Part A

Sandy beaches and macrofauna

Sunset at Sandy Point south. Near Yeppoon, central Queensland
[Photo: N. Hacking]

CHAPTER 1
Sandy Beaches

The description and understanding of ecological communities has occupied marine biologists for many years and research effort in this area has grown rapidly with the development of public and political awareness of the sea as an economic and recreational resource. Australia is one of the leading marine science and technology nations with a massive increase in knowledge and ability to manage our marine systems in recent times. Nevertheless, we are still a long way from possessing a comprehensive marine biological information base (Hammond, 1994).

Sandy beach fauna has long been utilised as a food source by indigenous and other peoples. This has been shown through time by numerous ancient shell middens, fire hearths and artefacts, right up to the present day use of beach dwelling animals as bait by fishermen. Sandy beaches as biological habitats, however, have always lagged behind other ocean realms in terms of scientific exploration; hence, our understanding of the structure and function of beach faunal assemblages is less than for other marine systems. This has been slightly remedied in the last fifteen years with attention to sandy beach faunal research rising overseas - particularly in South Africa and South America (see section 1.3). This has led, at least, to a conceptual framework for sandy beach ecology as a discipline.

However, despite this and the fact that Australia offers around 16,000 kilometres of soft sediment coastline, there has been little biological research to describe or test ideas on our own sandy shores. It seems sandy beaches and their inhabitants have been particularly neglected in Australia in favour of the animals of coral reefs, rocky shores and selected estuaries (Fairweather and Quinn, 1994). The present study aims to fill part of this gap by providing a broad-scale ecological and descriptive account of the fauna inhabiting a range of Eastern Australian beaches.

1.1 The sandy beach system

1.1.1 What is a sandy beach?

There are various definitions associated with the word "beach". To most people a beach is simply where "the land meets the sea" as represented by that part of the dry sand accessible for recreation or as a track to the ocean. In fact, the visible part of a beach seen above the water-line is part of a much larger system.

As a whole, sandy shores consist of dunes, beaches and surf-zones all closely connected by the interchange of sediment. Together these form a unit known as the *Littoral Active Zone*. This zone comprises two ecological systems: i) the terrestrial dune system inhabited by land-based biota and directly controlled by wind energy; and ii) the beach-surf-zone system characterised by marine organisms and controlled by wave energy (McGwynne and McLachlan, 1992). This study concentrates on the latter.

Beaches are essentially the outcome of waves interacting with a sandy bed at the shoreline. They are a wave deposited accumulation of sediment which is limited terrestrially by the highest reach of wave action, extending seaward of the surf-zone to the point at which waves can no longer transport alluvium (Short, 1993). That is, the beach is the area which can be actively reworked by wave action. This mobilised area of sediment is considered a *dynamic swept prism* by many researchers (Fig. 1.1). However, because these systems represent a continuum along a gradient of exposure and particle size, a fixed beach definition is not possible. So, although beaches are essentially simple systems in that only sand and waves are required for their development, they reflect a range of physical characteristics representing a contrast in entities to different researchers (McLachlan, 1983a).

