To Library

Department of CONSERVATION and ENVIRONMENT

Director,
National Parks Authority
of W.A.
Hackett Drive,
NEDLANDS 6009

your ref:
our ref:
enquiries:

Dear Sir,

COASTAL MANAGEMENT PAMPHLETS

Please find enclosed the first 12 pamphlets on Coastal Management in a continuing series to be produced by the Department of Conservation and Environment.

These pamphlets deal with natural coastal processes which are fundamental to our use of the coast. It is vital that anyone using the coast be aware of how it behaves in order to avoid costly mistakes and to maintain the environment that attracts us in the first place.

Later, pamphlets will deal with management and planning of the coast including topics such as dune stabilization, beach management, control of off-road vehicles, preparation of coastal management plans and coastal engineering. All of the pamphlets are intended as introductory in the sense that references and names for follow-up will be provided.

We hope you will use the pamphlet series as a working document, available to all in your organisation who work on or are interested in the coast. Please let us have any comments on the enclosed pamphlets and suggestions for future topics.

Yours sincerely

Colin Porter

COLIN PORTER
DIRECTOR

19 April 1981

Director
B.

1 Mount Street, Perth, W.A. 6000 tel. 322 2477

COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION & ENVIRONMENT

BULLETIN NO 49

NO 1

INTRODUCTION TO COASTAL MANAGEMENT IN WESTERN AUSTRALIA

This paper is an introduction to a series of pamphlets on the subject of Coastal Management in Western Australia.

Our coast, as many of us may like to think of it, is a place for swimming, fishing and going for a holiday or somewhere nice to live, but it is also a place where sewage is discharged and where large factories, power stations and ports are located. Examples like these illustrate the types of conflicting user-demands which take place along the coast. Coastal Management attempts to resolve these conflicts through co-ordinated planning and management.

The first step toward effective Management is to rationalise the system that already exists. To this end the Environmental Protection Authority (EPA) has agreed to appoint a Coastal Planner and Management Adviser who in association with a Steering Committee, will report and recommend on the best means of achieving effective Coastal Management in Western Australia.

The EPA recognises that as a start it is important to have a set of POLICIES so that everyone concerned can work within the same guidelines. In 1977 the Authority released draft Policy Guidelines for public discussion, the GOAL of the draft being (in part) that:

in the Coastal Zone, optimum use should be made of coastal resources whilst minimising any degradation of the coastal environment.

Lighthouse at Cape Leeuwin

Yacht in Cockburn Sound

Coast at William Bay

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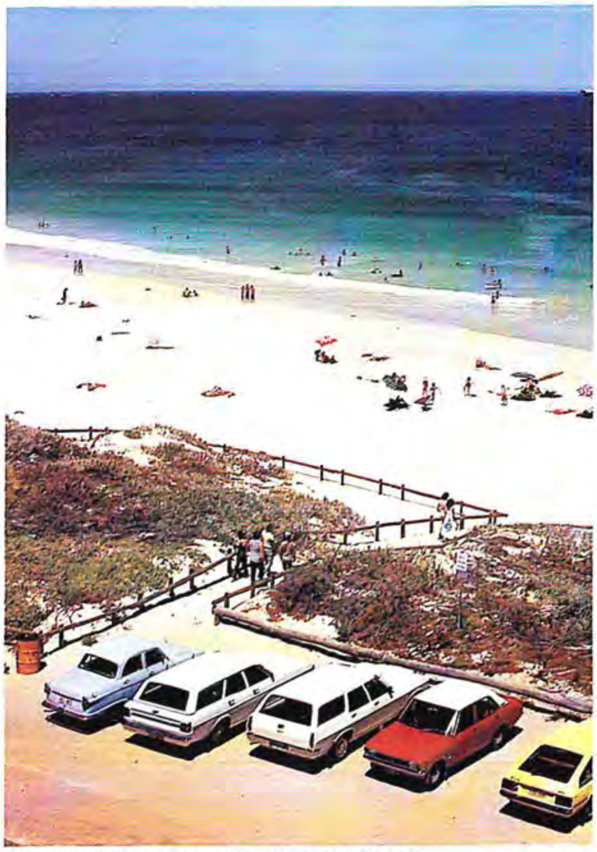
The draft policies are:

1) Appropriately regulated recreational, tourist and residential activities are proper uses for designated areas within the Coastal Zone.
2) Public access to the waterfront for recreation and tourism should be freely available consistent with the need to protect the coastal environment.
3) Uses of the Coastal Zone other than the above should not be permitted unless directly dependent on resources within the Coastal Zone.
4) Any proposed use should not detract from, but as far as reasonably possible, should enhance or protect coastal environmental quality, including natural scenic amenities.
5) If the proposed use would adversely affect the coastal environment to a serious extent it must be determined to be of overriding public benefit.
6) Uses of the coast should allow adequate protection for areas which are of particular scientific, educational or aesthetic importance.

The key to effective Coastal Management depends on the way in which policies are implemented. The EPA has emphasised that both State and Local Government authorities must play an important role in implementation and that success will depend on future attitudes and actions of both levels of government.

A poorly sited residence - Ledge Point

Recreation at Cottesloe Beach



Car park and access path - Leighton Beach

Commercial fishing boat

The State Government can assist implementation:

a) through provision of funds, to acquire and manage coastal reserves and where necessary to initiate coastal studies;
b) by ensuring that coastal lands and waters under State control are managed properly and that development carried out under existing statutes is consistent with the best coastal management practices; and
c) by gathering and providing information and advising agencies concerned with Coastal Planning and Management.

Local Authorities will play a major role in the implementation of policies through the adoption of flexible Town Planning Schemes and more detailed Management Plans so that effective management of their own coastal zone is possible.

The success of implementation however will depend directly on how well coastal processes are understood by agencies or people with responsibilities in the coastal zone and how well planners, developers and managers take these processes into account.

There is a lot of information on Coastal Management available from individuals and groups in Western Australia and from other parts of the world. The Department of Conservation and Environment has already been involved in the collection and dissemination of material through seminars, films, written advice and practical demonstration. It is now intended that this material will be compiled into a series of semi-technical pamphlets.

The pamphlets will conform to a standard format and a cover folder will be issued. It is the Department's aim to produce a series of pamphlets that will contain in time a comprehensive collection of information, rather than a Newsletter which consists of isolated or repeated topics. The first pamphlets which deal with natural coastal processes are intended to give background information to later articles which deal with:

a) the influence of Man on these processes; and
b) the management and planning procedures which as a result of Man on the Coast become necessary.

The series will be added to, or pamphlets replaced as more up-to-date articles are produced. Each pamphlet will contain references for further reading and sources where more information may be sought.

The series is aimed at Local Government Officers and Councillors, developers, planning consultants or anyone with an interest in the coastal zone.

In this way it is intended that coastal planners and managers will become more aware of coastal processes and Man's affect upon them which in turn should lead to optimum use of coastal resources.

Industry on the coast

Fremantle Harbour - of benefit to the State

National Park - Kalbarri Cliffs

Holidays on the South West coast

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The Department of Conservation and Environment will prepare the pamphlets as part of its general co-ordinating role in environmental matters. Many other Government Agencies are concerned with Coastal Planning and Management and can provide specific advice and assistance. The following is a list of the more directly involved.

Public Works - coastal engineering and shoreline protection.

Agriculture (Soil Conservation Service) - dune stabilisation and erosion control.

Conservation and Environment - coastal planning and management.

Town Planning - planning and development of coastal land.

Lands and Surveys - planning and management of coastal Crown land.

Fisheries and Wildlife - management and protection of coastal flora and fauna.

National Parks - management of Coastal National Parks.

Youth, Sport and Recreation - organising community use of the coast.

Harbour and Lights - control of navigable waters.

Industrial Development - utilisation of coastal land for industry.

Mines - utilisation and rehabilitation of coastal mineral resources.

CSIRO - land resource management and related research.

Port Authorities - control of West Australian harbours.

Local Authorities - control of vested coastal lands.

Instructions to readers:

- further pamphlets will be issued from time to time. Each will be distinguished by a characteristic number eg. Bulletin 49 No.1 or Bulletin 49 No.7.
- when requesting a pamphlet from the Department please specify the Bulletin and pamphlet numbers.
- A cover folder to contain the pamphlets will be issued to local authority offices, libraries and schools etc.
- Pamphlets are available free of charge to organisations, and individuals concerned with the coast.
- For further information contact the Department of Conservation and Environment, 1 Mount Street, Perth, or phone 322 2477.

REFERENCE

Environmental Protection Authority, 1977, Guidelines for an Environmental Protection Policy on the Coastal Zone in Western Australia, Working Draft, Department Conservation and Environment, West Australia, Bulletin No. 26.

TERMS COMMONLY USED IN COASTAL MANAGEMENT

ACCRETION — The buildup of land by deposition of waterborne or airborne material on a beach. Opposite EROSION.

ADVANCE — The seaward movement of a shoreline. Also progradation.

AEOLIAN SANDS — See EOLIAN SANDS.

BACKSHORE — That zone of the beach lying between the foreshore and the coastline and acted upon by waves only during severe storms. It comprises the berm or berms (Fig. 5). Also backbeach.

BACKWASH — The seaward return of water following the uprush of waves (Fig. 5).

BAR — A submerged or emerged bank of sand, or other unconsolidated material built on the sea floor in shallow water by waves and currents (Fig. 5).

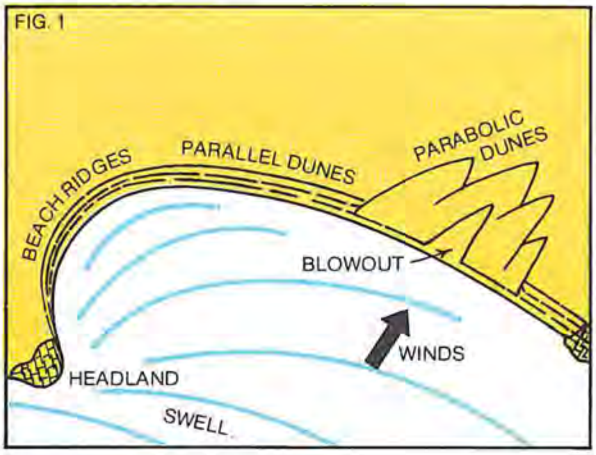
BARRIER BEACH — A bar parallel to the shore, the crest of which is above normal high water level. Also barrier island.

BATHYMETRY — The measurement of depths of water in oceans, seas and lakes. See ISOBATH.

BEACH — The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves). The seaward limit of a beach, unless otherwise specified, is the mean low water line. A beach includes foreshore and backshore (Fig. 5).

BEACH RIDGE — A low sand ridge parallel to the shoreline and formed by the action of waves. It is usually lower and more regular than a sand dune (Fig. 1).

FIG. 1



BERM — A nearly horizontal part of the beach or backshore formed by the deposition of material as a result of wave action. Some beaches have no berms, others have one or several (Fig. 5).

BLOWOUT — A wind scoured hollow, usually aligned parallel to the dominant wind direction, formed when sand is blown inland through a weak point in a dune. Blowouts often occur where vegetation has not become established, or has been destroyed, or where sand supply overwhelms the existing vegetaion. Also DUNE, Parabolic Dune (Fig. 1).

BREAKER — A wave breaking on a shore or over a reef.

COAST — A strip of land of indefinite width (may be several kilometres) that extends from the coastline inland to the first major change in terrain features (Fig. 5).

COASTAL PLAIN — The plain composed of horizontal or gently sloping sediments fronting the coast, and generally representing a strip of sea bottom or coastal dunes that has emerged in the last 1,000,000 years or so.

COASTAL ZONE — The waters and land extending offshore to the 30 m depth contour, and inland for one kilometre from the high water mark, and including the beds and banks of water bodies subject to tidal action (Fig. 5).

COASTLINE — Technically, the line that forms the boundary between the coast and the shore (Fig 5.)

CURRENT — A flow of water. A Coastal Current flows parallel to the shoreline in deeper waters beyond the surf zone. It is not related to waves but may be related to tides and winds. A Longshore Current flows parallel to the shoreline and is generated in the surf zone by waves breaking at an angle to the shore. A Tidal Current is the horizontal movement of water associated with the rise and fall of the tide. See LITTORAL DRIFT and RIP CURRENT.

CUPSATE BAY — A curved bay with its shoreline parallel to the incoming swell (Fig. 1). Also crenulate bay.

DEEP WATER — Water of such a depth that surface waves are not affected by the bottom. Usually water depth is greater than one half the surface wave length (Fig. 7).

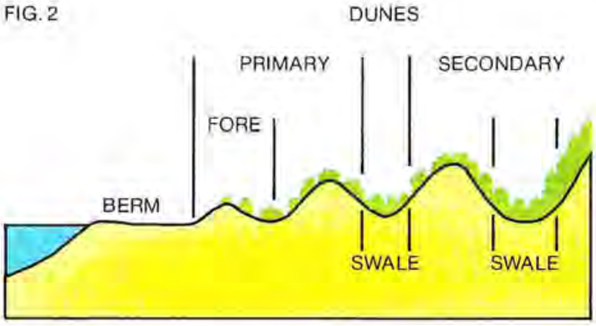
DEFLATION — The removal of loose material from a beach or other land surface by wind action. Also wind erosion. See EOLIAN SANDS.

DIFFRACTION (of water waves) — The phenomenon by which energy is transmitted laterally along a wave crest. When part of a train of waves is interrupted by a barrier, such as a breakwater, the effect of diffraction allows waves into the sheltered area behind the barrier.

DIVERGENCE — The increasing distance between orthogonals in the direction of wave travel during refraction. Denotes an area of decreasing wave height and energy dispersion. See WAVE REFRACTION (Fig. 4).

DUNE — A term applied loosely to ridges or mounds of sand deposited by wind or water action. Where dunes are parallel to each other they are termed Parallel Dunes. Where dunes are U shaped they are termed Parabolic Dunes. Parabolic dunes moving across coastal lands are termed Transgressive Dunes. See SAND DUNE, MOBILE DUNE, BEACH RIDGE and BLOWOUT (Figs. 1 and 2).

FIG. 2

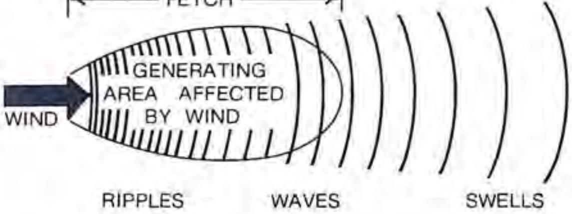


EOLIAN SANDS — Sediments of sand size or smaller which have been transported by winds. Also wind blown sands. See DEFLATION.

EROSION — The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.

FETCH — The area in which seas or wind waves are generated by a wind having a constant direction and speed (Fig. 3). Also generating area.

FIG. 3



FOREDUNE — The dune immediately behind the backbeach. It is usually colonised by sand-trapping plants and marks the seaward limit of vegetation (Fig. 2).

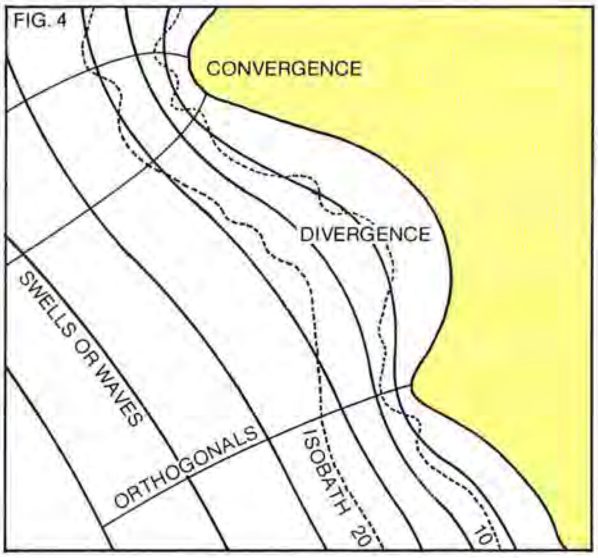
FORESHORE — The part of the shore lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the low water mark. It is traversed by the uprush or backwash of waves as the tides rise and fall (Fig. 5). Also beach face.

HOLOCENE PERIOD — Period of geological time between the last glaciation or ice age around 20,000 years ago and the time when world sea level reached its present level around 6,000 years ago.

INSHORE (ZONE) — The zone of variable width extending from the low water line through the breaker zone (Fig. 5).

ISOBATH — A contour line connecting points of equal water depths on a chart (Fig. 4).

FIG. 4



LAND BREEZE — A light wind blowing from the land to the sea caused by unequal cooling of land and water masses (c.f. SEABREEZE).

LITTORAL DRIFT — The sedimentary material moved in the littoral zone under the influence of waves and currents.

LITTORAL TRANSPORT — The movement of littoral drift in the littoral zone by waves and currents. Includes movement parallel (longshore transport) and at right angles (onshore-offshore transport) to the shore.

LITTORAL ZONE — An indefinite zone extending seaward from the shoreline to just beyond the breaker zone. The area influenced by waves and tides (Fig. 5).

MOBILE DUNE — A dune where the constituent sand grains are still subject to movement under the influence of wind. Mobile dunes often occur where vegetation is lacking or where it cannot cope with the supply of sand. See STABLE DUNE, BLOWOUT, SAND SHEET.

OFFSHORE ZONE — The zone extending from the breaker zone to the seaward edge of the continental shelf, or a direction seaward from the shore (Fig. 5).

ONSHORE — A direction landward from the sea.

ORTHOGONAL — A line drawn at right angles to the wave crests on a wave refraction diagram. See WAVE REFRACTION (Fig. 4).

PERCOLATION — The process by which water flows through the pores in a sandy sediment.

PLUNGE POINT — The point at which a wave curls over and breaks (Fig. 5).

PRIMARY DUNE — The main dune body behind the backbeach. It usually comprises the foredune and the first major sand dune or beach ridge (Fig. 2). Also Frontal Dune.

QUATERNARY PERIOD — The period of geological time extending from the present back to 1,000,000 years ago.

RECENT PERIOD The period of geological time extending from the present back till the time when the rising world sea level reached its present level approximately 6,000 years ago.

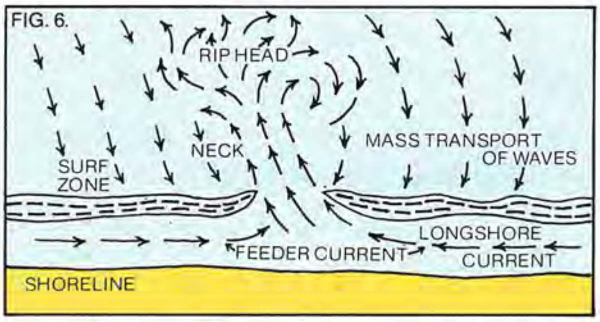
RECESSION (of a beach) — A landward movement of the shoreline. Also retreat, regression. Opposite ADVANCE.

REFRACTION DIAGRAM A drawing showing positions of wave crests and/or orthogonals. See WAVE REFRACTION (Fig. 4).

RIP — A body of water made rough by waves meeting an opposite current.

RIP CURRENT — A strong surface current flowing seaward from the shore which usually returns water piled up on the shore by incoming waves and wind. A rip current consists of three parts: the Feeder Current flowing parallel to the shore inside the breakers; the Neck, where the feeder currents converge and flow through the breakers in a narrow band or "rip"; and the Head, where the current widens and slackens outside the breaker line (Fig. 6).

FIG. 6.

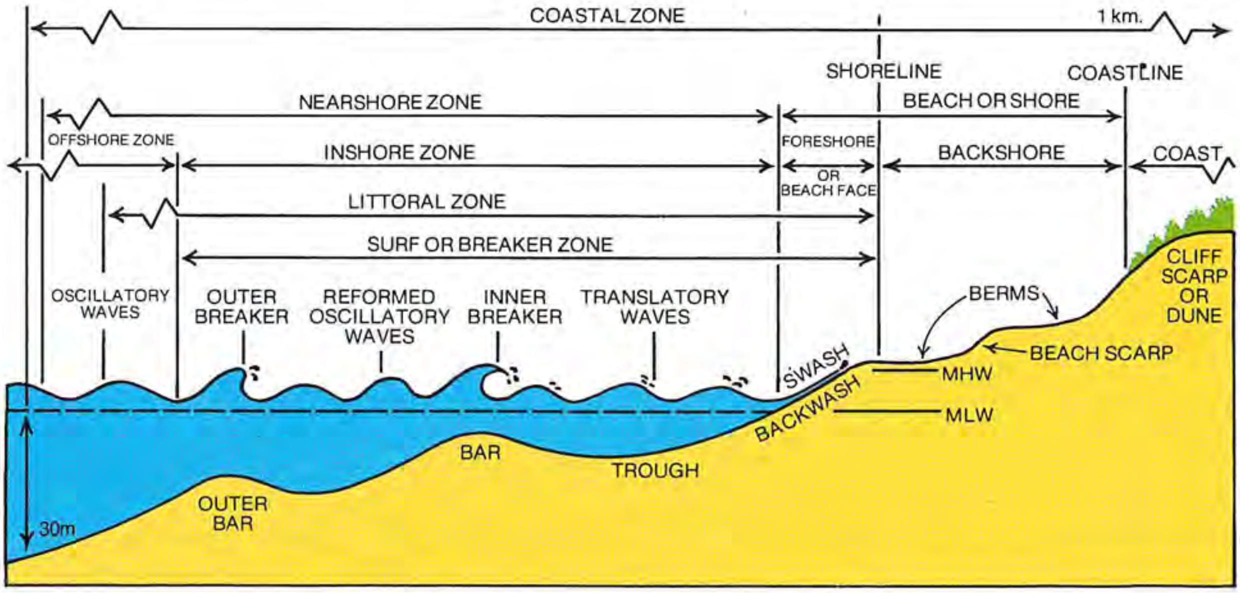


SAND DUNE — A ridge or mound of wind blown sand, usually higher and steeper than a beach ridge. See DUNE, PRIMARY DUNE (Fig. 2).

