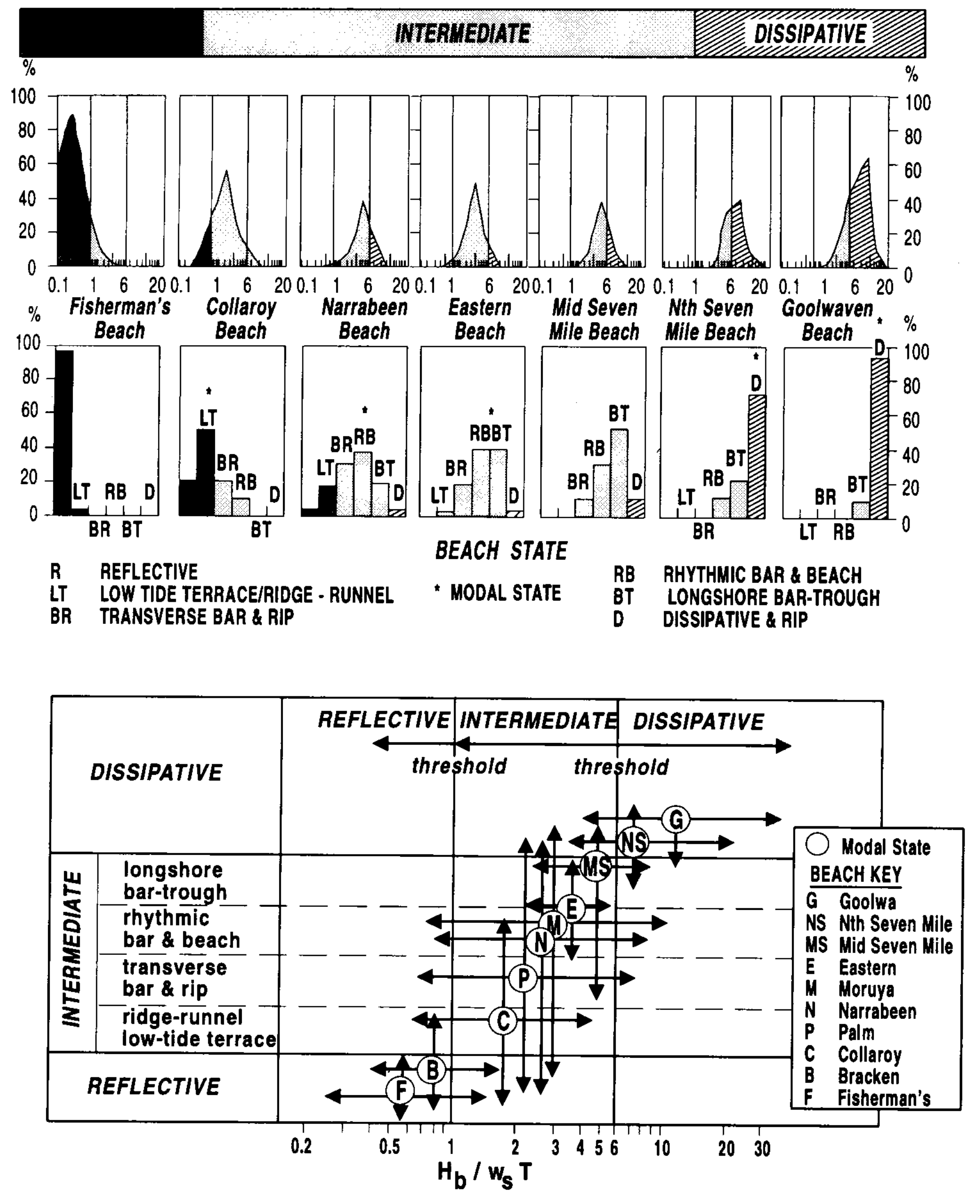


Fig. 9: A plot of beach state curves for selected representative south east Australian beaches. The top graphs plot annual distribution of Ω based on the beach's Hb, T and Ws. The bar graphs plot the frequency of occurrence of each beach type in response to the Ω distribution, while the lower graph plots the modal beach state, together with the temporal range in Ω and beach type for each beach. (Source: Short & Wright 1984).

Gráfico de curvas de estadios de playas de sitios representativos del sur este de Australia. Los gráficos superiores representan la distribución anual de Ω basado en altura de la olas (Hb), período de las mismas (T) y velocidad de sedimentación de la partícula (Ws). Los gráficos de barras representan la frecuencia de ocurrencia de cada tipo de playa en respuesta a la distribución de Ω, mientras que los gráficos inferiores representan el estado modal de playas, junto con el rango temporal en Ω y tipo de playa para cada sitio (Fuente de origen: Short & Wright 1984).

changes are predictable, as all are related to changes in the regional and/or temporal contribution, of the wave, tide, sediment, slope and embayment parameters that control all beach systems.