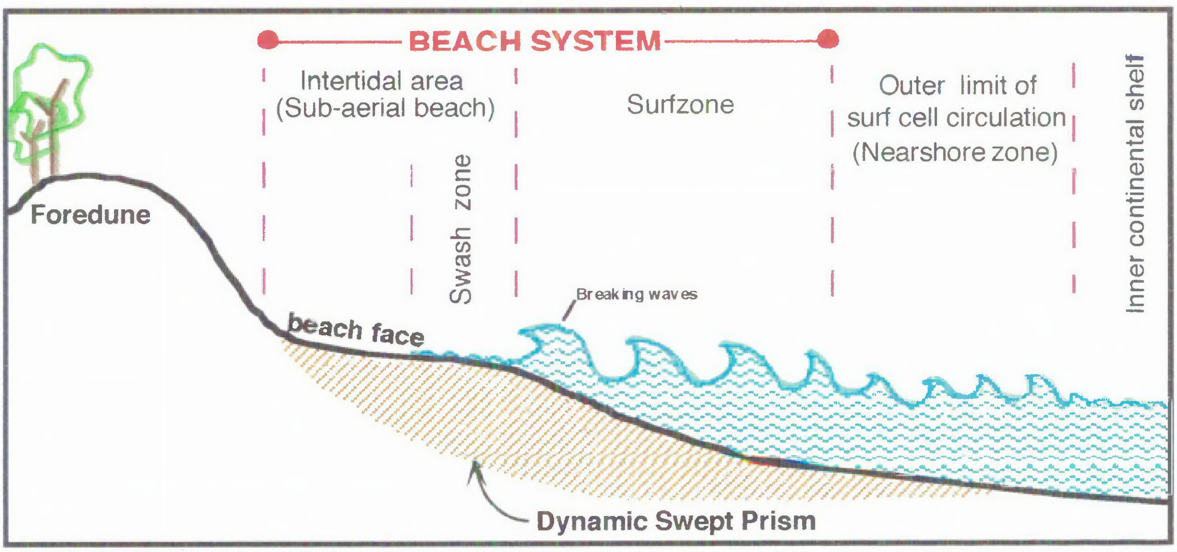

Figure 1.1: Generalized sandy beach profile showing major features.
[after Jones and Short (1995), Robertson (1994) and Brown and McLachlan (1990)]

The simplest way to describe the beach unit (or *dynamic swept prism*) is across the shore[1] in two dimensions (Short, 1993)(Fig. 1.1). The system basically consists of:

i) The sub-aerial beach - the section above sea level which is shaped by wave run-up or "swash". It begins at the high water mark and extends seaward to the low-tide water line. This is the area considered by most as "the beach".

ii) The surf-zone - the section extending seaward of the water-line into the area of breaking waves. Here the waves are continually expending energy and reshaping the seabed. The sub-aerial beach and surf-zone are together considered a "battleground" between sand and waves (Brown and McLachlan, 1990).

iii) The near-shore zone - the section extending seaward of the outer breakers, within the depth range at which waves are able to convey sediment (usually to around 20m). This is the base of wave activity.

Some evidence suggests that the sub-aerial beach and surf-zone function together as a semi-closed ecosystem. The boundaries of the system are at the dune/beach interface and the outer limit of surf circulation cells (ie. the most outward extension of rip-head activity[2]). In this area, rip currents[2] and ocean swells act to re-circulate water through the near-shore and surf-zone (McLachlan, 1980; McLachlan and Romer, 1990). However, although beach and surf-zone components are inextricably linked, the present study concentrates mainly on the sub-aerial or "inter-tidal" sandy beach[3].

This leads to another important definition: what constitutes "sandy"? Generally a sandy beach is any beach consisting of sediment with a median grain size in the range of 50μm to 2000μm (0.05mm to 2mm). Any other beach is outside the scope of this work.

1.1.2 Physical characteristics of sandy beaches

Before attempting to comprehend the living community of an environment it is first essential to understand the physical processes which distinguish the habitat in question. This is not simple in the case of beaches as they continually fluctuate in form. The

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[1] **Across-shore** and **down-shore** refer to a beach area running perpendicular to the horizon or waters edge (ie. from high to low tide). **Along-shore**, **longshore** and **shore-line** refer to beach sections running parallel to the horizon or waters edge.

[2] **Rip currents** are narrow, seaward, return flows of water. They comprise: i) **rip feeder currents** which flow towards shore inside the surf-zone; ii) the **rip neck** close to shore where feeder currents converge and flow seaward (their path through the breakers termed a **rip**); and iii) the **rip head** outside the surf-zone where rip currents slow and form vortices. (Short, 1993)

[3] Throughout this manuscript the term **beach** will refer to the intertidal/sub-aerial beach unless otherwise indicated. The term **beach system** will refer to the beach/surf zone/near shore unit as a whole.

primordial elements of a beach are, as mentioned, sand and water. The interaction between these components is termed *beach dynamics*.

a) Sand

Sand particles usually originate from erosion of the land. They are carried to the sea by rivers and streams and subsequently re-deposited on the beach by waves and tides. Beaches may also receive sand from marine biogenic sources in the form of animal skeletons and shell fragments. Thus beaches may consist of quartz or silica sands of terrestrial origin and/or carbonate sands of marine origin. Beach sands may also include heavy minerals, volcanic basalt and feldspars (Hedgpeth, 1957; Carter, 1988; Brown and McLachlan, 1990).