SAND SHEET — A thin sheet of unconsolidated sand moving across a landscape under the influence of wind. See MOBILE DUNE.

SEA LEVEL (or Mean Sea Level) — The average height for the surface of the sea for all stages of the tide over a 19 year period. Similarly for Mean High Water (MHW) and Mean Low Water (MLW). Mean High Water Springs (MHWS) is the average height of high waters occurring at spring tide. Abbreviation: High Water Springs (HWS). See SHORELINE.

FIG. 5



SEABREEZE — A light wind blowing from the sea toward the land caused by unequal heating of land and water masses.

SEAS — See WAVES, WIND.

SECONDARY DUNE — The dune landward of the primary dune (Fig. 2).

SHALLOW WATER — Water of such a depth that surface waves are noticeably affected by bottom topography. It is customary to consider water of depths less than one half the surface wavelength as shallow water. See DEEP WATER (Fig. 7).

SHORE — The narrow strip of land between the coastline and low water mark. A shore of unconsolidated material is usually called a beach (Fig. 5).

SHORELINE — The line that forms the boundary between land and water, usually taken as Mean High Water (Fig. 5).

STABLE DUNE — A dune that is no longer subject to further movement by wind action. Stabilisation occurs through vegetation cover or through cementation of the sand grains. See MOBILE DUNE.

STORM SURGE — A rise above normal water level on the open coast due to the action of wind stress on the water surface. Storm surge resulting from a storm or cyclone also includes the rise in level due to low atmospheric pressure as well as that due to wind stress.

SURF ZONE — The area between the outermost breaker and the limit of wave uprush (Fig. 5).

SWALE — A valley or interdunal depression (Fig. 2).

SWASH — The rush of water up the beach face following the breaking of a wave. Also uprush, runup (Fig. 5).

SWELL — Waves generated by distant storms that have travelled out of their fetch or generating area. Swells characteristically exhibit more regular and longer periods with flatter crests than wind waves. (Fig. 3) See WAVES, WIND.

TIDAL WAVES — (1) The wave motion of the tides. (2) In popular usage, any unusually high and destructive water level along a shore. It usually refers to storm surge or a tsunami.

TIDE — The periodic rising and falling of water that results from gravitational attraction of the moon and sun acting upon the rotating earth. A Diurnal Tide has one high water and one low water in a day. A Semi-Diurnal Tide as two high waters and two low waters in a day. Tides rise or flood and fall or ebb. A Spring Tide has the largest range and occurs near full or new moon. Neap Tides have the smallest range.

TOMBOLO — A bar or sand spit that connects or "ties" an island to the mainland or to another island.

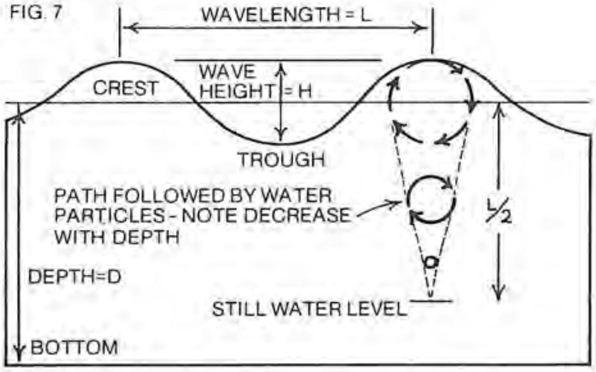
TROPICAL CYCLONE — An intense tropical depression in which winds spiral clockwise inward toward a core of low pressure, with maximum surface wind velocities that equal or exceed 65 knots.

TSUNAMI — A long period wave caused by an underwater disturbance such as a volcanic eruption or earthquake. Commonly miscalled tidal wave.

UNDERTOW — A seaward current near the bottom caused by return, under the action of gravity, of the water carried up on the shore by waves. Often misnomer for rip current.

WAVE — A ridge, deformation or undulation on the surface of a liquid (Fig. 7). The Wave Height is the vertical distance between a crest and the preceding trough. The Wavelength is the horizontal distance between similar points on two successive waves measured perpendicular to the crest. Wave Period is the time for a wave crest to traverse a distance equal to one wavelength or the time for two successive wave crests to pass a fixed point. See WAVES, WIND (Fig. 7).

FIG. 7



WAVE GENERATION — See FETCH.

WAVE REFLECTION — The part of a wave that is returned seaward when the wave strikes a steep beach, or other reflecting surface.

WAVE REFRACTION — The process by which the direction of a wave moving in shallow water at an angle to the contours is changed. The part of the wave advancing in shallower water moves more slowly than that part advancing in deeper water, causing the wave crest to bend toward alignment with the underwater contours (Fig. 4).

WAVES, WIND — Waves generated by wind. Wind waves or seas characteristically are steep, less regular and have shorter periods than swells. Loosely, any wave generated by wind (Fig. 3).

COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION & ENVIRONMENT

BULLETIN NO 49

NO 3

INTRODUCTION TO COASTAL PROCESSES

INTRODUCTION

Two main areas are of concern to people who plan or manage the coast. First there are the physical or natural processes which have been occurring through time and which have formed the features of the coast we see today, e.g. dunes, cliffs, sandy beaches, estuaries, vegetation, bays and spits.

Second there are consequences arising from Man's use of the coast. People have been on earth for a short time, geologically speaking, but they have already had a marked effect on parts of the coast through their desire to live near the sea and their ability to influence some of the natural processes.

Land, sea and air interact in the coastal zone. In nature the three elements are dynamically linked. On one side are the forces of air and sea, on the other is land which absorbs the energy of these forces and is continually being modified as it accommodates them. Modifications are often small with the land retaining much of its original shape and position. (Fig. 1a). At other

FIG. 1a

(a) 'balance' between sea, wind and land.

FIG. 1b

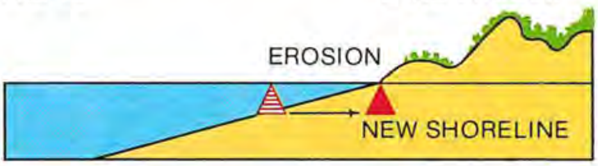
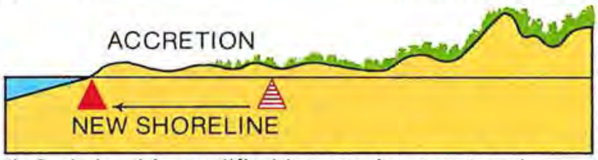


FIG. 1c



(b & c) land is modified by a major event and a new shoreline is established as the 'balance' is regained.

times, extreme forces resulting from climatic or geological changes can cause major variations in the landform. In these cases the coastline usually does not return to its original state (Figs. 1b, c).

People too, can seriously influence the stability of the coast through design or mistake, to their benefit or misfortune. An understanding of the factors affecting the coast should enable people to minimise their mistakes and to plan for their benefit. This pamphlet gives a general description of the factors and shows how they combine and influence one another in the coastal zone.

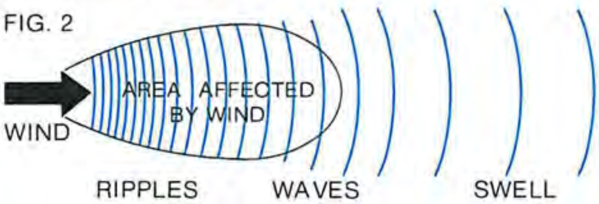
NATURAL PROCESSES

1. **Interaction of Sea and Air**

   Western Australia fronts the Southern and Indian Oceans where the major weather patterns produce westerly winds in the "Roaring Forties", southeast tradewinds further north and northwest monsoons along the North West Coast. Occasional cyclones and northwest gales disrupt the prevailing system. Localised seabreezes prevail at other times.

   Wind blowing over water generates local wind waves (waves). Waves which travel out of the generating area are called swell waves (swells) (Fig. 2).

FIG. 2



As swell and wave patterns parallel the winds, our coast is subject to a prevailing westerly swell and waves from a variety of directions (Fig. 3).

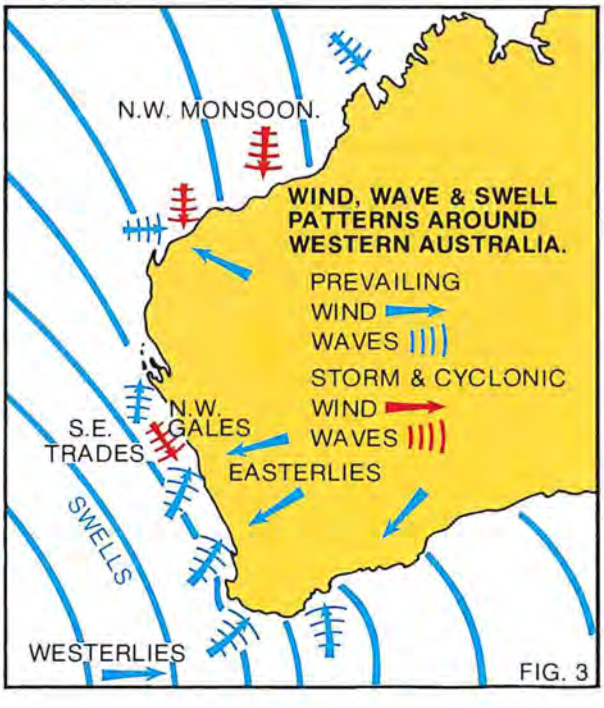


FIG. 3

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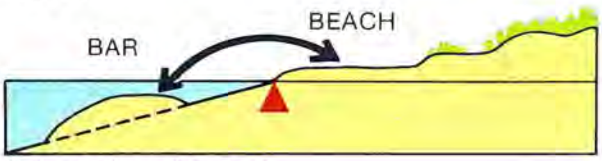
2. **Interaction of Air and Land**

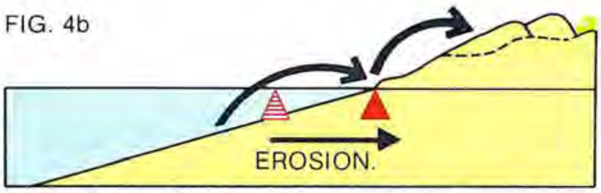
The direct effect of wind is important in sandy areas of the coast. Onshore winds transport sand from the water's edge. If the landward part of the beach is well vegetated, sand blown inland is trapped by vegetation and a foredune is formed. This dune is occasionally eroded by storms and the sand is recirculated to the active beach zone. The position of the shore is relatively stable. (Fig. 4a). If the landward part of the beach is not well vegetated, then sand may be blown inland to form blow outs or sand sheets. These bare sands may continue to migrate landwards and overwhelm the vegetated hind dunes. This results in a vast loss of sand from the active beach system and erosion will follow as the beach compensates for the loss and consequently the position of the shoreline will alter. (Fig. 4b).

FIG. 4a



'balanced' sand budget

FIG. 4b



'unbalanced' budget and shoreline moves as land compensates for loss of sand.

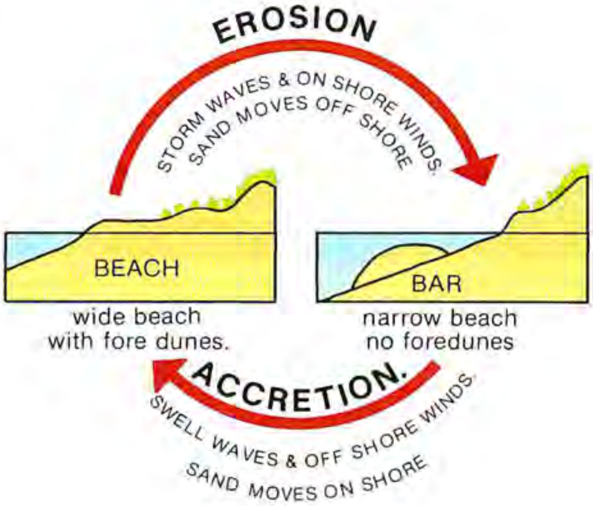
3. **Interaction of Sea and Land**

The shape of any coast is largely determined by the geology of the shore (rocky or sandy) and the action of the prevailing swells and currents. The shape however is not fixed. Whenever wave or current patterns change (i.e. during a storm) the land adjusts to a new set of conditions. With return to prevailing conditions the land re-adjusts and the shore regains its usual shape, although often with some minor differences.

Under the influence of the sea, rocky coasts are continually being eroded and the seabed swept by swells and currents providing a source of sediments to the shore. These sediments, together with those transported from inland by rivers or generated on the continental shelf are subject to wave and current action which erode and transport sediments to areas where deposition can occur. Deposition may occur onshore in which case a beach is formed, or offshore in submarine bars or sand sheets. Along a sandy shore, storm waves tend to erode beaches, whereas swells move sediments back onshore. If eroding and building forces are balanced, the coastline maintains a relatively stable position. If not, the beach will recede when erosion is dominant or prograde if accretion is dominant. (Fig. 5).

FIG 5

THE STABLE BEACH



In the short term, measured in decades, coasts remain relatively stable so long as the three factors, air, land and sea remain in balance. If not, the shape and position of the coast can change very rapidly.

Despite the fact that air, sea and land may reach an equilibrium at any one time there are long term changes which cause the three factors to adjust continually to meet new situations. As will be demonstrated in later pamphlets, these long term changes can have a marked effect on the position of the coast.

4. **Influence of Sun and Moon**

Movements of the sea can be attributed to:

i) gravitational effects of the sun, moon and earth, and
ii) to air movements caused by differential heating of the earth.

Gravity: Seawater is held to the earth by gravity. The water body is subject to extra terrestrial forces as the earth is also influenced by the gravity of the moon and sun.

These forces pull bulges of water away from the earth causing alternate high and low tides on adjacent coastlines as the three bodies move in relation to each other. Tides lead to regular changes in sea level at any point as well as generating currents in the water mass.

Heat: Warmth from the sun affects land, sea and air.

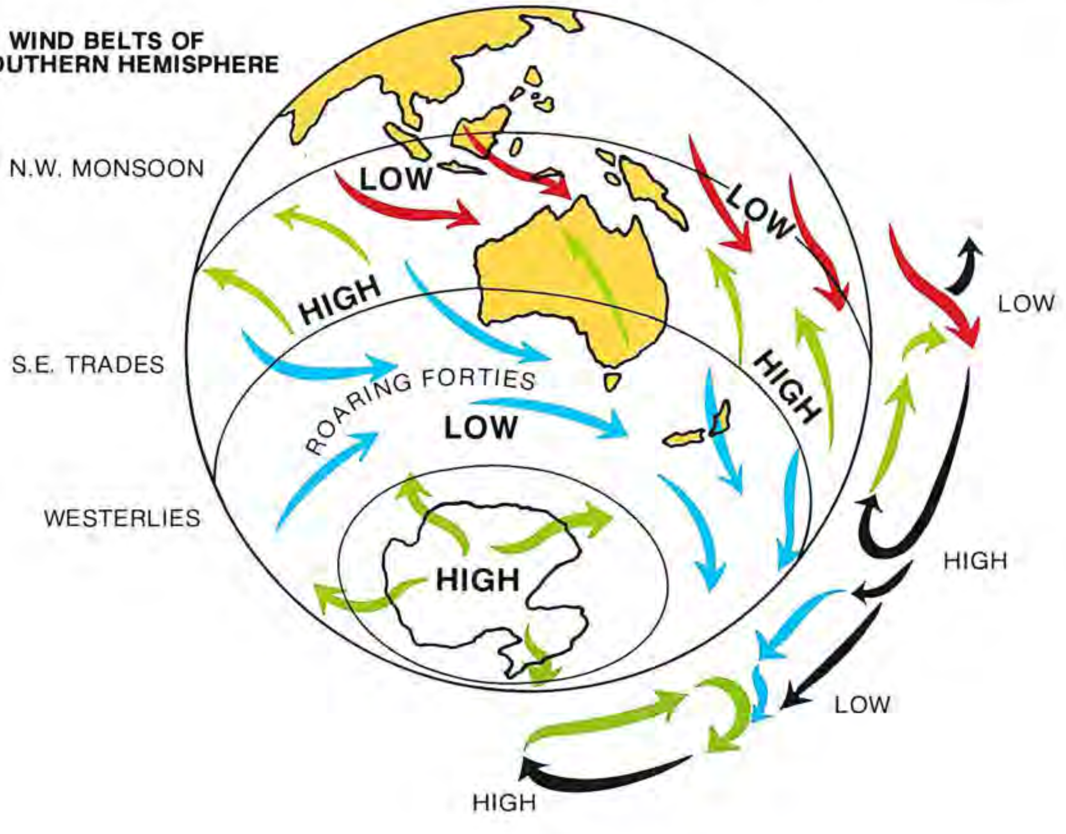
Differential heating and the resulting circulation of air in depth, provides the energy of all the earth's winds and storms. The major wind belts of the earth are basically the result of hot air rising at the equator and cold air descending towards the Poles (Fig. 6). Air moving back toward the equator produces the earths major wind belts. The incidence of summer cyclones and winter storms in Western Australia is the result of annual changes in weather patterns caused by the seasonal heating of different zones of the earth.

At a more local level, daily land and sea breezes result from different rates of heating and cooling of land and sea.

Interaction between the world's winds and its water bodies lead to generation of swells, waves and currents in the water mass.

FIG. 6

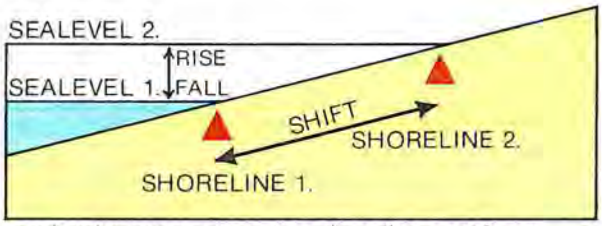
MAJOR WIND BELTS OF THE SOUTHERN HEMISPHERE



5. **Influence of Geophysical Changes**

Climate: Sea level is determined by the volume of water on the earth's surface. If there is worldwide cooling, water becomes trapped on high ground and at the Poles when snow and ice do not melt each summer. During the last ice age, trapping of water caused the sea level to drop over 100 m. As the earth warms, glaciers, ice and snow melt and water is released into the oceans. These worldwide, or eustatic, changes in sea level are slowly but continuously affecting the position of the coast. (Fig. 7). The results of changes in sea level are evident along much of the Western Australian coast, e.g. in old beach levels at Yoganup, Capel, Eneabba, and wave cut cliffs at Rottnest and Shark Bay.

FIG. 7



sea level movements cause shoreline position to alter.

Geological: Non-eustatic or local changes in sea level are caused by land movements. In different parts of the world, land is rising or sinking relative to sea level in response to movements within the earth. In Western Australia, land uplift, has resulted in the promontories which enclose Exmouth Gulf. The drowned valleys of the Kimberley region were caused by land sinking.

Influence of Man on the Coastal Zone

A stable coastline is desirable from a coastal management point of view. Popular sandy beaches and existing structures such as roads, buildings or industrial complexes which have been built close to the beach may be in danger if the forces of sea and air change as a result of climatic, geological or man-induced activity and the land shifts its position in response to the new conditions. People have no control over the climate, the sun and moon, or the prevailing winds and waves, but they do have some influence over coastal land, its vegetation and the wind and waves in the coastal zone.

People can change the direction and extent of the forces acting on the coast through use of groynes, launching ramps, storm water pipes, and dredging. They can also change the response of the land to the forces,in their efforts to use the coast. Disturbing dune vegetation, building seawalls or locking up dune sand beneath coastal roads and houses can seriously affect the ability of the land to respond to extreme conditions that occur occasionally, but naturally.

People using the coast must recognise that land acts as a sink for energy associated with the forces of wind and waves. As the forces change, the land responds by adjusting to the new set of conditions. If the forces are altered or the land prevented from responding, the beach system alters to compensate for the interference.

If people using the coast recognise that they have little control over large scale climatic and geological processes, but that they can and do influence wind, waves and the response of the land, then they have made a first step toward living in harmony with the coast. If they also recognise that forces acting on the coast change from day to day, season to season and from time to time they will be able to plan their use of the coast. In order to maximise the chance of successful planning, maintenance and protection, an understanding of the processes acting in the coastal zone is necessary.