Using the two parameters, Ω, and RTR, all open coast (and many estuarine) sandy beaches, dominated by waves and influenced by tides, can be classified as to their three dimensional morphology and dynamics;

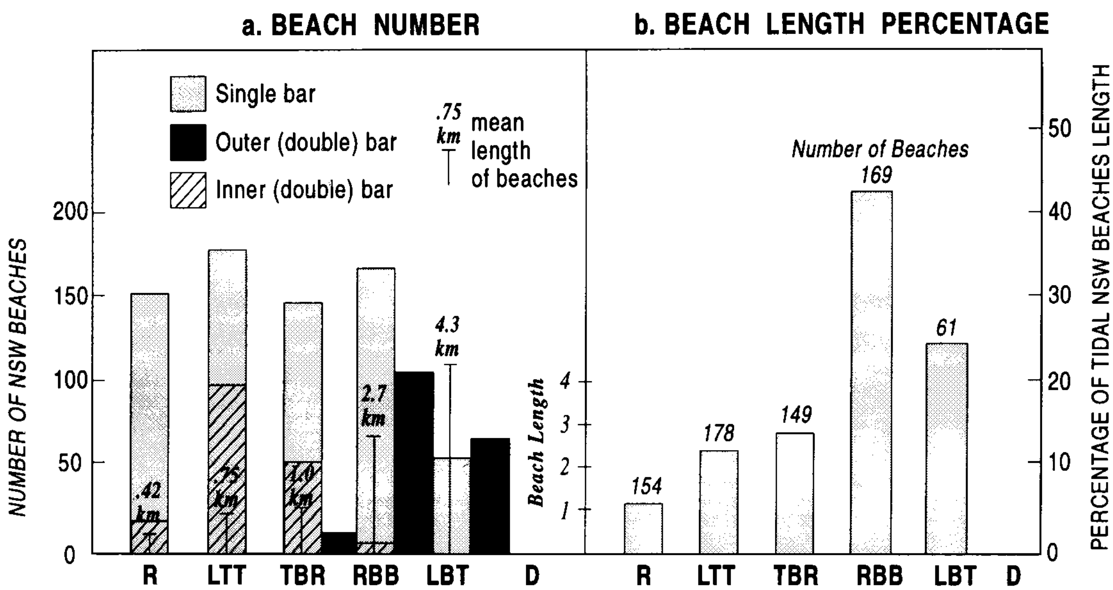


Fig. 10: Occurrence of single and double bar beach types/states on the micro-tidal New South Wales coast. (a) plots the number of each beach type, its average length, and whether it is part of a single or double bar system. (b) plots the total length of each beach type along the coast. (Based on Short 1993).

Ocurrencia de estadios/tipos de playas con sistemas de barras simples y dobles en la costa micromareal de New South Wales. (a) se representa el número de cada tipo de playa, su longitud promedio y si son parte de un sistema de barras simples o dobles. (b) se representa la longitud total de cada tipo de playa a lo largo de la costa (De Short 1993).

while the bar parameter B* will indicate the number of bars; and the δ' parameter the potential impact of headlands. The three parameters, using five variables (wave height and period, sand size, beach slope, embayment dimensions), can provide the key elements in a globally applicable sandy beach classification.

Beaches in micro-tidal environments may be reflective, intermediate or dissipative and have from none (reflective) to several bars, with one or two favoured by open coast swell environments, while multi-barred beaches are favoured by storm effected, short period, sea environments, with low nearshore gradients. Where multi-barred beaches exist they always have an hierarchy of bar types, with more dissipative outer bars and more intermediate to reflective inner bar/s. Embayed beaches have circulation dominated by strong rip currents (megarips) at the embayment ends, with normal circulation between. As Hb increases and/or embayment length decreases, the headland controlled circulation grows to dominate the entire embayment.

Increasing absolute or relative tide range will increase the role of tide induced shoreline excursion, which leads to the increasing dominance of wave shoaling, over the surf and swash zone processes. This initially results in a disassociation of the surf zone from the swash zone, then a plantation of the surf zone with no bars or rips, and finally, with high RTR, a shift from beach to tidal flat environments.

All beach systems can be therefore classified according to the above parameters. As parameters change in time and space so to do beaches. Consequently by understanding the role of each parameter in beach type, spatial and temporal changes in beach type, including erosion and accretion, can be predicted if the change in the formative parameter/s is known.

ACKNOWLEDGMENTS

This paper presents a synthesis for research funded by the Australian Research Council. My colleagues Gerd Masselink, Troels

Aagaard and Danny Martens assisted with many of the ideas presented here, while John Roberts drafted all figures.

LITERATURE CITED

AAGAARD T (1990) Infragravity waves and nearshore bars in protected, storm-dominated coastal environments. Marine Geology 94 181-203.

AAGAARD T & B GREENWOOD (1995) Suspended sediment transport and morphological response on a dissipative beach. Continental Shelf Research 15 1061-1086.