In beach dynamics, the most important feature of the sand is its grain size. Particles fall through water at a rate proportional to their size - large particles settling more rapidly than small. The force of flow of moving water determines the range of sediment sizes transported and deposited - strong flows more capable of carrying a wide range of particle sizes. Thus, the grain size composition of a beach is ordered by the prevailing energy regime of waves and currents acting on the geologically available material. Beach sediments often exhibit a definite microstructure resulting from repeated erosion and accretion during cycles of water movement. In turn, the nature and sorting of the sediment affects its porosity (total volume of pore space) and penetrability. Penetrability is of particular importance to sandy beach macro-organisms which must be able to burrow into the substratum in order to survive (see section 1.2).

b) Water

All particles on a natural beach are deposited (or eroded) by waves. Therefore the physical features of a beach reflect the interaction of wave height, length and direction with the available sediment (Short, 1993). Surface gravity waves, which are the result of wind acting on the ocean surface, along with the secondary currents they produce, comprise the driving force behind most physical processes acting on a sandy beach (Badenhorst, 1988; Brown and McLachlan, 1990).

Waves "feeling" the sea floor will decelerate and such an alteration in one section of a wave will cause it to change direction. This causes the refraction of waves and their subsequent alignment with the coastline as they approach the shore (Brown and McLachlan, 1990). Crests become pronounced as a wave approaches land and enters increasingly shallow waters, these eventually descending as a *breaker*[4] toward the shore-line.

[4] A **breaker** is a wave breaking on a shore or over a reef.

Wave energy is dissipated in the breaker zone; either gradually via *spilling breakers* [5] or more rapidly via *plunging breakers* [6]("dumpers"). After breaking in the surf-zone, these waves form a bore which advances towards the sub-aerial beach. Once the shore is reached the bore collapses to form the swash which runs up the beach face. Water accumulated against the beach in this way will be discharged out of the surf-zone by rip currents. However, much wave energy may be consumed in the surf-zone so that not every incident wave results in a swash reaching the beach face. A *surging breaker* [7] may also occur when a wave does not break in the surf-zone; instead descending directly onto the beach face.

The above types of water movement result in sheer stress on the sea bed, lifting sand into the water column where it may be transported. Sand movement may be on- or offshore, relative to conditions - swash/backwash processes defining the beach face gradient. The physical appearance of an intertidal sandy beach is thus the direct consequence of sediment distribution according to the the prevailing wave energy. In other words, waves are the major source of energy to build and change the sub-aerial beach in a way predetermined by the available sediment. Fine grain size is usually conducive to a flat beach slope (and vice versa).

Spatial variation in wave and sediment characteristics also controls other factors which may be of importance to sand-dwelling organisms. In particular, oxygen concentration within the sediment decreases with depth and porosity. Where sands are fine, the equilibrium between oxygen, sulphur and nitrogen may change below the surface to produce a dark grey reduced layer (Dye, 1981; Malan and McLachlan, 1991).

c) Exposure

The *exposure* of a beach refers to the hydrodynamic forces it experiences and the resulting volume of seawater percolating through the sand. McLachlan (1980a) developed a compound 20-point index which rates individual beaches accordingly. This index is based on wave action, sand particle size, beach slope and sediment oxidation, with consideration also given to the intertidal presence of permanent macrofaunal burrows. The exposure ratings are:

[5] A **spilling breaker** can be recognised by bubbles and turbulent water spilling down the front face of a wave. The upper 25% of the front face may become vertical before breaking. Breaking usually occurs over quite a distance (Badenhorst, 1988).