Future pamphlets will describe and explain in more detail some of the subjects raised here in an attempt to provide useful information for planners and managers in the coastal zone.

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Peter Woods, Department of Conservation and Environment, Perth, Western Australia, 1980.

COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF
CONSERVATION &
ENVIRONMENT

BULLETIN NO 49

NO 4

GEOLOGY OF THE WESTERN AUSTRALIAN COAST

INTRODUCTION

The coast of Western Australia is extremely varied. This to a large extent is due to two factors:

i) the geology, structure and composition of the solid rocks which make up the coast, and
ii) the variation in the wind and wave processes that affect the coastal lands.

This pamphlet describes in broad terms the solid rocks that make up the coast of Western Australia.

The shape of the present Western Australian shoreline has only recently been achieved. Seas have fluctuated above and below present sea level in the past and as a result coastal lands have alternately been drowned or exposed as sea level rose or fell. Our coast today is the result of a major rise in sea level over the past 20,000 years which inundated previously exposed land.

As seas rose to present levels, valleys were flooded forming bays and inlets whilst old dunes, high spots and ridges of resistant rock formed reefs, islands and headlands. Another major effect of the rising seas was the sweeping ashore of vast quantities of unconsolidated sedimentary material from the drowned continental shelf. This material has been deposited in bays between resistant headlands or behind islands and reefs. Thus the nature and topography of pre-existing coastal land has had an important bearing on the shape of today's coast. The fact that the basic character of our coast was pre-determined by the rocks which formed prior to the last rise in sea level must be appreciated by anyone who intends to use the coast today.

GEOLOGY OF BASEMENT ROCKS AROUND OUR COAST

Western Australia is largely made up of very old crystalline granites and recrystallised volcanic and sedimentary rocks which formed more than 600 million years ago. The rest of the State consists of younger sedimentary rocks, mainly sandstones and limestones that flank the older rocks. In places the sedimentary rocks extend offshore as a continental shelf (Fig. 1).

Today's coast is in contact with both the old rocks and the younger sedimentary rocks (Fig. 2). This to a large extent provides a basis for the variation in coastal features found around the State. A description of the rocks forming the margins of our coast will therefore help in understanding how they have influenced the formation of the present coast.

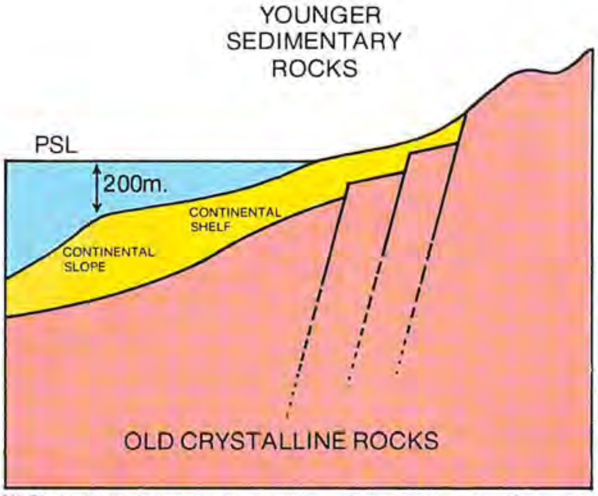

FIG. 1 Idealised cross section of a continental margin showing the relationship between sediments of the continental shelf and the old crystalline rocks which core the continent.

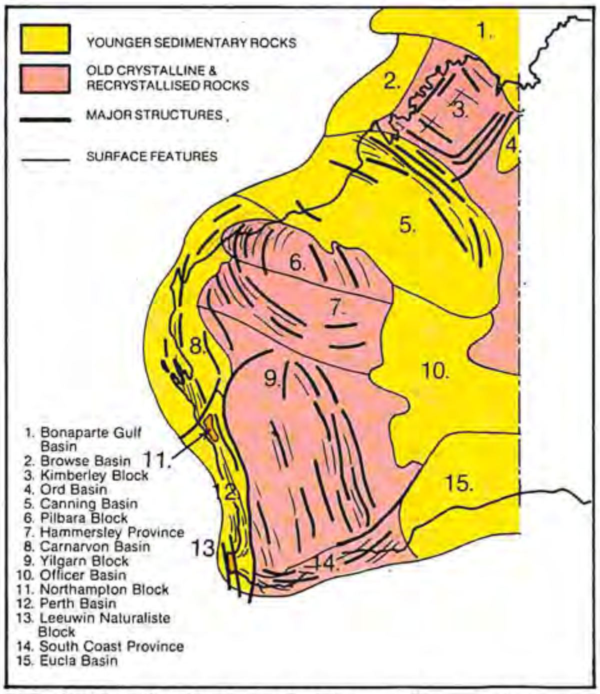

FIG. 2 The distribution of old crystalline and recrystallised rocks and younger sedimentary rocks in Western Australia showing major structures and surface features.

DEPARTMENT OF CONSERVATION & ENVIRONMENT

Kimberley Block
(Northern Territory border to Derby)

The Kimberley Block is made up of old sedimentary and volcanic rocks that have strong north west trending structures. Lesser structures follow a north east trend (Fig. 2). As a result of erosion over a long period of time, the surface rocks display topographic features such as valleys and ridges that parallel these structures.

Canning Basin (Derby to Port Hedland)

The Canning Basin is occupied by relatively flat lying sedimentary rocks (Fig. 3). There are few prominent or resistant features in the centre of the basin. The surface is known as the Great Sandy Desert and is characterised by long sand dunes which parallel the prevailing south east winds. To the east, the sedimentary rocks have been disturbed and have strong north west trending structures. As a result the topography to the east is more pronounced with ridges and valleys parallel to the structures. The sediments extend offshore forming a wide continental shelf (Fig. 2).

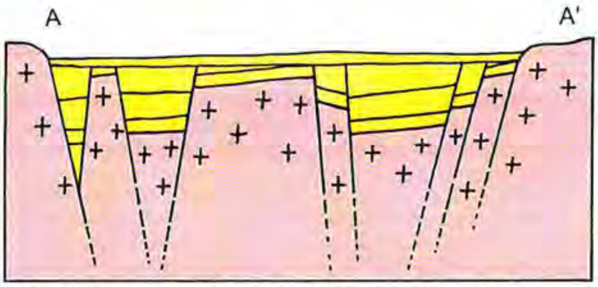

FIG. 3 Diagrammatic cross section through the Canning Basin showing a thick sequence of flat lying sedimentary rocks between the older rocks of the Kimberley and Pilbara Blocks.

Pilbara Block (Port Hedland to Onslow)

The Pilbara Block is made up of old recrystallised sedimentary and volcanic rocks which form ridges between low granite domes. The main structures in the northern most rocks trend north east. Material washed from the ridges has partially filled the valleys between them. The resulting land surface is a flat lying plain with the sediments and volcanics standing out as sharp ridges that trend north east.

Carnarvon Basin (Onslow to Kalbarri)

The Carnarvon Basin is occupied by sediments that display north trending structures. To the south, flat lying sandstones have been cut through by the Murchison River. To the north however, the sediments have been folded into large elongate ridges which are parallel to the present coast. The youngest sediments consist of massive limestone dune deposits which are aligned north-south.

Northampton Block (Northampton)

This block, which forms a positive feature between the Perth and Carnarvon Basins, consists of granites, and old sedimentary rocks.

Perth Basin (Kalbarri to South Coast)

The Perth Basin is occupied by flat lying sedimentary rocks. The present surface is covered by a succession of sand and limestone dune deposits which parallel the present shoreline. As a result, the surface topography consists of small valleys and ridges that parallel the shore. Sedimentary rocks extend offshore forming a continental shelf (Fig. 4).

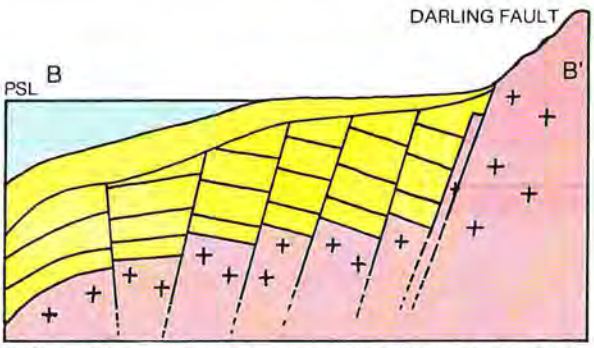

FIG. 4 Diagrammatic cross section through the Perth Basin showing the sedimentary rocks extending offshore from the old rocks of the Yilgarn Block.

Leeuwin - Naturaliste Block
(Cape Leeuwin to Cape Naturaliste)

The block consists of an elongate ridge of hard crystalline rocks. A thin veneer of limestone lies along the west of the ridge. The block is "joined" to the Yilgarn Block by sediments of the Perth Basin (Fig. 5).

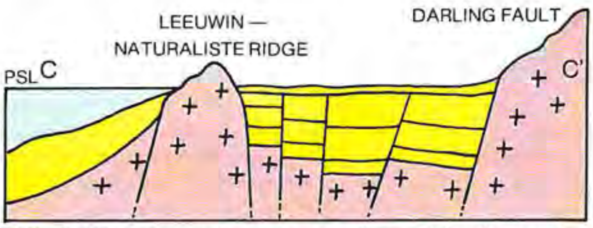

FIG. 5 Diagrammatic cross section of the Leeuwin-Naturaliste area showing how sedimentary rocks of the Perth Basin lie between older crystalline rocks.

South Coast Province
(Windy Harbour to Israelite Bay)

Rocks in the province comprise a mixture of granite and old deformed recrystallised sediments. Structures generally trend east to north east. Granites form low rounded hills, and the older sediments in places form rugged mountains. Between the hills the country is flat lying.

Eucla Basin

(Israelite Bay to South Australian Border)

The basin consists of a flat lying limestone plateau, a hundred metres above sea level. The surface is featureless and the rocks are homogeneous.

CONCLUSION

The above brief and general description of the major blocks and basins of Western Australia illustrates the variation in geology, structure and topography of the rocks that make up the present coastal zone. It is hardly surprising therefore that our coast is so varied (Fig. 6).

The topographic "skeleton" of the coast was provided by resistant rocks which had formed prior to inundation by the sea around 20,000 years ago.

With rising sea levels, the old land surface was slowly drowned and unconsolidated sediments were swept in from the continental shelf. The rock type, the direction of structural weaknesses and the orientation of topographic highs and lows were important in determining the shape of the present coast. For instance, resistant basement rocks (granite or sedimentary rocks) stood out as headlands, islands, promontories or reefs, whereas eroded areas were drowned forming inlets and

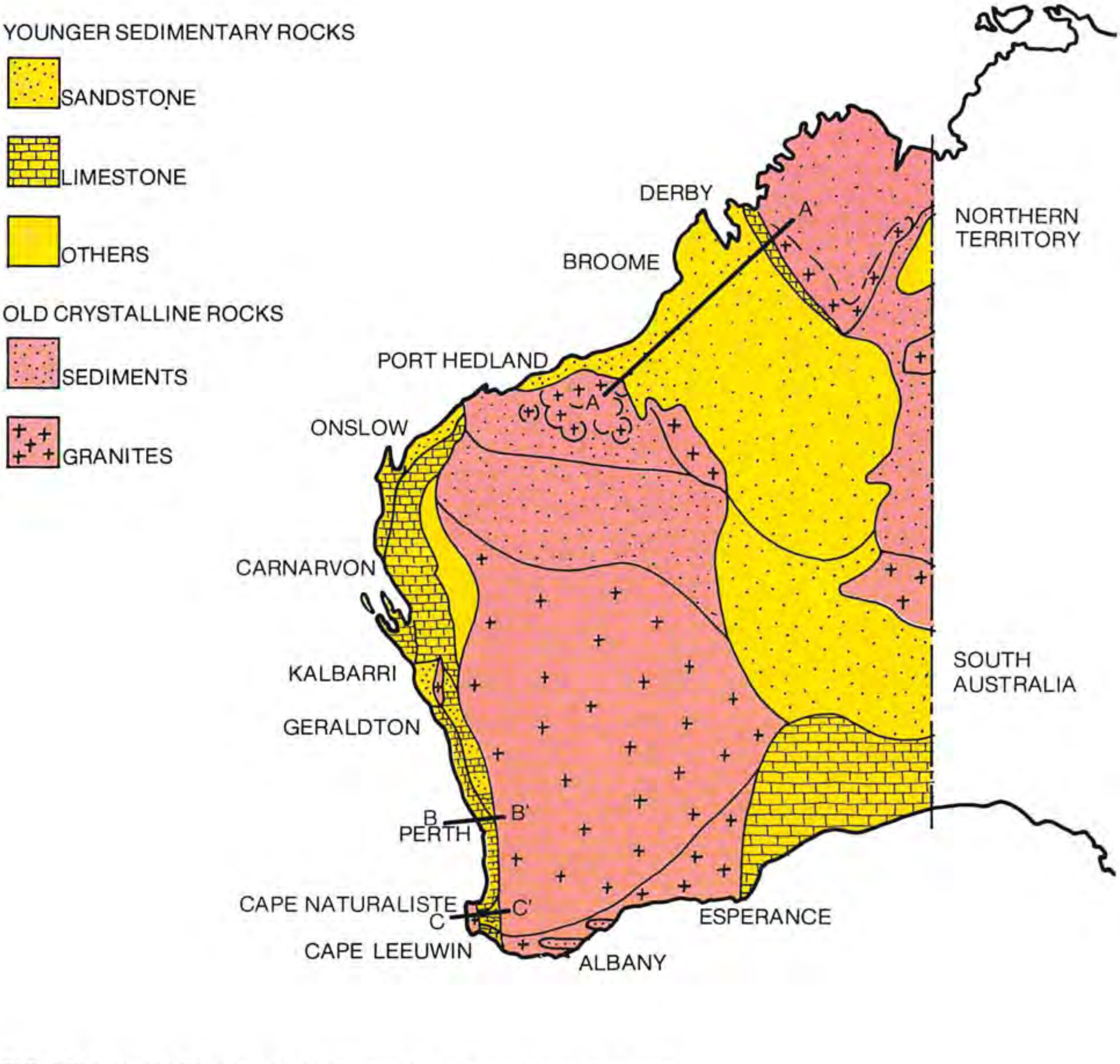

FIG. 6 The coast of Western Australia and its relationship to rock type, AA', BB', and CC' refer to cross sections shown in Figs 3, 4 and 5.

bays. The unconsolidated sediments have been deposited in the bays or behind resistant headlands and reefs. Where major structural elements of the resistant rocks paralleled the new shore, long straight beaches with elongate lake systems, estuaries and offshore reefs formed. Where these elements were at an angle to the shore, the coast became deeply incised with valleys, ridges and hills forming long narrow embayments, headlands and islands respectively. Where the basement rocks were flat lying and featureless such as the horizontal sediments in the Great Sandy Desert, the coast was also flat lying and often backed by dunes. With a more rugged basement (granites of the South Coast Province) the coast was controlled by resistant high points which became linked by curved sandy beaches. Offshore the high points formed islands.

The nature of the rock types that existed prior to the sea reaching its present level therefore played an important part in pre-determining the initial shape and basic character of our coast. For coastal managers, understanding the nature of the rocks that existed prior to the recent sea level rise is extremely important as they have played such an important part in controlling the shape of our coast.

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Peter Woods, Department of Conservation and Environment, Perth, Western Australia, 1980.

COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

BULLETIN NO 49

NO 5

COASTAL PROCESSES AROUND WESTERN AUSTRALIA

INTRODUCTION

As noted in Pamphlet 4 the coast of Western Australia is extremely varied due largely to:

i) the geology of the solid rocks which make up the coast, and
ii) the variations in the wind, wave and tidal processes that affect the coastal lands.

Pamphlet 4 describes the way in which the solid rocks that form the margins of the State have controlled the shape of today's coast. This pamphlet deals with the forces, or natural processes, that act on these rocks. Outlined in general terms are the prevailing and the more unusual natural processes that shape the coastline of Western Australia.

Each part of our coast is subject to a unique combination of wind, wave and tidal conditions. Planners and managers should appreciate the general setting of their particular stretch of coast so that decisions on its use take into account the natural forces which have interacted with coastal lands to produce the coastline as we know it today.

CLIMATE

Because of the size of the State, the climates of north and south Western Australia are quite different. Weather is largely controlled by movement of high pressure anticyclone systems which travel from west to east.

In winter, the anticyclones travel on a northern path across the centre of the State often remaining stationary over the interior for several days. In summer they travel on a more southerly track across the Great Australian Bight. Air streams around the systems are anticlockwise with easterly winds to the north and westerlies to the south.

WINDS

In winter the anticyclones bring mild dry south east winds to the northern tropics and cool moist westerlies to the southern regions of the State. The westerlies, which are reinforced by depressions (low pressure systems) in the Southern Ocean, influence the climate in the south. Winter storms, which subject the southern half of the State to north west and west winds, occur when cold air is directed northward by intense depressions (Fig. 1).

In summer the anticyclones move south and easterly winds and fine warm weather prevail over most of the State. The northern coasts come under the influence of monsoonal depressions which direct warm moist westerlies over the coast from Port Hedland north (Fig. 2).

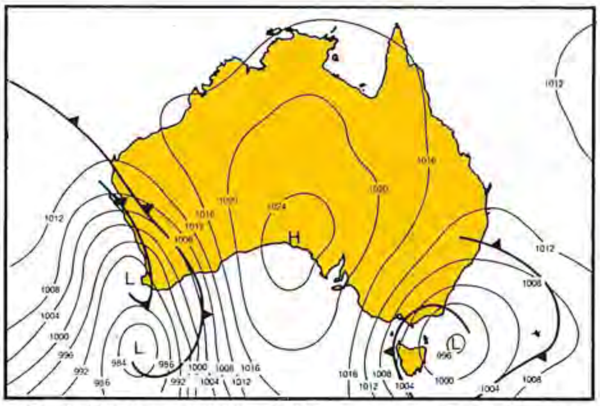

FIG. 1 Winter weather pattern showing winds of a Southern Ocean depression affecting the southern half of the State.

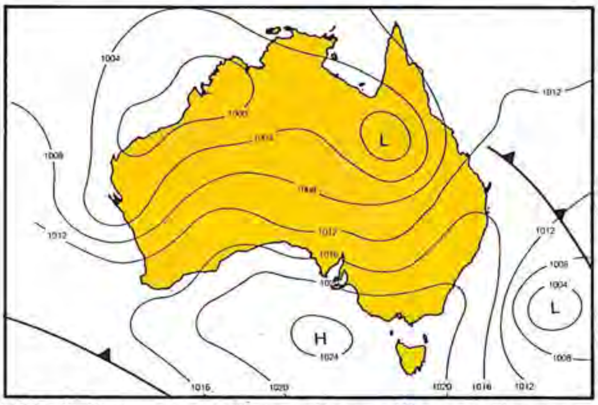

FIG. 2 Summer weather pattern with an anticyclone (high pressure cell) located over the bight.

Winter Gales

During winter when the belt of anticyclones is at its northern most extent, Southern Ocean depressions also have tracks further to the north so that the incidence of gales affecting the south western and southern coasts reaches a peak. North westerly gales primarily affect the westward facing coasts south of Geraldton but west and south westerly gales also strongly influence the southern coasts.

Tropical Cyclones

Cyclones which develop in the Timor Sea during summer bring strong winds and rain to the northern half of the State. Winds circulate in a clockwise direction about the eye of the cyclone so that coastal areas are typically affected by strong winds from a variety of directions as the centre passes. On average two cyclones cross the northern coast each summer.

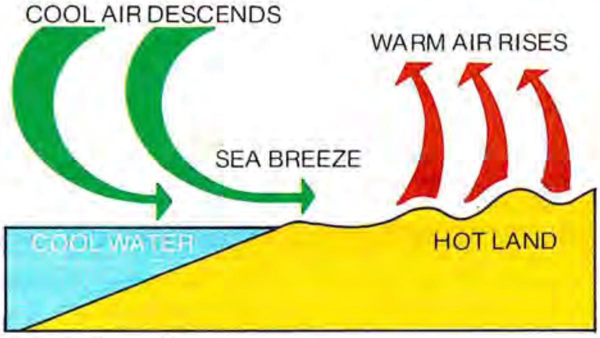

FIG. 3 Formation of a seabreeze.

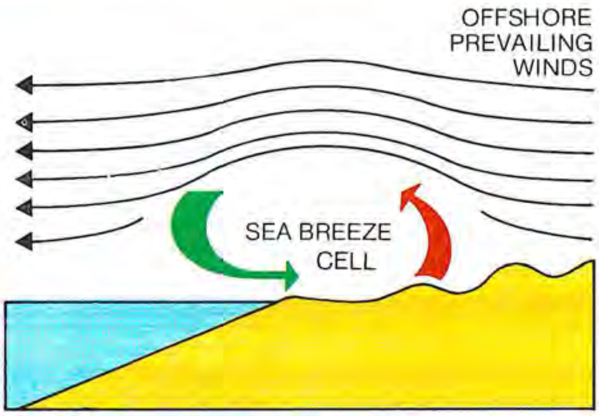

FIG. 4 A seabreeze cell along the coast beneath a prevailing wind system.