BOWMAN D & V GOLDSMITH (1983) Bar morphology of dissipative beaches: an empirical model. Marine Geology 51 15-33.

CARTER R WG (1988) Coastal Environments. London, Academic Press 617 pp.

DAVIS, R A, JR & MO HAYES (1984) What is a wave dominated coast? Marine Geology 60 313-329.

GREENWOOD B & RA DAVIS Jr. eds (1984) Hydrodynamics and sedimentation in wave dominated coastal environments. Marine Geology 60 473 pp.

GOURLAY, M. 1968. Beach and dune erosion tests. Delft Hydraulics Laboratory Report N° M935/M936.

MARTENS DM, DT WILLIAMS & PJ COWELL in press, Mega-rip dimensional analyses on the Sydney coast, Australia, and implications for beach-state recognition and prediction. Journal of Coastal Research.

MASSELINK G (1993) Simulating the effects of tides on beach morphodynamics. Journal of Coastal Research 15 180-197.

MASSELINK G & AD SHORT (1993) The effect of tide range on beach morphodynamics and morphology: A conceptual beach model Journal of Coastal research 9 785-800.

MCLACHLAN A & T ERASMUS eds, (1983) Sandy Beaches as Ecosystems. Dr. Junk Publishers, The Hague, 757 pp.

MCLACHLAN A, E JARAMILLO, TE DONN, & F WESSELS (1993) Sandy beach macrofaunal communities and their control by the physical environment: a geographical comparison. Journal of Coastal Research SI 15 27-38.

SHORT AD (1975) Multiple offshore bars and standing waves. Journal of Geophysical Research 80 3838-3840.

SHORT AD (1985) Rip type, spacing and persistence, Narrabeen Beach, Australia. Marine Geology 65 47-71.

SHORT AD (1983) A note on the controls of beach type and change, with examples from southeast Australia. Journal of Coastal Research 3 387-395.

SHORT AD (1991) Macro-meso tidal beach morphodynamics - an overview. Journal of Coastal Research 7 417-436.

SHORT AD (1992) Beach systems of the central Netherlands coast: Processes, morphology and structural impacts in a storm driven multi-bar system. Marine Geology 107 103-137.

SHORT AD (1993) Beaches of the New South Wales Coast. Australian Beach Safety and Management Program, Sydney, 358 pp.

SHORT AD (1996) Beaches of the Victorian Coast and Port Phillip Bay. Australian Beach Safety and Management Program, Sydney. 298 pp.

SHORT AD & Aagaard T 1993 Single and multi-bar beach change models. Journal of Coastal Research, Special Issue 15, 141-157.

SHORT AD, PJ COWELL M CADEE, W HALL & B VAN DIJCK (1995) Beach rotation and possible relation to the Southern Oscillation. Ocean and Atmosphere Pacific International Conference, Adelaide, abstract, 329-334.

SHORT, AD & PA HESP (1982) Wave, beach and dune interactions in south eastern Australia. Marine Geology 48 259-284.

SHORT, AD & CL HOGAN (1995) Rip currents and beach hazards, their impact on public safety and implications for coastal management. Journal of Coastal Research Special Issue 12 197-209.

SHORT, AD & LD WRIGHt (1984) Morphodynamics of high energy beaches and surf zones: An Australian perspective. In Thom, BG ed, Coastal geomorphology in Australia, Academic Press, Sydney. 43-68.

SUHAYDA JN, SA HSU, ROBERTS HH, AD SHORT (1977) Documentation and analysis of coastal processes, northeast coast of Brazil. Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana, Technical Report N° 238, 98 pp.

TURNER IL (1993) Watertable outcropping on macro-tidal beaches. Marine Geology 115 227-238.

WRIGHT LD (1980) Beach cut in relation to surf zone morphodynamics. Proceedings 17 th International Coastal Engineering Conference, American Society Civil Engineers, 978-996.

WRIGHT LD, RT GUZA & AD SHORT (1982) Morphodynamics of a high energy dissipative surf zone. Marine Geology 45 41-62.

WRIGHT LD, SK MAY, AD SHORT & MO GREEN (1984) Beach and surf zone equilibria and response time. Proc. 19th International. Conf. Coastal Engineering, Houston, 2150-2164.

WRIGHT LD & AD SHORT (1984) Morphodynamic variability of surf zones and beaches: a synthesis. Marine Geology 56 93-118.

WRIGHT LD, AD SHORT, JD BOON III, B HAYDEN, SK KIMBALL & JH LIST (1987) The morphodynamic effects of incident wave groupiness and tide range on an energetic beach. Marine Geology 74 1-20.

WRIGHT LD, AD SHORT & MO GREEN (1985) Short term changes in the morphodynamic states of beaches and surf zones: An empirical predictive model. Marine Geology 62 339-364.