[6] A **plunging breaker** occurs when the crest curls over an air pocket. Breaking is usually with a crash. Smooth spash-up usually follows. (Badenhorst, 1988)

[7] A **surging breaker** occurs when the wave peakes up, but the bottom rushes forward from under the wave and the wave slides up the beach face with little bubble production. The water surface remains almost plane though ripples may be produced on the beach face during run-back (Badenhorst, 1988)

a) Very sheltered - virtually no wave action, shallow reduced layers and abundant, obvious macrofaunal burrows (score 1-5),

b) Sheltered - little wave action, reduced layers present and some obvious macrofaunal burrows (score 6-10),

c) Exposed - moderate to heavy wave action, reduced layers deep if present, no obvious macrofaunal burrows (score 11-15), and

d) Very exposed - heavy wave action, no reduced layers, macrofauna consisting of only of robust motile forms (score 15-20) (McLachlan, 1980a).

Exposure of a beach to the open ocean imposes a greater fluctuation in physical conditions than experienced by a sheltered shore. The most important effect herein is an augmentation of the effect of wave action on the intertidal area. Exposed beaches are thus subject to a high degree of water movement and therefore exhibit greater average grain size, gradient and instability than sheltered shores. Exposed beaches also tend to display a large proportion of well sorted sediments and a high degree of sediment oxidisation (McLachlan, 1980a). Macrofaunal communities respond to these parameters with species numbers generally diminishing with degree of shore exposure (McIntyre, 1971; McLachlan *et al.,* 1981)(see also section 1.3.3). This study examines exposed sandy beaches.

1.1.3 Sandy beach morphodynamics

The concept of a beach *morphodynamic state* refers to the hydrodynamic processes behind its depositional form (Short and Wright, 1984). Sandy beaches exist in a wide range of physical climates and there has been notable research in Australia in regard to the physical nature of these systems. Information on the dynamics of beach morphology has been used to produce a scheme for categorising the physical beach (Wright et al, 1979; Short and Wright, 1981, 1983, 1984; Short and Hesp, 1982; Wright and Short, 1984; Wright *et al.,* 1985). Classification of beach types in this way is important in providing an understanding of the processes acting on and controlling the physical nature of the world's various beach systems.

The dimensionless fall velocity[8] (Gourlay, 1968), Ω, incorporates both wave energy and sediment size measurements and can be used to index beaches according to their physical characteristics (Short and Wright, 1984). It is expressed by the formula:

$$\Omega = H_b / W_s . T \qquad (1)$$

8 - sometimes mis-known as "Dean's parameter".

(where H_b is breaker height (cm), W_s is the sediment fall velocity[9](cm s^{-1})(Gibbs et al, 1971) and T is the average time between waves in seconds (s).

There have been six commonly occurring beach states identified and classified according to Ω. They are categorised in terms of:

i) the environmental conditions required for their development;
ii) their morphology, dynamics and mode of sediment exchange; and
iii) spatial and temporal variability.

The beach states include two extreme and opposite forms (Dissipative and Reflective) and four intermediate states representing a continuum in between (Long-shore Bar and Trough, Rhythmic Bar and Beach, Transverse Bar and Rip, Low Tide Terrace). These are described as follows:

a) Dissipative beaches

Dissipative beaches form under environmental conditions of high waves (>2.5m) and fine sand. They are characterised by low beach and surf-zone gradients, high surf scaling parameters and high values of the dimensionless fall velocity (Ω>7) (Fig. 1.2a). Dissipative beaches are found in regions of high breakers and abundant fine sediments (eg. storm wave and west coast environments of South Africa and Australia). They may also occur seasonally or periodically in areas where high waves persist for long periods.

Morphologically, a dissipative beach exhibits a wide, flat beach face which extends from the foot of the dunes to the surf-zone. Sand bars[10] and breakers are constantly present in the surf-zone causing wave energy to be diffused and retained here. In other words, energy is dissipated in the surf-zone by the many breaking waves. Because of this, dissipative *systems* are considered "high energy"[11] - although forces of rip circulation, long-shore currents and intertidal swash action are usually mild.