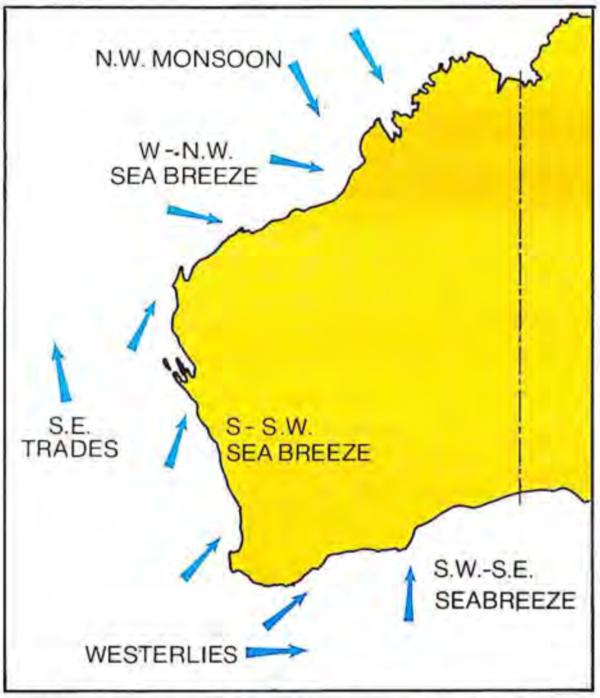

FIG. 5 The seabreeze system around Western Australia.

Seabreezes

The afternoon seabreeze is a common phenomenon along the Western Australian coast. A true seabreeze forms because land and sea heat at different rates. The land heats more quickly and consequently air over land warms and rises whilst cooler air from over the ocean flows in to take its place. This cool flow is the seabreeze (Fig. 3).

The local formation of a seabreeze can be affected by prevailing weather conditions. For instance if there are strong offshore winds during the morning, a late afternoon seabreeze may develop as a weak cell along the coast (Fig. 4). If, however, offshore winds are light, the seabreeze may develop early in the day. Seabreezes, when combined with prevailing onshore winds, are characterised by strong south to south east winds along the south coast, south to south west winds along the west coast, and west to north west winds along the northern coast (Fig 5).

EFFECT OF WIND ON WATER

Swells and Waves

Western Australia is surrounded by open oceans in which:

i) large swells are constantly being generated by distant depressions and tropical cyclones; and
ii) wind waves are generated by local winds and storms.

The almost constant south westerly swell that affects most of the State's coast is generated in the "Roaring Forties" in the Southern Ocean. As a result the south coast is subject to a moderate to heavy south west swell, the west coast to a moderate south westerly swell, and the northern coast to a low westerly swell.

The prevailing swell pattern has superimposed on it wind waves generated by seabreeze, cyclones and depressions so that the combination of swells and waves varies at each point along the coast.

The dominant wave conditions are associated with large storm events. These differ from north to south so that during summer the north coast is subject to cyclonic waves that arrive from northern quadrants. During winter the west and south coasts are subject to north west, west and south westerly waves generated by strong wind gales associated with Southern Ocean depressions (Fig. 6).

Littoral Drift

Along most of the coast the prevailing swell and the locally generated waves arrive at an angle to the shore (Fig. 6). This fact has important implications. When a wave reaches a shore at an angle, a current is set up which is often capable of transporting sediment. This phenomenon is known as littoral drift.

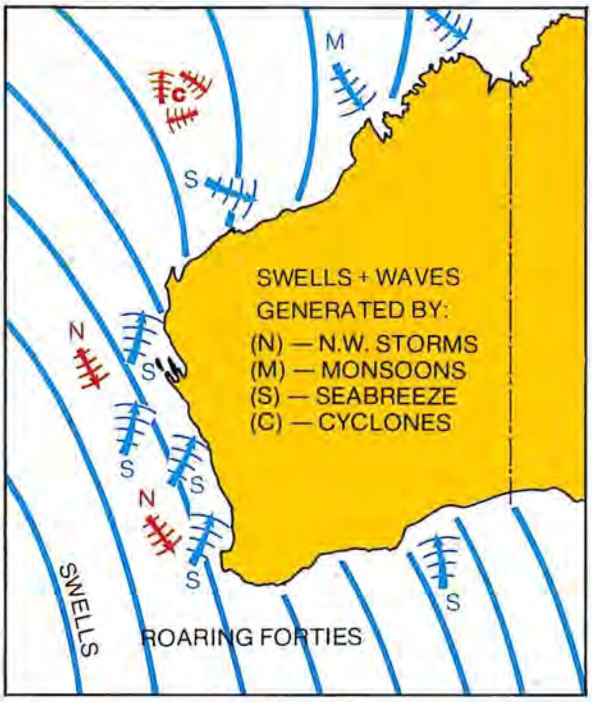

FIG. 6 The swell and wave patterns around Western Australia:

Under prevailing swell conditions, littoral currents move sediments to the east along the southern coast, to the north along the western coasts, and to the north east along the northern coasts (Fig. 7). The prevailing drift is interrupted or added to during cylcones or storms. Along the west coast, for instance, north west storm waves reverse the prevailing northern drift causing southern drift for the duration of the storm.

The distribution of sediment around the coast is largely a result of littoral currents which move material from active areas to less active areas where deposition takes place. In general, littoral currents remove sediment from the south west corner of the State and transport it to large depositional sinks north of Shark Bay and east of Israelite Bay.

Tides

Tides are movements in a water body set up by the gravitational effects of the sun and moon acting on the rotating earth. Tidal waters move onshore and offshore, however, currents which travel parallel to the shore may also be set up in the water mass.

The tidal range in the open ocean is in the order of one metre. However there is a marked increase in range when the tide invades shallow coastal waters or narrow inlets. Tidal range along the north west and Kimberley coasts is large with spring tides ranging over 10 m. There is a marked reduction in tidal range from Exmouth Gulf to Eucla.

Storm Surge

Wind blowing over the sea tends to move surface water in the same direction. Especially during a storm or cyclone onshore winds can pile water up against a coast. This has implications in low lying areas where a "storm surge" combined with high tides and low atmospheric pressure can cause flooding and increase the reach of storm waves. Likewise offshore winds can decrease local sea level.

EFFECT OF WIND ON LAND

Wind along the coast is often strong enough to move loose sedimentary material. Onshore winds play an important role in beach buildup by blowing sand up the beach and into dunes where it is trapped by foredune vegetation. This store of sand is vital to the beach sand cycle. During storm events sand in the foredune is returned to the active beach system, i.e. the beach and its offshore sand bars. Normally therefore there is a constant exchange of sand between the foredune, the beach and the sand bars. If this cycle is broken and sand is lost from the system, the beach compensates for the loss by shoreline erosion.

If sand is not trapped by vegetation it moves inland as blowouts, parabolic dunes or sand sheets. Coasts subject to strong onshore winds are therefore liable to lose material from the active beach zone if vegetation is not sufficient to trap and hold the sand in dunes. Active dunes are present along the coast today. They are frequently superimposed on well vegetated remnants of very large older dunes indicating that sand losses from the beach have occurred in the past.

The orientation and shape of the active blowouts around the coast indicate the direction of the dominant winds, and provide information to the coastal manager on the winds most likely to move sand inland (Fig. 7).

Evidence of phases of large scale sand movement indicate that in the past sediment supply to the coast has exceeded the rate of erosion, and that conditions were not conducive to sand retention near the shore. The awesome size of the older dune systems, some of them 70 m high and extending several kilometres inland, should serve as a warning to coastal managers. Initiation of large scale sand movement on developed parts of the coast should be actively discouraged.

IMPLICATIONS FOR MANAGERS

The forces that affect the coastal lands of Western Australia are varied because of the size of the State. A manager of coastal land therefore needs to understand the natural setting of his own coast.

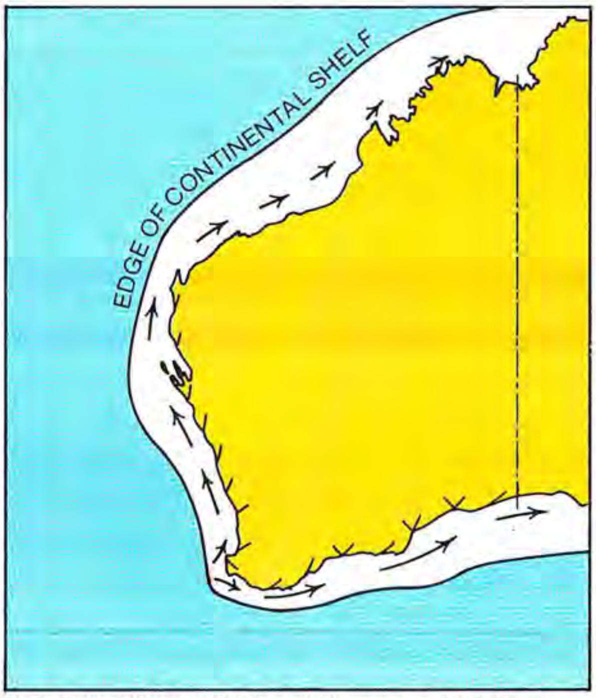

FIG. 7 Net littoral drift and blowout orientation around the coast of Western Australia (Length of arrow is proportional to the amount of drift).

He must understand the forces that affect the shore and what effect these forces have on land forms, coastal shape and sediment mobility. In this way he can determine the likely effect of the forces on his planned use of the coast and likewise the effect the planned land use will have on the coast and its processes.

It is important to realise that the coast of Western Australia is subject to an almost constant south westerly swell, and to a variety of prevailing winds which change from season to season. These winds and local seabreezes generate wind waves which also affect the coast.

The direction and intensity of the swells and waves depend on coastal location. In most cases they arrive at an angle to the shore inducing littoral currents which are capable of transporting sediments. Due to the size and shape of the State and the variety of its winds, littoral currents move sediments in different directions at different rates. Prevailing waves and swells are instrumental in transporting sediments throughout most of the year; however extreme storm or cyclonic events, although short lived, disrupt prevailing patterns and often have a marked effect on sediment transport. It may not be the most common forces which shape the coast but the infrequent, high energy events. Knowledge about these varied events is therefore of benefit to anyone planning to use coastal land.

Many of our sandy beaches are subject to onshore winds that are capable of moving sand. The presence of active and dormant blowouts and parabolic dunes is evidence that wind plays an important part in shaping the coast. The role that vegetation plays in subduing the effects of wind is also important. Prevailing winds may not be the dominant force associated with sand movements. A study of land form will help determine which winds are the most active. This will provide a basis for the identification of high risk areas for coastal developments.

The range of tides can also be important. In areas subject to large tidal range, the reach of storm waves can be increased if combined with a high tide. Tidal range varies around the State due to the present or absence of a wide continental shelf, the configuration of the coast and the atmospheric conditions. In low lying areas particularly, the potential for this combination should be borne in mind.

When planning to develop an area of coast it is essential to determine whether the development is in an area that is subject to net erosion or accretion. In the first case land will be subject to erosion by storm waves and strong littoral currents, necessitating location of any developments well inland of the shoreline. In the second case sediments may accumulate to such an extent that wind processes present problems. Developments could be sited closer to the shore, however the continued arrival of loose sediment will have to be dealt with.

Developments which disturb sea conditions or dune vegetation, or which lock up dune sand beneath roads and buildings, will disrupt the natural system. The likely results of poorly located developments are a requirement for expensive protection works or destruction of property.

In order to avoid these eventualities it is in the interests of the coastal manager to understand the forces at work on the coast and to appreciate their role in the natural system.

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Peter Woods, Department of Conservation and Enviroment, with assistance of Dr. Ian Eliot, Department of Geography, The University of Western Australia, and Alan Scott, Bureau of Meteorology, Perth, Western Australia, 1980.

COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF
CONSERVATION &
ENVIRONMENT

BULLETIN NO 49

NO 6

THE WESTERN AUSTRALIAN COAST

INTRODUCTION

Pamphlets 4 and 5 described the nature of the solid rocks which make up our coast and the natural forces acting upon them. Together the pamphlets identify reasons for the variety of coastal features found around the State. In summary these are:

i) the nature of solid rocks in coastal areas,
ii) the position of world sea level,
iii) sediment supply both present and past,
iv) prevailing wind and wave conditions, and
v) dominant wind and wave directions.

With this background we can explain why various parts of our coast are different from others.

The shoreline of Western Australia as it is today is a relatively young feature. After the last ice age ended 20,000 years ago, world sea level rose until around 6,000 years ago when it stabilised at its present level. The major result of this rise was the drowning of pre-existing land around the margins of the State. Thus the basic shape of our coast was pre-determined by basement rocks which were present 20,000 years ago.

Another result of the rise in sea level was a change in sediment supply to the shore. Rising seas swept large amounts of unconsolidated sediment ashore. This led to a major phase of dune building and beach ridge development. When seas reached their present level an equilibrium was established with diminishing supplies of sand available from offshore and with sands onshore becoming stabilised as dunes or blown inland.

With sea level stabilised the forces of wind and wave have had a chance to attack solid coastal rock, and to move the unconsolidated sediments which were brought ashore by rising seas. Resistant rocks now stand out as headlands while loose sediments have been swept away by currents to be deposited as dune and beach ridge systems in sheltered bays or behind islands and reefs. Coasts which are protected from prevailing winds and swells have become traps for sediments transported from more active areas of the coast.

Western Australia is subject to a continuous south west swell which has been dominant in moulding the shape of softer parts of the coast. Imposition of prevailing wind waves on the swell system has favoured movement of sediment away from the south west corner of the State. Along the south coast heavy swells and waves sweep sediments to the east leaving behind a coast of sheltered bays largely protected by resistant granite outcrops. On the west coast, sediments are transported northwards along a coast parallel to the incoming swells. On the northern coast prevailing conditions are calm and little sediment transport takes place.

Periodic storms and cyclones disrupt the prevailing systems though the net pattern of sediment movement is not substantially altered. Along the south coast, the forces associated with both the prevailing and the periodic events combine in shaping the coast. Along the west coast, reversals to prevailing beach processes occur during periodic storm events. Prevailing conditions, however, dominate. On the northern coasts where prevailing conditions are calm the rare high energy cyclone events are dominant in shaping the coast.

Thus the impact of wave and wind action on the basement rocks and any unconsolidated material has modified the shape of the coastal skeleton. As the nature of the forces varies around the coast, the nature of the alteration has differed from place to place.

On the basis of basement geology and natural forces the coast of Western Australia can be subdivided into a number of regions.

COASTAL REGIONS

The Western Australian coast can be subdivided into eight major regions, each of which displays features that reflect the influence of the pre-existing solid rocks and the natural process acting on them (Fig. 1).

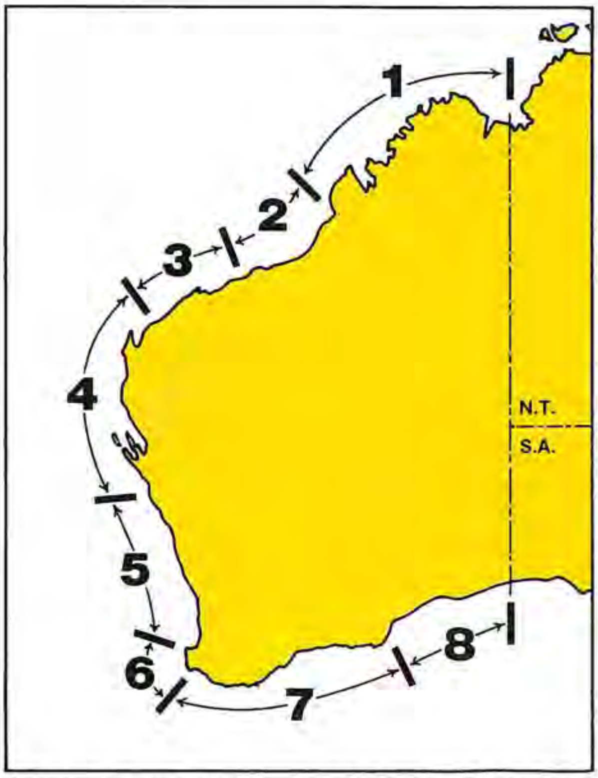

FIG. 1 The eight divisions of the Western Australian coast.

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1. Territory border to Broome
(Kimberley Coast)

This is a typical ria coast (drowned river valleys), characterised by resistant basement rocks having major structures orientated at an angle to the shore so that the coast is rugged and broken with many natural embayments, sounds, headlands and islands. Embayments and sounds grade shoreward into mangrove covered tidal flats whereas headlands and offshore islands lie in deep water and lack beaches. Prevailing conditions are calm though the tidal range is very large. Little is known about coastal processes in this region (Fig. 2).

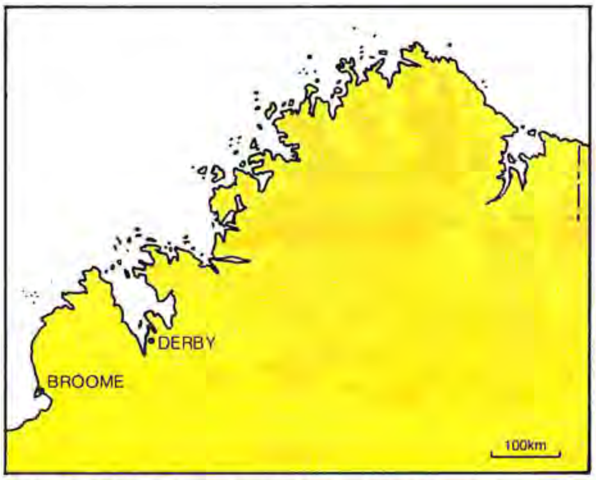


FIG. 2 The highly indented Kimberley coast with its many offshore islands.

2. Broome to Port Hedland

Most of this coast is underlain by flat lying sediments so that the coast is characterised by long straight sandy beaches unbroken by resistant headlands, and backed by sand dunes or mangrove flats. Prevailing winds are offshore and sea conditions are calm though waves and littoral currents generated by seabreezes sort sediments along the coast. Waves, winds and storm surge resulting from cyclones affect the coast periodically. Tidal range is large. Due to the prevailing calm conditions, sediments transported by the De Grey River have not been removed from the river mouth and a large delta has formed (Fig. 3).

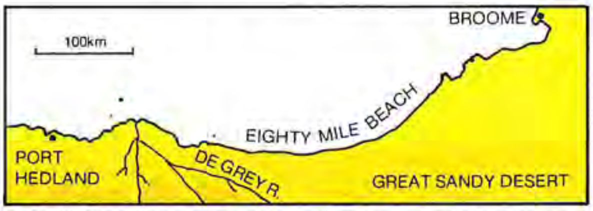


FIG. 3 The long straight and regular coast between Broome and Port Hedland. The De Grey delta is the only prominent feature on the coast.

3. Port Hedland to Onslow

Along this coast the resistant rocks of the Pilbara Block form headlands and islands. The rest of the coast is extremely flat lying. Bays behind the prominent features are shaped by the weak prevailing swell which arrives from the west. They are usually crescent shaped and open to the north west. Between the headlands the shoreline is marked by expansive mangrove covered tidal flats. These are often backed by large storm ridges which are formed by cyclonic waves (Fig. 4).

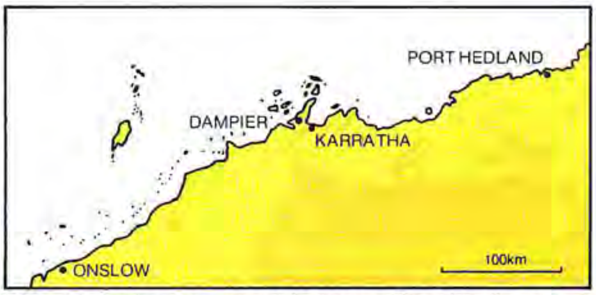


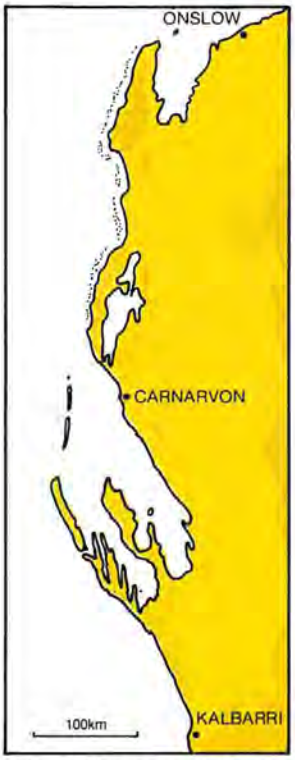
FIG. 4 The broken coast between Port Hedland and Onslow where resistant rocks form islands or protect crescent shaped bays that open to the north east.

Prevailing winds are offshore and sea conditions generally calm. Tidal range is large. Due to the broken coastline there is limited littoral drift or sorting of sediments. Waves, winds and storm surge resulting from cyclonic depression affect the coast during summer.