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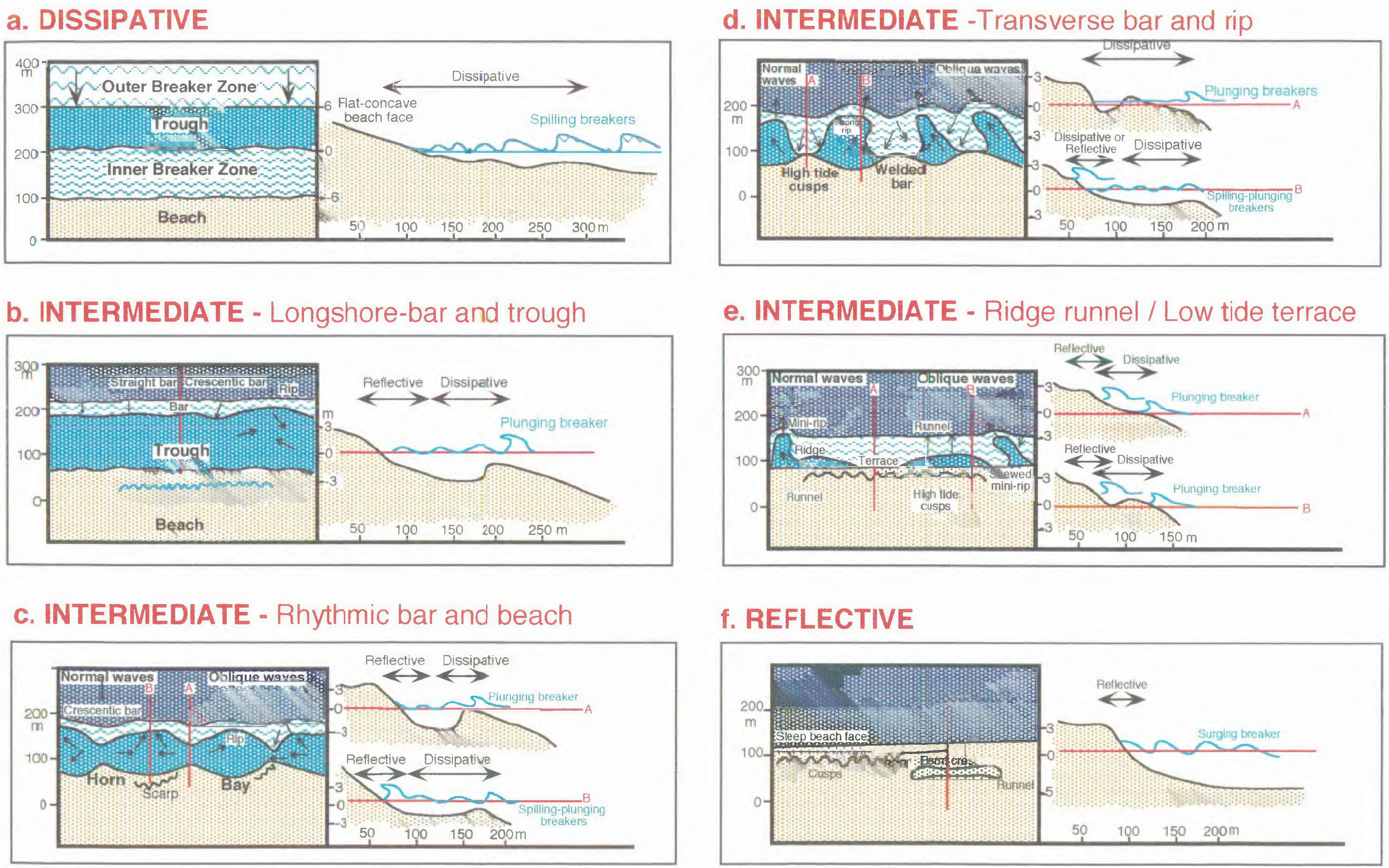
[9] Sediment fall velocity is based on Stoke's Law which defines sediment size by the rate of sinking particles in water.

[10] **Sand bars** are sections of shallow sand in the surf-zone on which a wave may break.

[11] Some authors describe "high" and "low" energy beaches as refering to the force of intertidal water movement; that is, dissipative beaches as "low energy" and reflective beaches as "high energy (eg. Hadley and Licari, 1980; Defoe, 1996). As with most of the literature and unless otherwise stated, this thesis defines beach " energy" related to the entire beach system (ie. dissipative beaches are "high energy", reflective beaches are "low energy").