4. Onslow to Kalbarri

Between Onslow and Kalbarri the coast is composed largely of limestone sedimentary rocks which have been uplifted and folded on a north south axis so that the coast is characterised by large promontories and islands which are parallel to the shore. These enclose large bays that open to the north. Within Shark Bay drowned dune valleys form a series of north trending inlets and promontories. To the south the coast consists of uplifted red sandstone. A coral reef lies along much of the northern coast (Fig. 5).

Prevailing south westerly swells combine with strong southerly winds and waves to induce northern littoral currents. Where the uplifted basement has been exposed to the full force of the swells and waves it has been cliffed, with loose sediment swept away to the north. Where the cliff line is broken, the more exposed beaches are sandy and backed by dunes whereas protected areas support mangroves. Beaches behind the reef consist of coral sands. Periodic cyclones and north west gales affect the coast, particularly those beaches that face north and lie within the open bays.



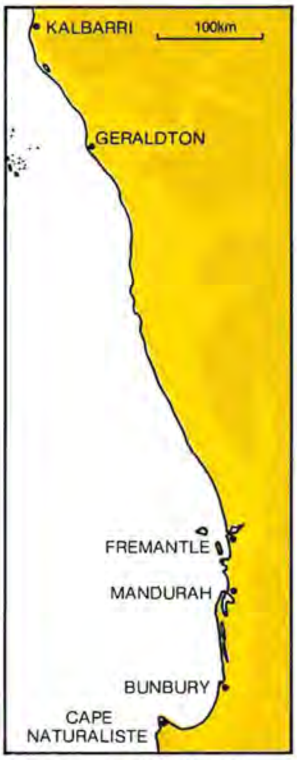


FIG. 5 The coast between Onslow and Kalbarri characterised by a coral reef and elongate promontories and islands which enclose large bays.

FIG. 6 The coast between Kalbarri and Cape Naturaliste is characterised by long sandy beaches and rocky limestone headlands, reefs and islands. Crescent shaped bays behind resistant features open to the north.

5. Kalbarri to Cape Naturaliste

This coast is characterised by long straight sandy beaches backed by old sand dunes and an elongate lake and estuary system. In places the old limestone dunes stand out as headlands, islands and reefs. Prevailing south west swells and waves induce a northern littoral drift. North west storms affect the coast by periodically reversing prevailing wave and current patterns. Tidal range is very low. The shape of bays is controlled by limestone hard points and the direction of swells. Typical bays are crescent shaped and open to the north. Man has settled in the lee of most of the hard points along this coast (Fig. 6).

6. Cape Naturaliste to Cape Leeuwin

Tough crystalline rocks which are resistant to erosion underlie the coast between Cape Naturaliste and Cape Leeuwin. The coast largely consists of steep cliffs and a rocky reef lies offshore. Sandy bays occur where the cliff line is broken. The coast is subject to prevailing heavy south westerly swells. Consequently the sandy bays are crescent shaped and open to the north.

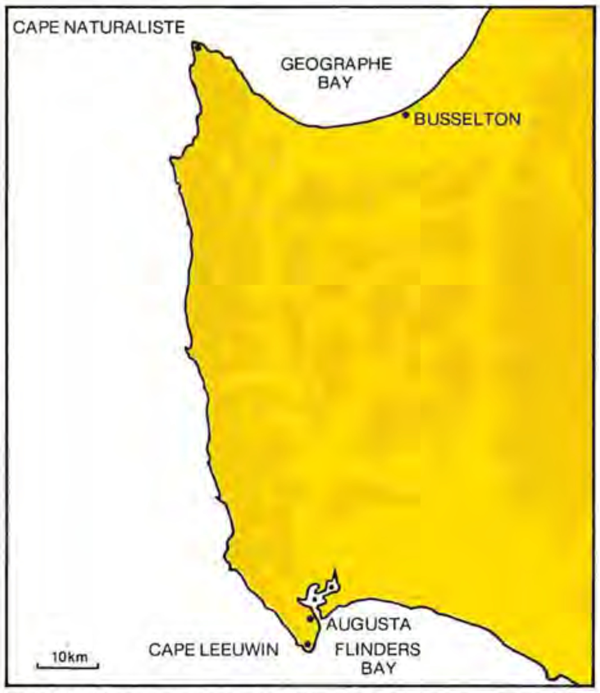


FIG. 7 The rocky coast between Capes Naturaliste and Leeuwin protects Geographe Bay to the north and Flinders Bay to the south. Small bays along the coast are open to the north.

North west gales affect the area during winter reversing wave and current patterns. Tidal range is low.

It is interesting to note that the hard rocks of the Leeuwin-Naturaliste Ridge have acted through geological time as an "island" lying off the main coast of Western Australia. As sediments were deposited in the Perth Basin this ridge protected the area behind it and sediments built out from the base of the Darling Range forming a "tombolo-like" structure. Geographe Bay is now a crescent shaped bay facing north and pivoted on Cape Naturaliste. Another crescent shaped bay pivoted on Cape Leeuwin extends to the east from Augusta. This area of the coast marks a point of divergence with south westerly swells and littoral currents taking sediments away to both the north and east (Fig. 7).

7. Cape Leeuwin to Israelite Bay

Between Cape Leeuwin and Israelite Bay the coast is underlain by tough granite rocks and old deformed sedimentary rocks which outcrop as mountains, headlands or islands. Rivers discharge into the low areas behind headlands forming estuaries. The coast is subject to a heavy south west swell and easterly littoral currents which sweep sediment past the headlands. Over time sediments have been moved out of the area and accumulated in the shelter of the Great Australian Bight near Israelite Bay.

The coast is typical of an area controlled by numerous hard points and swept by a prevailing and dominant swell from one direction. Under the influence of swells, crescent shaped bays pivoted on headlands are open to the east (Fig.8).

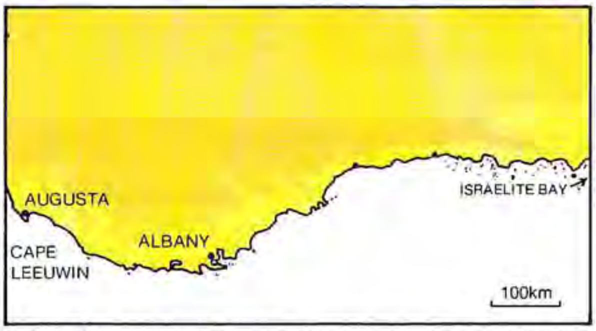


FIG. 8 The coast between Cape Leeuwin and Israelite Bay has resistant granite headlands protecting south east facing crescent shaped bays.

8. Israelite Bay to South Australian border (Eucla coast)

The coast is composed of homogenous limestones which have been uplifted and eroded to form massive cliffs. In places the cliffs are broken and sandy beaches backed by dunes are present. Near Israelite Bay and Eucla large amounts of sand from the west have come ashore forming dunes and beach ridges. The coast is subject to a heavy south west swell and easterly littoral currents which sweep erosion products away from the base of the cliffs (Fig. 9).

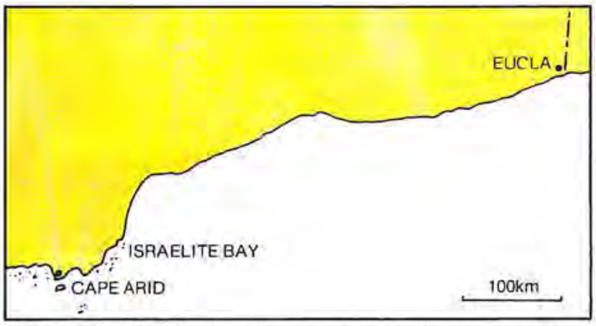


FIG. 9 The Eucla coast is backed by high limestone cliffs except behind Cape Arid and near Eucla where sediments have accumulated at the base of the cliffs.

IMPLICATIONS FOR COASTAL MANAGERS

Much of the character of the present coast has been pre-determined by basement rocks and sediments that existed before the sea inundated coastal lands 20,000 years ago. Since inundation, soft rocks, weaknesses and low points have been eroded or filled with sediments swept in by rising seas. The shape of sandy beaches and bays has been controlled by hard points which alter the direction of incoming swells and waves in the sheltered areas behind. Thus the present coast owes its shape to the combined effects of pre-existing rocks and the natural processes which take place around Western Australia.

In the main, the sandy parts of the coast are oriented parallel to the prevailing swells. On a large scale the west facing coast is composed of old dune deposits, which parallel the dominant south west swells. On a smaller scale, bays behind resistant headlands and islands are shaped by swells which have been affected by local headlands. Thus bays along the south coast are crescent shaped and open to the east whereas those on the west coast are open to the north.

Alterations to the shape of sandy parts of our coast occur when non-prevailing waves, winds and swells arrive as a result of cyclones or storm events. Re-adjustment to beach shape during storms often results in widespread movement of sand, the most noticeable feature being erosion of the beach and dune systems. In the lee of rocky headlands beach movements are smallest and this is one of the main reasons why these areas have been successfully settled. With increasing population, coastal developments are spilling over into less protected areas which are subject to greater fluctuations in natural conditions and shoreline movements.

An appreciation of the role of basement rocks and the natural processes that sculpt them, will help coastal managers understand why the coast has a particular shape. This in turn will allow more informed decision making on coastal land use. If it is appreciated that rocky headlands control coastal shape; that sandy beaches are oriented with respect to prevailing swell and wave directions; and that changes in coastal shape occur during storm events, there is more chance that coastal developments will be compatible with coastal processes. Less property damage, and low maintenance costs should result from planning based on a sound appreciation of coastal processes.

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COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION & ENVIRONMENT

BULLETIN NO 49

NO 7

COASTAL CHANGES (PART I)

INTRODUCTION

Perhaps the most important aspect of coastal planning and management is understanding that the shoreline is not fixed. In fact the coast is subject continually to phases of erosion or accretion which cause the shoreline to move landward or seaward. This pamphlet is an introduction to the idea that the natural shore is mobile, its shape changes and its position at any one time is temporary.

Modification to shoreline position and shape occurs as a result of changes in sea level or changes in wave and swell patterns. The changes can conveniently be separated and distinguished on the basis of time scale. They are:

1. long term sea level changes and shoreline response which have taken place on a geological time scale, i.e. over the last 1-2 million years;
2. sea level changes and shoreline development which have taken place over the last 10,000 years;
3. shoreline movements which result from long term changes in climate over hundreds or thousands of years; and
4. shoreline movements which result from short term storm events.

These changes are interrelated and their effects on any coast can be seen in the landforms which develop.

SHORELINE CHANGES ON A GEOLOGICAL TIME SCALE

The position of the coast is directly dependent on the relative position of sea level and land. In geological time where sea level is known to have fluctuated in response to ice ages, or land has risen or fallen due to processes within the earth, the shoreline has moved correspondingly. Within the last 1 million years or so, sea level is known to have fluctuated markedly from 100 m above to 100 m below the present level whilst the postion of the Western Australian land mass has remained relatively stable. In some areas the effect of the fluctuating sea level has caused the Western Australian shoreline to move many tens of kilometres (Fig. 1).

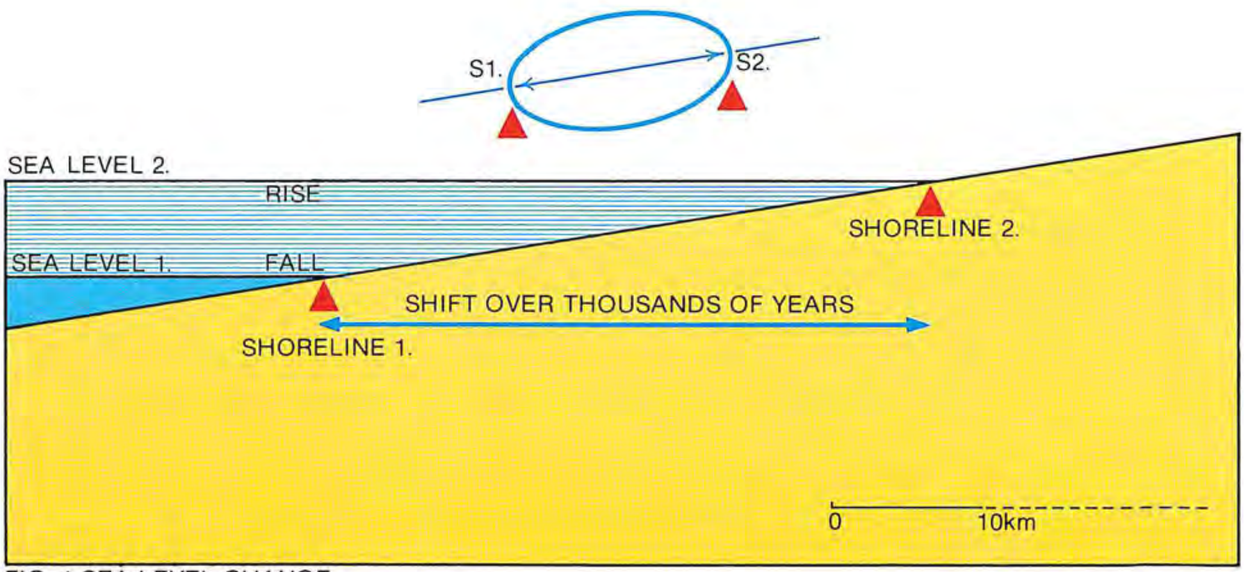

FIG. 1 SEA LEVEL CHANGE

SHORELINE DEVELOPMENT OVER THE LAST 10,000 YEARS

Over the last 10,000 years there has been a marked change in world sea level. After the last ice age ended 20,000 years ago, the sea rose from 100 m below its present level. It reached its present position around 6,000 years ago and since then it has remained relatively steady. As a result of sea level movements in this time, there have been marked changes in shoreline position and shape. Almost all the landforms - the dunes, beach ridges, blowouts and sandy beaches along our coast today, were formed in this geologically brief period of the earth's history. As we live upon and wish to use many of these young landforms, the fact that they are so young is very significant.

SHORELINE MOVEMENTS DUE TO LONG TERM CLIMATIC CHANGES

There is evidence that world climate has varied within the time of recorded history. For instance, Greenland was once warm enough to support agriculture, and only a 100 years ago the Thames at London froze over. In this century the deserts of Africa have been expanding and even in the short history of Australia there have been fluctuations in rainfall and storm activity. All this suggests that worldwide climatic patterns change over tens and hundreds of years.

By studying the coastal landforms which were built in the last 10,000 years there is clear evidence that their development did not take place under constant conditions. Rather there is evidence that periods of dominant erosion alternated with periods of accretion. These changes are most likely due to changes in world climate which affected the frequency of storms, cyclones and calms around the Western Australian coast (Fig. 2).

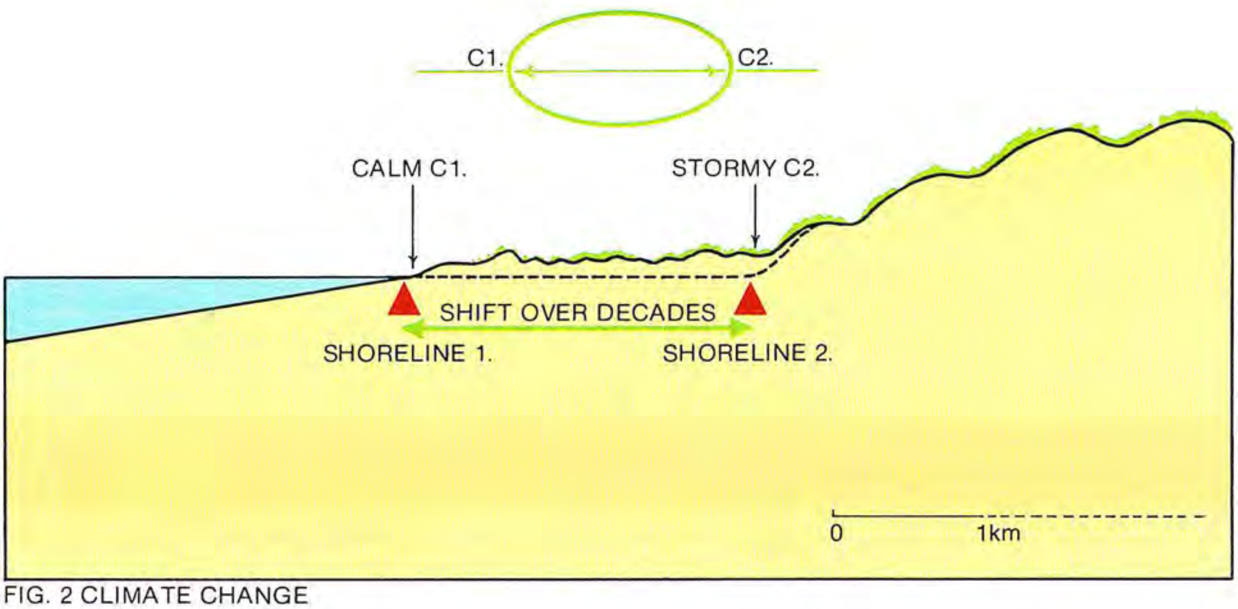

FIG. 2 CLIMATE CHANGE

SHORELINE MOVEMENTS DUE TO SHORT TERM STORM EVENTS

A readily observed phenomenon is beach erosion and shoreline retreat after a storm or cyclone. Storms or cyclones may occur more frequently in some seasons than others so that often there is a seasonal shift in shoreline. Coasts are characterised by wide beaches during the season when calm conditions prevail and narrow beaches during the stormy season (Fig. 3).

The effect of a change in climate will alter the frequency of storms. A change to a more stormy climate would result in a greater tendency for beaches to erode. Conversely a change to calmer conditions would allow beaches to build up and shorelines to advance (Fig. 2).

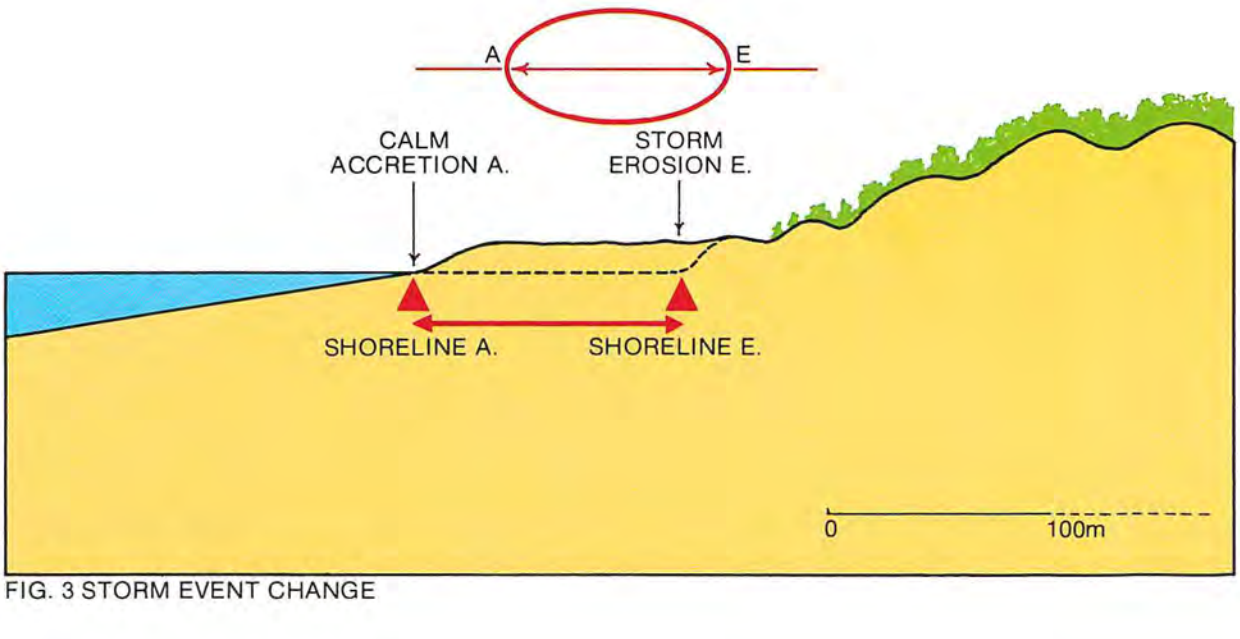

FIG. 3 STORM EVENT CHANGE

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IMPLICATIONS FOR COASTAL PLANNERS AND MANAGERS

It must be appreciated that land along the coast is continually adjusting in response to forces generated in the sea. As sea level, climate, or seasons change so too do the forces affecting the land. As a result the position of the shore moves and in summary the shoreline changes can be brought together on the following diagram (Fig. 4).

It should also be appreciated that there is a time lag between imposition of new conditions and shoreline adjustment. As sea conditions can change quite rapidly, and the land responds relatively slowly, it is not unusual for coastal land to be out of phase with new sea level conditions. The land therefore is unstable and liable to further movement.

The next four pamphlets set out in more detail the four factors that influence the shape and position of our coastline:

- long term changes in world sea level
- sea level changes over the last 10,000 years
- long term changes in climate, and
- storm events

The West Coast of Western Australia has been used to illustrate the pamphlets because the record of changes here is well preserved and well documented. Lessons learned here however can be applied to other areas of the coast. For coastal planners and managers, an understanding that the coast is continually adjusting to changing conditions is vital. Without this appreciation sound decisions on coastal planning, development and management will not be possible.

FURTHER READING

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PREPARED BY:

Peter Woods, Department of Conservation and Environment, with assistance of Dr. Ian Eliot, Department of Geography, The University of Western Australia, Perth, Western Australia, 1980.

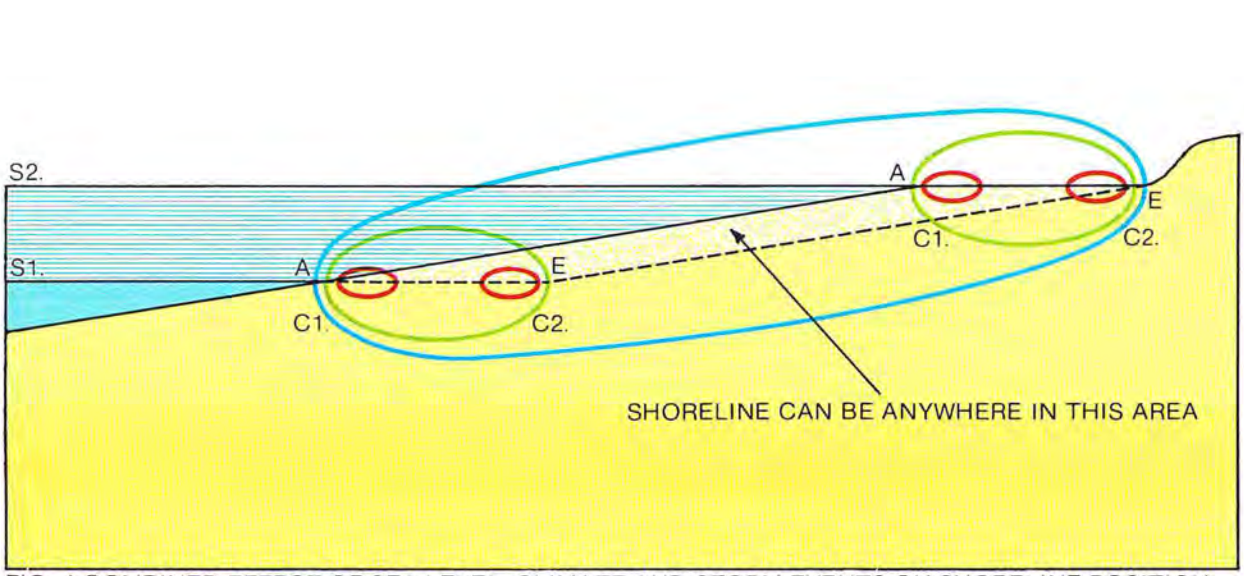


FIG. 4 COMBINED EFFECT OF SEA LEVEL, CLIMATE AND STORM EVENTS ON SHORELINE POSITION.

COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF
CONSERVATION &
ENVIRONMENT

BULLETIN NO 49

NO 8

BEACH CHANGES (PART II)
SHORELINE CHANGES ON A GEOLOGICAL TIME SCALE

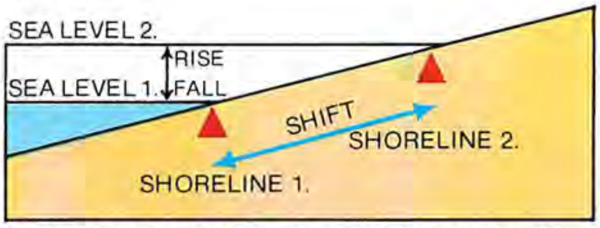
INTRODUCTION

This pamphlet illustrates the temporary nature of the present shoreline position and deals with changes measured in thousands of years. Although changes over this length of time might not seem relevant to coastal planners, it is important to know that they do occur. The long term changes which have a marked effect on shoreline position, set the stage for the short term fluctuations by directly affecting the availability of sediment to the coast. When planning coastal structures (suburbs, roads, harbours, factories, jetties, etc.) which will be in place for many decades, the effects of long term trends can be important.

CHANGES IN SEA LEVEL

Large scale shoreline movements result from changes in sea level. A coast will retreat as seas rise, and advance as seas fall. Thus the relationship between sea level and land is very important in our understanding of the coast (Fig. 1).

FIG. 1



Sea level movements cause shoreline position to alter.

During the Quaternary Period of the earth's history, which extends back a million or so years, there is evidence that there have been large scale fluctuations in sea level resulting in marked movements of the shoreline.

Geological Time Scale

		Present
Quaternary	Recent	
		5,000 years BP
	Holocene	
		20,000 years BP
	Pleistocene	
		1-2 million years BP
Tertiary	Pliocene	

BP: Before Present

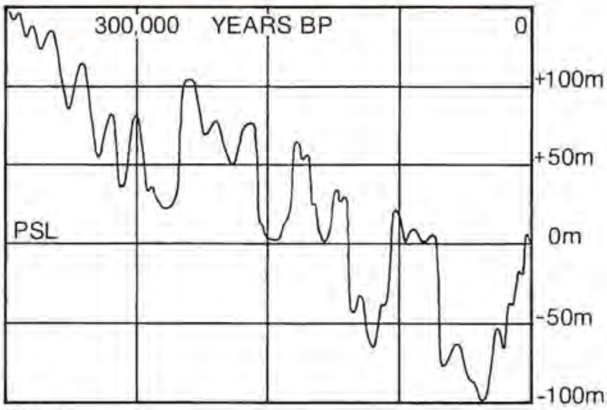


FIG. 2
Position of sea level over last 300,000 years.

Quaternary Ice Ages

One of the major causes of a change in sea level is an **ice age**. During an ice age or glacial period, water is locked up in snow fields and glaciers as ice and snow. As large amounts of water are involved, world sea level drops. During inter-glacial periods ice melts and sea level rises. To date there have been five major glacial periods in the Quaternary. Due to alternate locking up and releasing of water, sea level has fluctuated markedly during this time. To complicate the picture, the floor of the Pacific Ocean has been sagging since the Pliocene resulting in a steady lowering of world sea level. Thus during each successive interglacial period, sea level has failed to reach the level of the previous high (Fig. 2).

Over the past 300,000 years sea level has fluctuated from 100 m above to 100 m below present sea level (PSL) and as a result shorelines have changed markedly. The questions "Where is sea level at the moment, and what is it likely to do in the future?" must therefore be of interest. Both questions are difficult to answer. However, by studying the geological history of old beaches the effect of changing sea level on the coast becomes apparent. The information can then be used to imply the sort of changes likely to be experienced in the future.

QUATERNARY HISTORY OF THE SWAN COASTAL PLAIN

The effects of changing sea levels can be demonstrated by studying the Swan Coastal Plain. The distribution of major sedimentary units along the coastal plain is shown on Fig. 3. It is obvious that the units, in the main, parallel the present shoreline which is the first clue to their marine origin. A description of the units, starting with the oldest, gives further evidence of their marine origin.

1. **Yoganup Formation** — beach and dune sediments found on a shelf along the Whicher and Darling Scarps at elevations of 35-50 m above PSL.
2. **Bassendean Sand** — widespread quartz dune sands found at elevations of 8-25 m above PSL.
3. **Tamala Limestone** — dune limestone (known as Coastal Limestone or Spearwood Dunes) found along the west and south coasts.
4. **Quindalup Dune Formation** — sands and dunes recently formed or forming along the coast today.

In order to determine the history of these sediments, three things must be borne in mind:

i) world sea level has been dropping since the Pliocene;
ii) world sea level falls during glacial periods and rises during interglacials; and
iii) because of (i) above, successive interglacial seas did not reach the level of the previous high (Fig. 2).

As a result of these sea level changes, shoreline sediments laid down during previous highs have not been eroded. By correlating the position of the sediments with world sea level curves a history of the coastal plain can be determined.

Yoganup sea level

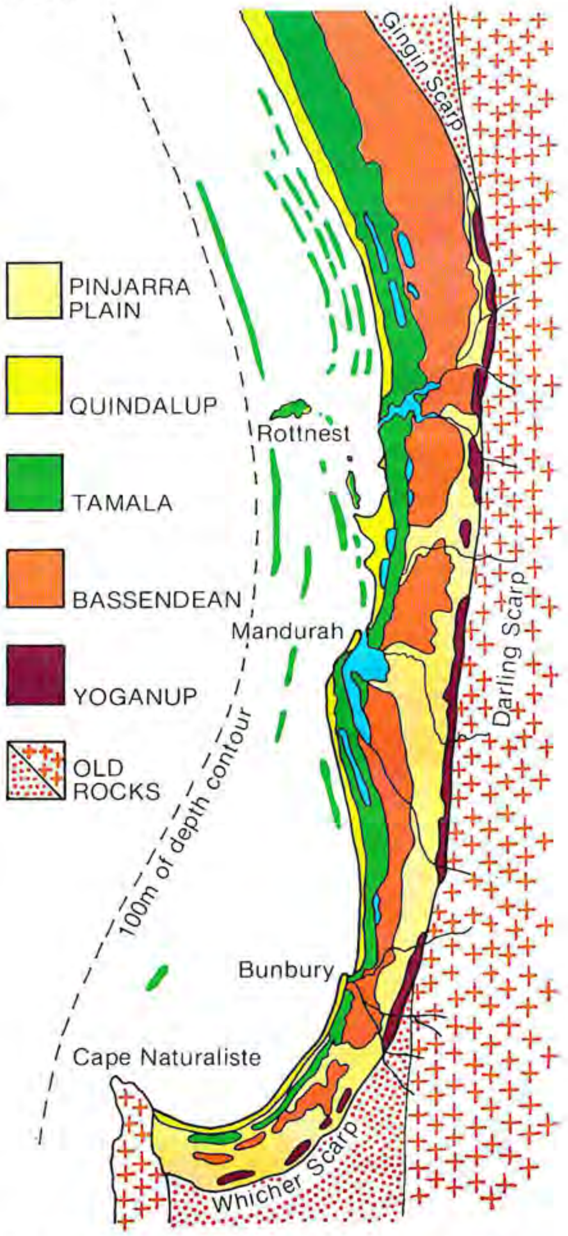
Several hundred thousand years ago, possibly during the interglacial period around 175,000 years ago Yoganup sediments were deposited on a shelf cut into older sediments and rocks at levels 35-50 m above PSL (Figures 2 and 4). At this time the shoreline lay at the base of the Darling Range. It appears that sea level then dropped, reaching its present level by about 150,000 years BP. A wide expanse of the coastal plain was exposed as a result.

Bassendean sea level

The sea then rose to +25 m by 140,000 BP and large areas of the plain were again drowned. Seagrasses and carbonate shelled organisms colonised the seafloor as is the case today. Shelly material forming on the shelf was mixed with quartzose material derived from underlying older quartz-rich sediments and piled up into dunes. As sea level fluctuated around the high, mixed sediment was brought ashore with different sea level stands being represented by lines of dune ridges separated by lakes or swamps (Figures 2 and 4). These old strand lines are now the dunes of the Bassendean Sand.

During the following glaciation about 120,000 years ago, the sea again retreated. A wide expanse of coastal plain was exposed and leaching of shelly material in the dunes took place leaving white quartz sand that is characteristic of the Bassendean Sand today.

FIG. 3



Distribution of Quaternary sediments on the Swan Coastal Plain (McArthur and Bettenay, 1974).

Tamala sea level

With return of the sea around 100,000 years ago the recently drowned plain again became colonised by seagrasses and carbonate shelled marine organisms.

It is probable that sea level fluctuated around the high as shelly sediments were moved on shore. As a result the Tamala dune system consists of a series of parallel limestone dune ridges some lying to the east of today's coast and others lying to the west. This indicates that there were great movements of the shore this time, with smaller scale sea level fluctuations superimposed on the major high (Figs. 2 and 4).

During the most recent glaciation, occurring between 60,000 and 25,000 years BP the shoreline retreated beyond Rottnest and the coastal plain was again subject to exposure and weathering. Leaching of the newly deposited dunes took place resulting in a layer of yellow quartz sand over unleached Tamala Limestone below. Cementation of the underlying limestone into hard capstone and pinnacles, and formation of caves at Yanchep and Yallingup, took place at this time.

Holocene - Recent sea level

Around 20,000 years ago the sea level again began to rise and the shoreline retreated. Many of the ridges of Tamala Limestone were drowned forming the lines of islands and reefs along the west coast. The sea rose to about its present level around 6,000 years ago cutting off Rottnest, Garden Island and the Abrolhos from the mainland. Again sea depths were conducive to colonisation by seagrass and marine organisms. Limestone material, forming on the shelf, was brought ashore to contribute to the Quindalup dune system. Sea levels fluctuated and as a result, waves of sediment were brought ashore forming the loosely cemented dune ridges common along the west coast.

The Busselton coast is composed entirely of Quindalup dunes whereas further to the north, Quindalup sands form the beaches and dunes between cliffs and reefs of Tamala Limestone. Where offshore islands protect coastal waters, Quindalup sands have been concentrated behind them as dunes, sand ridges, spits and tombolos. Rockingham, Warnbro, Cervantes and Jurien Bay are all built on Quindalup sands which accumulated during the last 6,000 years. In some places the generation of Quindalup sediments is still occurring today. The sand bar at Dunsborough and the sand spit at Penguin Island are evidence that new sediment is still coming ashore at these places. How long this will last however is not clear. It does appear that major onshore movement of sediments has slowed if not ceased along most of the coast with the result that erosion and not accretion may dominate in future.

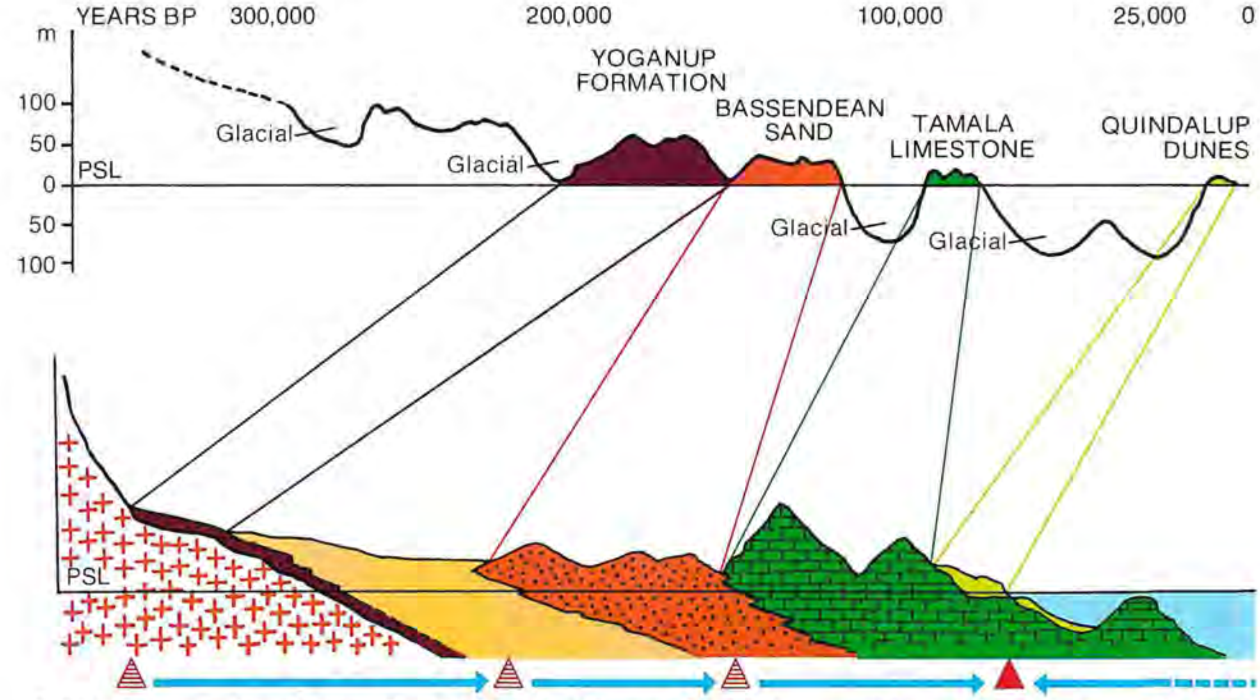


FIG. 4 Cross section of Swan Coastal Plain, looking south, showing possible correlation between the Quaternary sediments and the sea level curve. Note that the shoreline position has been displaced westward.

CONCLUSION

As yet it is not possible to correlate with confidence the sediments of the Swan Coastal Plain with the world sea level curve. However, the above brief history, which is one possibility, illustrates the effect of relative sea level movements on shoreline position. As described, the shore lay along the base of the Darling and Whicher Scarps around 200,000 years ago whereas only 25,000 years ago, it was several kilometres west of Rottnest Island. In many areas of Western Australia, records of high sea level stands have not been preserved as well as on the west coast, although the sea level rises and falls affected the whole coastline. The message however is clear.

Coastal planners need to be aware that sea level changes can cause major movements in shoreline position and vast changes in the amount of sediment being supplied to the coast. In Western Australia the west coast has been building out westward in response to a steady or gradually falling world sea level. Whether the trend continues in the short or long term is debatable.

Only by appreciating that the sands and dunes of today's coast are a most recent veneer, partly covering older dune deposits, do we realise that the shoreline is ephemeral. The present position can be seen as only recently achieved - hence temporarily stable. This is specially so when there is evidence that seas can vary several hundred metres above or below present levels. People can do nothing to alter the vast processes operating. All that can be done is to plan around them.

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COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION & ENVIRONMENT

BULLETIN NO 49

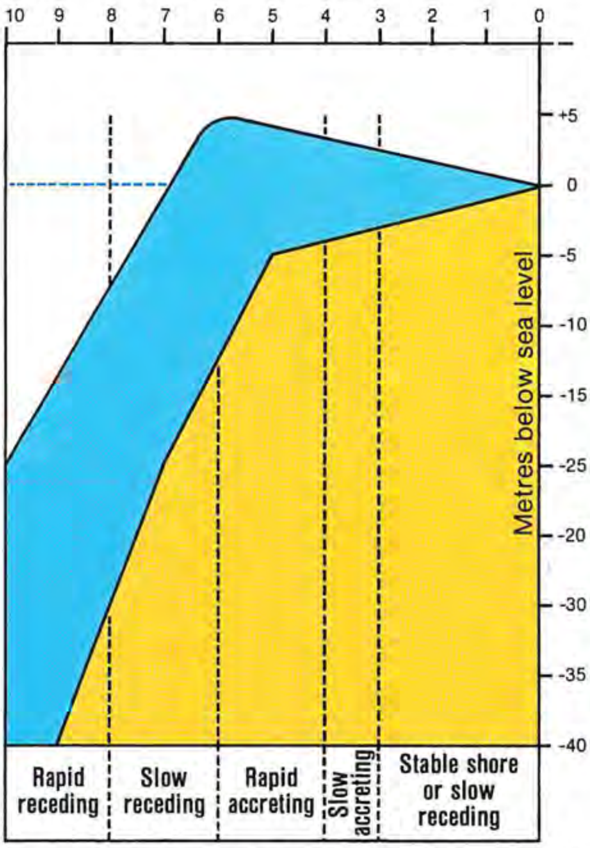
NO 9

COASTAL CHANGES (PART III)
SHORELINE DEVELOPMENT OVER THE LAST 10,000 YEARS

INTRODUCTION

This pamphlet describes shoreline changes that have taken place during the Holocene Period, spanning the last 10,000 years of the earth's history. The present coastline, including the coastal landforms of the Quindalup Dune System, have all developed in this geologically brief period. Changes described here have taken, and are taking, hundreds of years to complete. They are beyond the scope of engineering control but profoundly influence utilisation of the Quindalup dunes and beaches.

FIG. 1 Thousands of years*B.P.



Generalised relationship between sea level over the past 10,000 years, and the pattern of shoreline change. The shaded area covers a range of sea level estimates. Sea level rose rapidly until about 6,500 years ago as the glaciers melted; during this period shorelines receded. This tendency slowed and about 5,000 years ago, with sea level at approximately its present height, the coast began a period of rapid growth. Beach ridges continued to prograde until about 3,000 years ago. Since that time either a large foredune has developed behind the beach or most ridges have been eroded by wave and wind processes (After Thom, 1974).

* BP = Before Present

SEA LEVEL CHANGE AND SAND SUPPLY

The general response of Australian shorelines to Holocene sea level changes is now well established from studies of dune landforms, their geology, soils and vegetation. Sea level rose from 100 m below its present level after the last ice age ended some 20,000 years ago. It reached its present position approximately 6,000 years BP and since that time has remained fairly steady, although with some minor oscillations (Fig. 1).