Figure 1.2: Morphodynamic beach types (aerial view and profile)
[After Short and Wright, 1983]



A dissipative beach is at the erosional end of the spectrum of beach types, remaining relatively stable as long as waves are high. The most potentially active sand is stored inand seaward of the surf-zone and, due to its fine nature, will only move shoreward if waves fall below modal height (thus allowing the fine sediment to settle on the beach). Dissipative beaches are also spatially stable owing to the uniformity of physical processes along the shore.

b) Reflective beaches

Reflective beaches form under conditions of low waves in areas of coarse sediment (Ω<1). They occur in areas of modally small waves; on open coasts in deeply embayed or protected environments. Here wave shoaling[12] and refraction significantly lower deep water wave energy so that sand bars and breakers do not form a prominent surf-zone. Reflective beaches may also form on more exposed coasts during prolonged periods of low waves.

Morphologically, reflective beaches are the accretionary extreme of beach types. Most of the potentially active sand is stored in the intertidal area. The beach is usually fronted by a steep face which may grade into a coarse low tide step. Because there are no surf-zone or sand bar features, incident waves are usually in the form of surging breakers. These cross the near-shore zone, surge over the step and break directly onto the steep intertidal area (Fig. 1.2b). The waves are thus reflected seawards. Reflective beaches are termed "low energy" due to the lack of breakers in the surf-zone area. Nevertheless, surging breakers on the beach face may be extremely powerful (carrying and depositing a wide range of sediment sizes).

Reflective beaches are unstable as any increase in water flow energy will lead to erosion. However, this happens infrequently in reflective beach areas and a return to modal wave conditions will again lead to rapid beach face accretion. Like the dissipative extreme, a reflective beach is physically uniform along the shore.

c) Intermediate beaches

The four intermediate beach types represent a transition from dissipative to reflective conditions. They have a medium sediment grain size and moderate to high waves (1-2.5m). Ω values range from 1-6.

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[12] **Wave shoaling** is the process by which waves moving into shallow water interact with the sea bed/beach sediments

On intermediate beaches, sand usually resides in the surf-zone in the form of bars and wave energy is rarely consistent. This means that these beaches may move from one intermediate state to another in response to changes in conditions. So, although it is convenient to separate beaches into categories, in fact beach states reflect a continuum from reflective to dissipative. Intermediate beaches occur on coasts exposed to high deep-water waves where some energy is lost due to refraction. Where multiple bars occur, the inner beach system functions as intermediate while the outer area remains more dissipative. The range of intermediate beach state morphologies are characterised by pronounced long-shore variability caused by alternating rip and bar formations.

The four intermediate states, from most dissipative to most reflective, are:

i) Long-shore bar and trough

This morphodynamic state has a reflective beach face, a wide, deep, shore-parallel trough and a prominent shore parallel bar. Waves plunge on the bar, reform in the trough and surge up the beach face. Weak rip circulation leads to onshore migrating lobes of sand called *crescentic bars* (Fig. 1.2c).

ii) Rhythmic bar and beach

On this beach type, a decrease in surf-zone wave intensity causes the crescentic bars to migrate. During this process the bars become segmented by rip channels. Erosion and scarping occur in the rip channel areas and accretion occurs at the concentric bars. This produces rhythmic intertidal beach features in the form of horns and embayments (Fig. 1.2d).

Surf-zone dynamics of rhythmic bar and beach systems are dominated by the above rip circulations. Waves break heavily on the crescentic bars with water flowing off the bars into rip channels where it is returned seaward. On the beach face, waves alternate from surging over the bars to plunging in areas of rip channels where less energy dissipation has occurred.

iii) Transverse bar and rip

This type of beach is produced by continued onshore migration of the crescentic bars due to a further decrease in breaking wave intensity. The beach is characterised by strong rip circulation amongst the alternate bar and rip channels (Fig. 1.2e) and is dangerous for swimmers. As the bars accrete they become relatively shallow with deep rips transversing across them. Skewing of the bars may occur due to slanting waves and thus the intertidal protrusions of the former rhythmic bar and beach appear more subdued as the adjacent embayments begin to fill with sand.