Shoreline changes have followed the sea level shifts. The shoreline retreated as the sea level rose and stabilised as sea level steadied. Several phases of shoreline development are recognised within this broad trend (Fig. 1):

10,000-8,000 years BP - sea level rose rapidly, drowning the coastal plain and the old dunes of Tamala Limestone. As the seas rose, the shoreline retreated.

8,000-6,000 years BP - sea level rose and shoreline retreat slowed. With seas near their present level, large amounts of sediment were swept in from offshore and the coast began a phase of rapid accretion.

6,000-4,000 years BP - beach ridges were formed along much of the coast as sediments were swept ashore and shorelines advanced. In some instances embayments and river mouths were cut off; in others the ridges were superimposed on older Tamala dunes. Where embayments became blocked, river borne sediments became trapped in the estuaries that developed. Large amounts of sediment became locked up in dunes and ridges.

4,000-3,000 years BP - major dune building phase as sand was blown into dunes or inland as blowouts. Overall there was net loss of sediment from the beach zone with river borne sediments trapped in estuaries and diminishing amounts coming from offshore. Shoreline advance slowed.

3,000-present - with supply of offshore sediment nearly exhausted, shoreline advance in many areas ceased. Active blowouts continued to move landwards, e.g. Esperance, Mullaloo and Geraldton. The tendency for beach erosion increased as any sand lost inland could not be replaced by sand from offshore.

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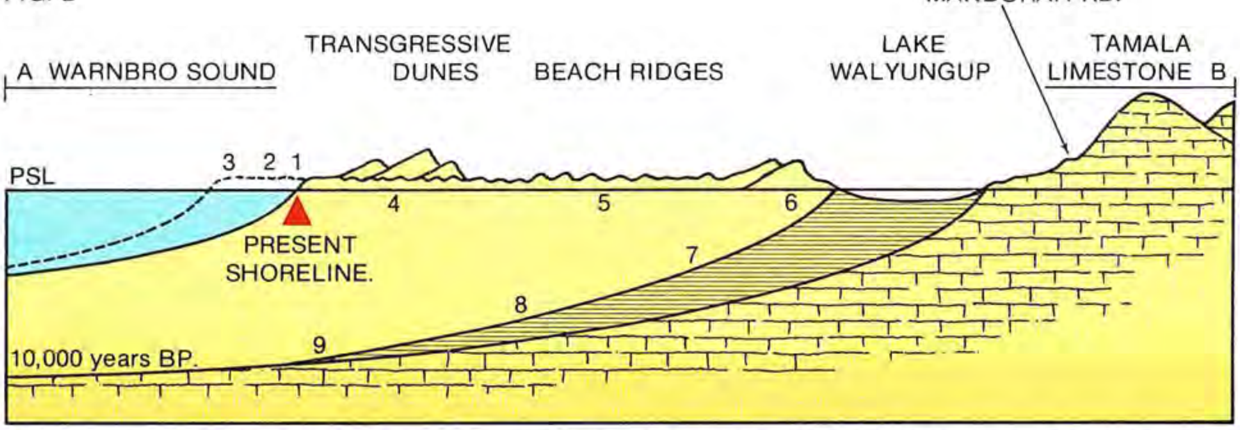
HOLOCENE HISTORY AT WARNBRO SOUND

The effect of a changing supply of sand to the West Coast of Western Australia can be seen at Warnbro Sound (Figs. 2 and 3).

Around 10,000 years ago with seas rising from well below their present level, the shoreline began its retreat. Around 6,000 years BP with the sea at its present position, the shore lay along the line of the Mandurah Road at the base of an old Tamala Limestone dune. With abundant supplies of sand available from offshore, a series of beach ridges built out toward the offshore islands and reefs. As a result the shoreline advanced some 4 km during the next several thousand years. Shoreline advance slowed as offshore sand supplies diminished. Remobilisation of beach ridge sediments led to landward movement of sand in blowouts or transgressive dunes which covered the older beach ridges. This loss of sediment from the beach was not countered by offshore sediments and as a result the coast began to erode. Today the beach is very narrow and is backed by steep transgressive dunes - typical of a beach which is in a steady or eroding state.

The effect of changing sand supplies can be seen at many other places along the coast. The dunes at Busselton and Quindalup; the tombolos at Point Peron, Cervantes, Jurien Bay and Geraldton; and the dune ridges and sandy beaches along most of our coast all formed during the last 6,000 years. Since their formation however, with sand held beneath vegetation and with diminishing sediment available from offshore, the likelihood of further beach buildup and shoreline advance is unlikely. Rather, the tendency for erosion is more likely. This is already evident along much of our coast, e.g. at Busselton, Mandurah, Becher Point, Metropolitan Coast, etc., where erosion of coastal land has already taken place.

FIG. 2



Cross section of Warnbro Sound area showing development of coast during this time and probable position of shoreline over past 10,000 years (cf. Fig. 3). 9 = shoreline at 9,000 years before present (BP.)
PSL = Present sea level

FIG. 3 Aerial photograph of Warnbro Sound area.

CONCLUSION

The fact that some of our beaches have ceased to accrete and are therefore liable to erosion in the long term must be of interest to anyone who intends to use or develop any part of the coast. New suburbs at Rockingham, Warnbro, Peelhurst, Busselton, Quindalup, Jurien Bay, Cervantes, Geraldton and along the Metropolitan Coast have been built on beach ridge and dune deposits which were formed during the last 6,000 years under conditions of sediment accumulation. The source of sediments was the drowned Continental Shelf which extends beneath the present seas to a depth of 100 m. This is extremely significant as it means that parts of our coast which built out during the Holocene could now be liable to long term erosion. This point must be taken into consideration by anyone planning to use the coast for an extended number of years.

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COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION & ENVIRONMENT

BULLETIN NO 49

NO 10

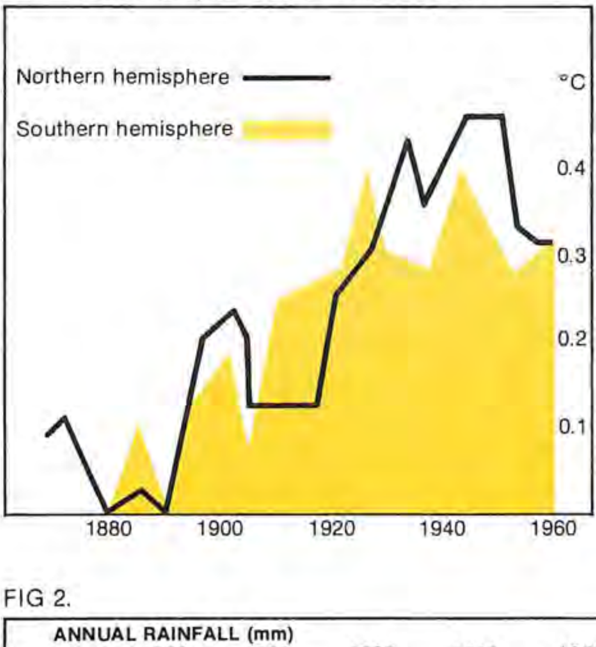
COASTAL CHANGES (PART IV)
SHORELINE MOVEMENT DUE TO LONG TERM CLIMATIC CHANGES

INTRODUCTION

During the last 6,000 years, sea level has been relatively stable. Sediment supply from the Shelf has slowed considerably and other factors which affect shoreline movement have become evident.

Climate has a major influence on the position of the shoreline. The coast of Western Australia is subject to prevailing calm conditions which are interrupted by infrequent storms or cyclones. During these intermittent episodes, beaches erode and shorelines move landward. Thus a climatic change to more frequent storms will result in greater potential for coastal erosion causing the shoreline to move landward. Conversely when storms become less frequent, erosive episodes will be fewer and the coast has a chance to accrete and prograde seawards. This pamphlet deals with shoreline movements which have taken place over the last 6,000 years and which appear to have been a result of long term changes in climate.

FIG 1. World temperature curve since 1880



LONG TERM CLIMATIC CHANGES

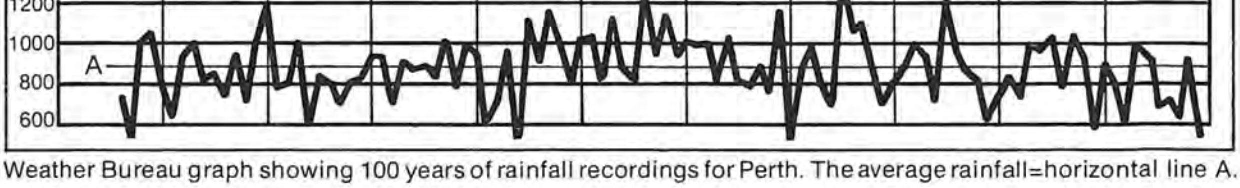
Within recorded history there is evidence that the earth's climate has been through a number of cycles. In the southern hemisphere it is thought that the Polynesians were able to sail the Pacific Ocean because it was much calmer than it is today. Evidence also suggests that the world has been warmer, or colder than at present, e.g. agriculture was practised in Greenland a thousand years ago, and the Thames at London last froze over in the 1850s.

There is clear historical evidence that climates of parts of the earth and possibly the earth as a whole, undergo change. The mechanism which causes these long term climatic changes is not clear though there seems to be a correlation with sunspot activity cycles.

Sunspot activity which appears to be affected by the alignment of the planets undergoes a basic 11 year cycle, a 22 year Hale cycle, a 44 year Double Hale cycle and other longer cycles related to conjunction of the planets.

Changes in climate can be seen in rainfall figures, frequency of cyclones or severe winter storms, spacing of drought years and temperature records (Fig. 1). There is evidence in Western Australia that there are changes in the climatic record (Fig. 2) and the effect of these changes on shoreline position can be seen in the landforms that have developed along the coast.

FIG 2.



Weather Bureau graph showing 100 years of rainfall recordings for Perth. The average rainfall=horizontal line A.

FIG. 3 Aerial photograph of Jurien Bay.

RECENT HISTORY OF THE JURIEN BAY COAST

To illustrate the changes outlined in this pamphlet, we can look at development of the coast near Jurien Bay. Jurien itself is built on a "tombolo" consisting of sandy beach ridges which built towards an offshore island during the last 6,000 years. The ridge lines mark episodes of accretion. If conditions had been constant one would expect the ridge lines to be uniform and parallel. This however is not the case (Fig. 3).

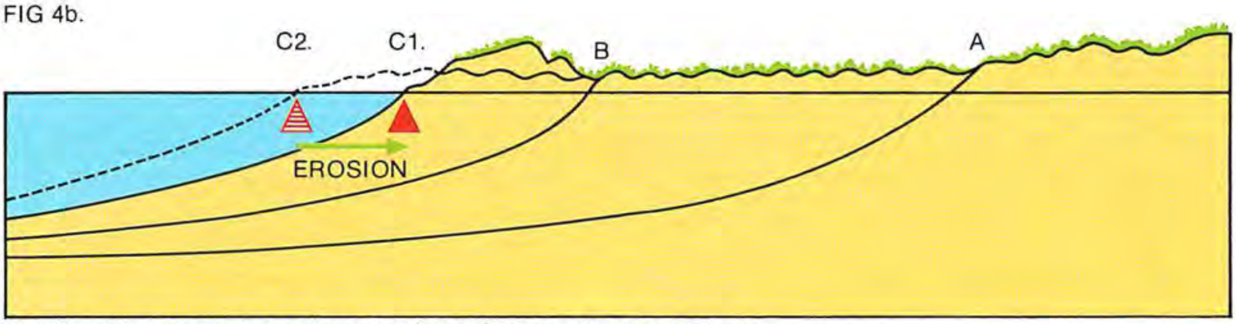
It can be seen that there are at least 5 interruptions in the accretionary record. First the dunes grew out rapidly (A-B) before being severely cut back to line C. After this the shoreline built out northward with smaller scale interruptions at D, E and F.

Another point to note is that today the northern beaches are growing while the southern beaches are eroding (Fig. 4a, b). Even in the last 100 years the northern shore has advanced over 100 m, whilst the southern shore retreated.

Within the life of this tombolo, these large scale shifts in shoreline position are possibly the result of long term climatic changes, that have varied the frequency of north west storm events along the west coast. Under prevailing calm conditions (C_1), north west storms or cyclones are rare and the tombolo will tend to erode along its southern side under the influence of south west swells and waves, whilst the "protected" northern shore builds up (i.e. C-D-E etc). Conversely, change to a climate (C_2), in which there is an increased frequency of north west storm events, will cause the northern beaches to erode.

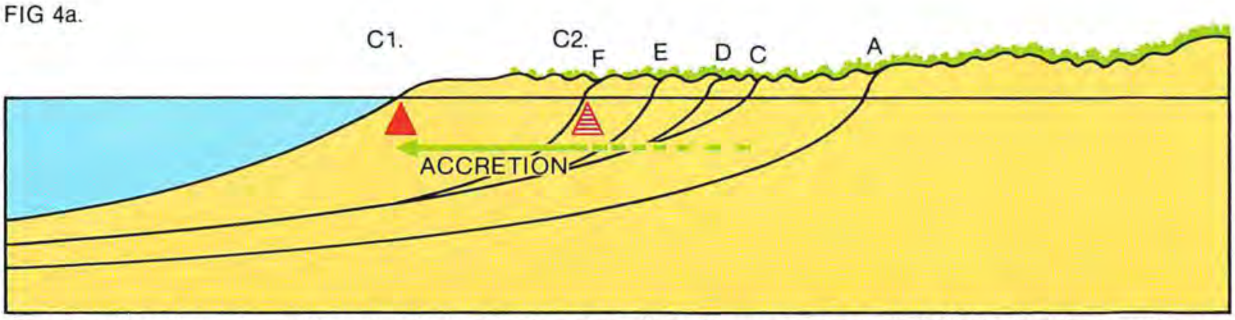
It appears that the climate has changed dramatically during the growth of this tombolo. The massive erosion back to line C implies a stormy climate, whereas the northward advance of the tombolo up till the present, suggests that there has been a change to calmer conditions. By comparing the size of the Jurien township to the massive scale of erosion, the implications of a change in climate can be seen.

FIG 4b.



Cross section through southern tombolo showing shoreline retreat.

FIG 4a.



Cross section through northern tombolo showing shoreline advance under 'calm' (C1.) climatic conditions.

There are many other places along the coast where marked changes in shoreline have taken place since settlement in 1829. At Mandurah, for example, a road situated on dunes has recently been eroded. Old fences have been found within the dunes beneath, indicating that prior to the present erosion phase, an accretion or dune building phase must have taken place after the fence was built. Likewise at Busselton and along the Metropolitan Coast, parts of the shore that accreted and were built on, are now eroding. Possibly these changes are also due to variations in climate which influenced the amount of sediment coming ashore or leaving an area.

CONCLUSION

This pamphlet points out how unreliable the present sandy shoreline and its foredune system is as a guide to its position over an extended period, although sea level is now relatively steady. Other factors, such as climate, have an influence on coastal processes. As climate itself is subject to long term trends, marked changes to shoreline position and shape are still taking place.

Coastal planners and managers must take note that although a particular part of the shore has been accreting for a number of years there is no guarantee that it will always continue to do so. Rather a reversal is more likely as supplies of sand or the climate undergo changes. Research is often necessary to establish the nature of the changes taking place.

By appreciating that the beaches and dunes of today's coast are not fixed and that the coast is subject to long term periods of erosion or accretion, the chance of using the coast successfully can be increased. Even though changes in beach shape and position may seem slow, the same change could be quite appreciable if one is planning engineering works along the coast, or developments on low lying beach ridge land, where projects have anticipated lives of many decades.

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COASTAL MANAGEMENT IN WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION & ENVIRONMENT

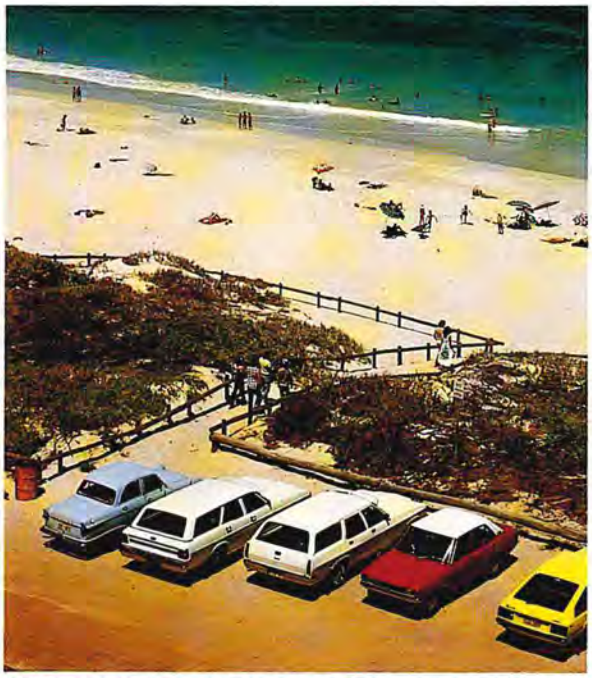
BULLETIN NO 49

NO 11

COASTAL CHANGES (PART V)
SHORELINE MOVEMENTS DUE TO SHORT TERM STORM EVENTS

INTRODUCTION

This pamphlet deals with shoreline changes that can be seen every year. Once again, Man has little control over the processes operating but he can minimise his chance of conflict with these processes if he is aware of them and how they affect the coast.



Wide sandy beach formed under swell conditions.

THE BEACH SAND CYCLE

Perhaps one of the most important points to appreciate when dealing with a sandy coast is that there is a beach sand cycle. Around the coast of Western Australia beaches commonly build up in summer in response to generally calm conditions when the prevailing south westerly swell generated in the Roaring Forties south of the continent is the dominant force. This condition is interrupted by summer cyclones or winter storms which generate wind waves that erode the shore. As a result of these changes in weather the shoreline retreats after a storm, but advances during the calm period that follows.

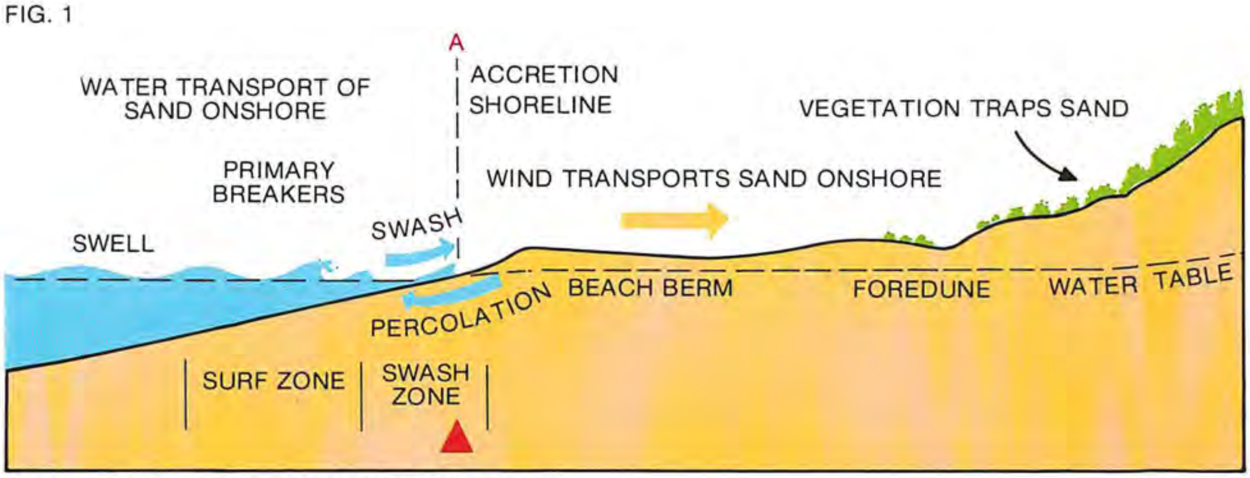
Accretion or Calm Phase

During most of the year, the west and south west coasts of Western Australia are subject to long westerly swells which break along the coast as the water becomes shallow. The resulting swash rushes up the beach carrying sand with it.

As there is sufficient time between each swell most of the water returns seaward by percolating through the beach sand. As a result backwash is minimal and the net movement of sand is landward.

Once sand has been brought ashore, onshore winds often combine to blow grains up the beach to where they are trapped by vegetation forming dunes behind the beach (Fig. 1).

FIG. 1



Beach under accretion phase: berm-type profile.

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Erosion or Storm Phase

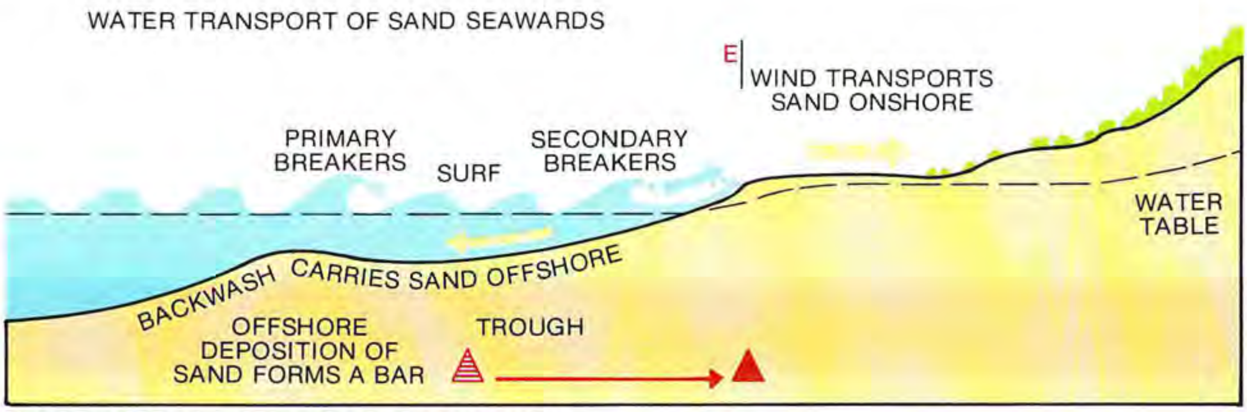
Under storm conditions high energy waves arriving in quick succession saturate the beach, and water unable to percolate through the sand returns as a strong backwash. Onshore winds and low barometric conditions combine with storm waves to pile water up against the coast. This is referred to as storm surge.

The onshore movement of water is countered by rips and currents which flow offshore. At such times beach sand is easily moved seaward. As a result the net movement of sand is offshore with sand being deposited in deeper waters where conditions are relatively quiet (Fig. 2). Storm waves dissipate their energy in moving beach sand to the offshore bar and then in crossing the bar (Fig. 3). Erosion of the beach will continue until the storm peaks.

Changes to the Beach Sand Cycle

Under the influence of intermittent stormy periods, a sandy shoreline oscillates between two positions - a calm (accretion) shoreline which is found at the edge of a wide beach and a storm (erosion) shoreline which is at the base of the foredune. These two conditions are characterised by berm and bar type profiles respectively (Figs. 1 and 2).

FIG. 2



Beach under early erosion phase: bar-type profile.

IMPORTANCE OF VEGETATION IN THE CYCLE

In order to keep sand available to the beach system, it must be held in an accessible form. Vegetation prevents sand from being blown inland whilst it also allows its release during a storm.

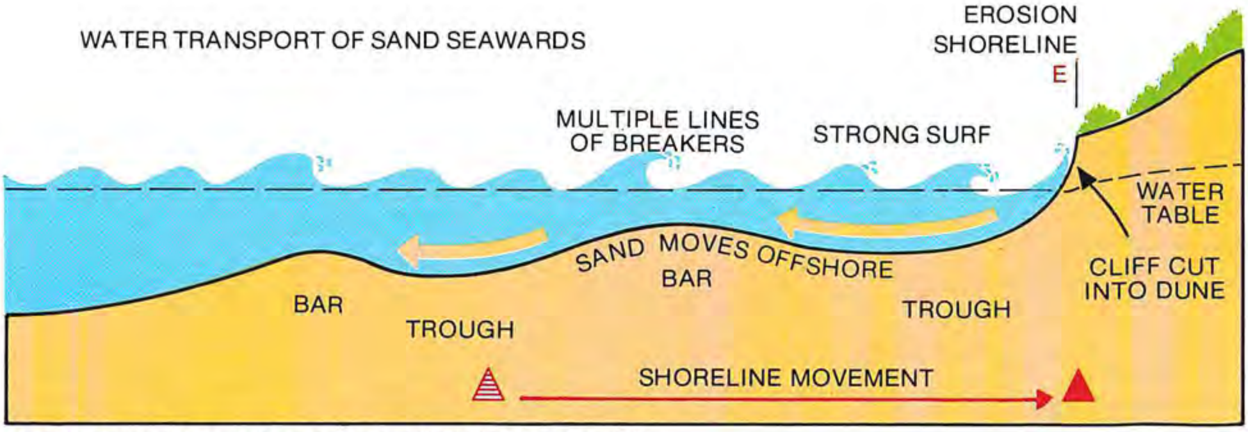
As shown in Figure 1 sand is brought ashore by swells and then blown up the beach where it is trapped in dunes. The dune sand is held in reserve for storm events. Without the presence of vegetation to trap and hold, sand would be blown further inland resulting in a two-fold problem:

i) As sand blows inland it overwhelms vegetation and mobile dunes form. These may overrun nearby roads, carparks and buildings resulting in continuous maintenance to keep facilities operational.
ii) Loss of sand from the beach and foredune system will "unbalance" the beach sand cycle as this sand is no longer available during the erosion phase. The result is dominant erosion and continuing retreat of the shoreline.

In order to avoid these problems it is necessary to maintain a well vegetated dune system so that sand is prevented from moving inland which in turn enables beach recovery following an erosion event.

A narrow beach and dune cliff formed during a storm event.

FIG. 3



Beach under late erosion phase: multiple bar-type profile.

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CONCLUSION

This pamphlet shows that the shoreline can move markedly due to variations in weather.

The present shoreline position on a sandy coast is a temporary feature. Planners and developers should be aware of:

i) the mobility of the shoreline which results from the beach sand cycle; and

ii) the role of dunes and their vegetation.

By appreciating that a rough balance exists between erosion and accretion and that this balance relies upon available supplies of sand, the importance of vegetation and dunes becomes clear. Planning or using a coast in a way that disturbs dunes and vegetation will alter the balance with the result that a more permanent change in shoreline position is likely to occur.

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COASTAL MANAGEMENT
IN WESTERN AUSTRALIA

DEPARTMENT OF CONSERVATION & ENVIRONMENT

BULLETIN NO 49

NO 12

COASTAL CHANGES (PART VI)
IMPLICATIONS FOR COASTAL PLANNERS AND MANAGERS

INTRODUCTION

As outlined in the last five pamphlets, the position of the shoreline is quite changeable both within the short term and the long term. This factor is of critical importance to coastal planners and managers who make decisions on coastal use.

LONG TERM SHORELINE CHANGES

Within the last 300,000 years world sea level has fluctuated so that the west coast of Western Australia has been located at various times between the base of the Darling - Whicher - Gingin Scarps (Dunsborough - Yoganup - Waroona - Gingin - Eneabba) and the 100m depth contour which lies many kilometres west of Rottnest (Fig.1).

Over the last 6,000 years the sea level has remained relatively stable. Even within this geologically short time, there have been marked changes in shoreline position at several places along the Western Australian coast. South of Garden Island, the shore built out 7km from the Mandurah Road. At Busselton and Quindalup, the dunes beneath the townsites were deposited and at Cervantes, Jurien Bay and Geraldton, tombolos built out several kilometres toward offshore islands and reefs. Along the rest of the coast, however, shoreline movement has been less dramatic.

The thin veneer of Quindalup dunes upon which much of our coastal housing, industry, roads, surfclubs, etc., are located, was deposited during the 6,000 years and evidence suggests that factors which led to its deposition may no longer be operating. As a result, the coast as we know it may be more susceptible to erosion than in the past, and a long term erosion trend is not out of the question. Thus anything done by a coastal manager to increase the likelihood of the coast to erode is unlikely to be countered by natural processes.

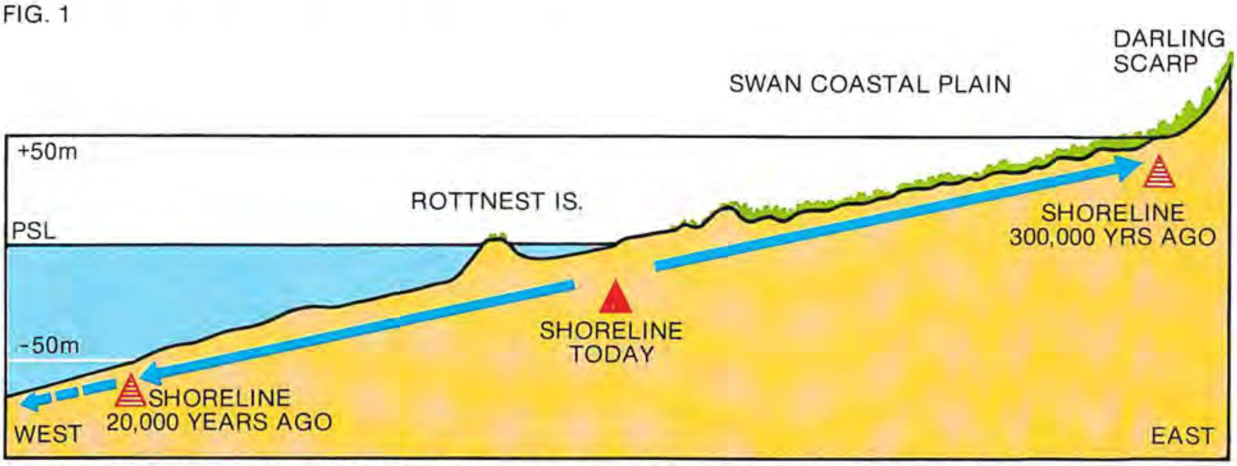
MEDIUM SCALE CHANGES

Closer observation of the Quindalup sediments reveals that their deposition was not straightforward. The pattern of dune ridges indicates that changes which affected rates of erosion or accretion have been operating over the last 6,000 years. These changes can be attributed to long term trends in climate which have altered the frequency of winter storms, summer cyclones and calm periods.

SHORT TERM CHANGES

Observation of a sandy beach reveals that erosion following a storm or cyclone is usually made up in the calm period that follows when the beach builts back to its previous position and shape. Short term changes in shoreline position can be seen every year.

FIG. 1



Cross section of Swan Coastal Plain showing the shoreline position over the last 300,000 years.

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IMPORTANCE OF BEACH CHANGES

By taking all the changes together, the mobility of the shoreline can be appreciated. Of prime importance to any coastal manager are the effects the changes will have on the coast during the life of a project. He should therefore be concerned with the effect of changes in sea level, climate and season which in turn affect the position of the shoreline and the nature of the coastal landforms.

The Western Australian coast as we know it is a young feature. It is possible that the land has not yet fully adjusted to the effect of the sea level rise over the last 20,000 years and as a result the shoreline could still be liable to further movements in the long term.

As set out in Pamphlet 9, there is evidence that under the present conditions of stable sea level, offshore sand supply is diminishing along most of our coast with the result that the Quindalup veneer may increasingly become subject to erosion.

As detailed in Pamphlets 10 and 11, long and short term changes in climate effect shoreline position. The combined effect of seasonal cycles on the longer term climatic changes is of vital importance to coastal managers, as these changes will take place within the life of almost any planned use of the coast.

In planning a coast, the combined effect of the various scales of change which affect shoreline position and its stability become very relevant.

IDEALISED BEACHES AND RELEVANCE OF CHANGES

As there is nothing that can be done about sea level, climate or storm events and the resulting shoreline movements, coastal planning decisions must take these factors into account. Three examples can be used to illustrate the relevance of the changes:

1. **Rocky coast** with hard cliffs and small sandy beaches. Here the impact of medium scale changes and storm patterns is unlikely to alter shoreline position to any great extent. Decisions relating to shoreline stability are therefore relatively unimportant.

2. **Sandy coast** with rocky headlands and islands. Here the impact of changing patterns of erosion and accretion is greater. In calm periods, sand may accumulate between headlands or built out towards islands forming tombolos. During stormy years, erosion may remove much of the foredune system and alter the shape of tombolos. Planning decisions must therefore take into account the greater potential mobility of the sandy shoreline and the importance of dune vegetation in holding sand in reserve.

3. **Sandy coast**. Here storms and erosion cycles have the greatest impact. Without protection behind headlands or islands, a sandy coast is liable to large scale erosion during stormy years. Planning decisions must take into account the fact that such a coast is probably relatively young and has built up in response to an accretion phase which evidence suggests is possibly complete. Once erosion does start, there is little to stop it. Maintaining the beach sand cycle in equilibrium becomes very important, as any change to the cycle is unlikely to be reversed by nature. Preservation of the dunes and their vegetation is important in facilitating beach recovery following storm onset and beach erosion. Any sandy coast has a high potential to erode and any planned use of nearshore land must take this into account.

FIG. 2. Position of shoreline over last 50 years for an idealised coast subject to storm events and long term climatic change. Long term climatic change — C_1, C_2, C_3. (refer Figs. 3 and 4a, 4b).

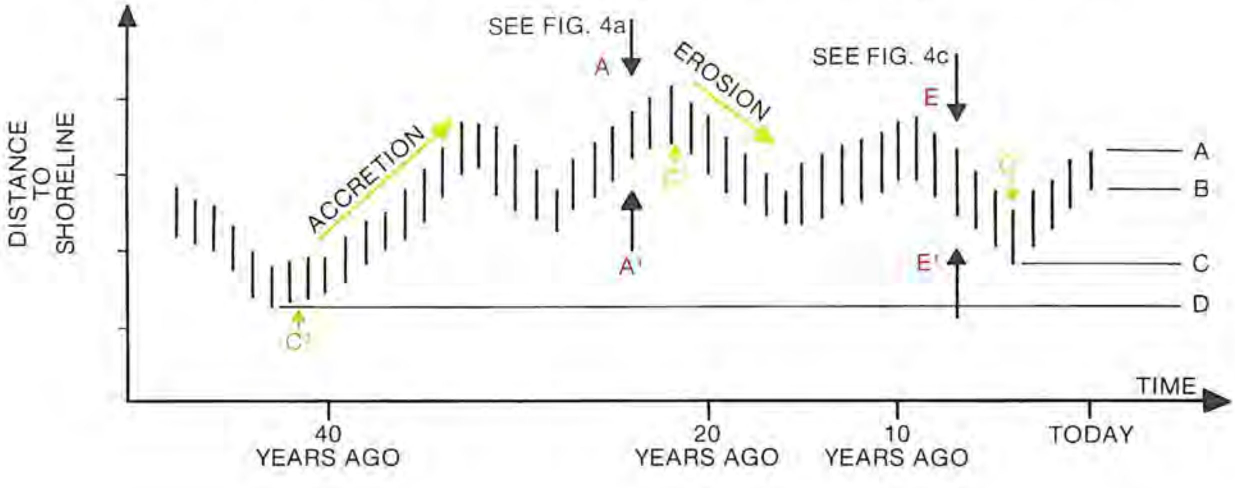


Figure 2 shows the changing shoreline position of an idealised sandy coast which is affected by storm events and long climatic changes.

Figure 3 is a cross section of the same coast and shows:

i) the seaward extent of the annual beach plants which marks the limit of the last storm event (Point B);
ii) the foredune that accreted over the last four years (B-C) which is colonised by sand trapping plants;
iii) the dunes (C-D) which are colonised by plants and bushes that have been established for many years; and
iv) dunes colonised by trees which have been in place many years.

Cross sections of the beach and dune while the coast is accreting or eroding are shown in Figures 4a and 4b. These show that accreting beaches are flat and wide and are backed by one or more foredunes whereas eroding beaches are narrow and steep and lack foredunes.

Any decision to use part of this hypothetical coast must be made in the light of its erosion potential. Decisions must also take into account the effect development itself will have on the natural processes. By taking these factors into consideration, the chance of choosing a location or contributing to coastal erosion, either of which would subject a development to risk, can be avoided.

Given the past movement of this coast, it would obviously be unwise to plan permanent development on land A-B as it will in all probability be eroded during the next storm. It would also be unwise to build on land B-C as this was eroded only four years ago and could be subject to erosion in the future. Land C-D which from human memory might appear safe could be subjected to erosion in the longer term under different climatic conditions (i.e. eroded around 40 years ago).

Using this simplified example as a guide, the value of setting back permanent developments can be appreciated. Major roads, housing and industry would be better located behind D, whilst beach access roads, carparks and less expensive and non permanent buildings could be located on land C-D. If any structures are planned in C-D they should be considered expendible in the long term. Given the high erosion potential of land B-C only temporary structures such as fenced pathways to protect the fragile dune system should be contemplated.

Although many beaches will not show such a clear pattern as the example, the principle of establishing erosion potential and set backs on a sandy coast should be followed.

Fig. 4a

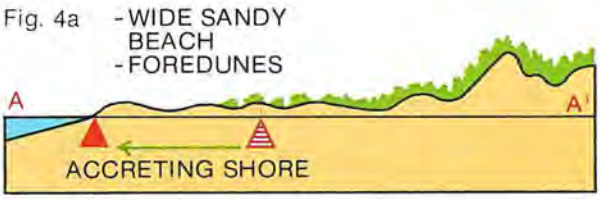
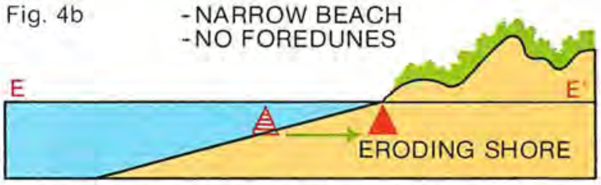
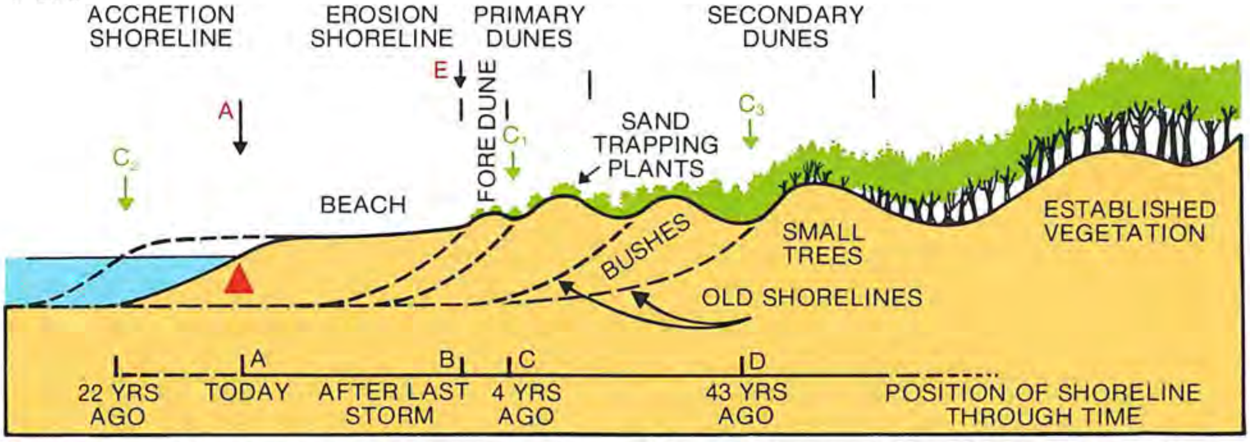


Fig. 4b



(a & b) Cross sections of the coast following several years of accretion, or erosion (refer Fig. 2).

FIG. 3



Cross section of the idealised coast showing positions of the shoreline over the past 50 years. (refer Fig. 2)

CONCLUSION

The position of the Western Australian shoreline will move naturally in response to changes in sea level, climate, sand supply or storm events. The effect of past shoreline change can be appreciated by studying the coast, its shape and landforms. For the coastal manager, the fact that the shoreline does move should be of great significance as near shore developments could be subject to erosion in both the short or long term.

Some coasts are far more susceptible to erosion than others and a study of a particular shore will reveal its erosion potential.

In deciding to use a particular piece of coast for an extended period, the fact that the shoreline could move significantly must be appreciated. A use which contributes to loss of sand from the beach is unlikely to be countered by natural processes in the long term. Likewise beaches which accreted over the last 6,000 years are not likely to continue accreting in the long term as sand supply from the offshore continental shelf diminishes.

Many of our beaches are subject to phases of erosion and accretion linked to long term climatic trends. Before developing a near shore area, it is necessary to understand the history of the coast so that predictions on its possible future movement can be made. Coastal planners and managers should therefore determine:

i) the prevailing wind, wave and current conditions;
ii) the role of hard points in controlling beach shape;
iii) the effect of storm events on beach shape;
iv) the sedimentary history of the dunes and beach ridges behind the beach; and
v) the potential effect of sustained erosion on the position of the shoreline.

By doing this the coast can be classified according to its erosion potential, and the siting of developments in a position where they are likely to be eroded, or where they affect the beach system, can be avoided.

When dealing with a sandy coast, subject to the forces of wind and sea, the following should be considered when areas are being allocated for development.

1. Any planned use of a beach should leave sufficient space in front of permanent structures to ensure that shoreline movements, resulting from seasonal or climatic changes, can proceed without interference. This means that expensive and permanent buildings, roads, etc., should not be located on dunes which could be subject to erosion during storms or longer term erosion phases.
2. The primary dune and its vegetation should be preserved and maintained, so that sand is trapped during the accretion phase and is available during the erosion phase of the beach sand cycle. This means that sand in the primary dune should not be removed or "locked up" beneath buildings and roads.
3. The beach sand cycle should be interfered with as little as possible to prevent the erosion cycle becoming dominant. This means that access through the primary dunes must be controlled so that vegetation remains intact and sand is effectively trapped.
4. It must be recognised that if enough space is not left between developments and the limit of erosion, then without expensive protection, maintenance and restoration works, loss of the developments is likely to occur. In other words, correct siting of developments is often by far the cheapest way of using a sandy coast.

FURTHER READING

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