Journal of Coastal Research	12	3	761–773	Fort Lauderdale, Florida	Summer 1996

Shoreline Salients, Cuspate Forelands and Tombolos on the Coast of Western Australia

Peta G. Sanderson and Ian Eliot

Department of Geography
The University of Western Australia
Nedlands 6009, Western Australia
Australia

ABSTRACT

SANDERSON, P.G. and ELIOT, I., 1995. Shoreline Salients, Cuspate Forelands and Tombolos on the Coast of Western Australia. *Journal of Coastal Research,* 12(3), 761–773. Fort Lauderdale (Florida), ISSN 0749-0208.

Shoreline salients, cuspate forelands and tombolos on the Coast of Western Australia were examined photogrammetrically to determine the suite of landforms that comprised the structures and whether there were regional differences in their geometries. Aerial photographs from three regions were examined, including the South Coast, from Cape Arid to Esperance; the Central West Coast, between Guilderton and Dongara; and the Ningaloo Coast, from Point Cloates to Exmouth.

The landforms were broadly classified according to morphological and genetic criteria, such as growth mechanism, degree of mobility, contemporary activity/processes, main processes involved in the supply of material, sources of supply, conditions of wave regime and stage of development. Second, morphometric information was taken directly from the aerial photographs. Following work reported by SILVESTER and HSU (1993), this was analysed to determine the constant and exponential values in the curvilinear relationship between the length of the offshore structure relative to its distance offshore and the difference between offshore distance and the ratio of salient protrusion to island length. Separate graphs have been compiled for all observations from Western Australia as well as for each region to indicate geographic differences. An examination of the geometric differences between each coastal region was undertaken using analysis of variance techniques. At the 5% significance level, the results indicated that, there are significant differences between the coastal regions for most ratios when tombolos are excluded from the data sets. Most of the South Coast forelands and tombolos are formed by the deposition of sediment resulting from the convergence of swell behind an obstacle, whereas on the Central West and Ningaloo Coasts the submerged reef provide an offshore barrier. Swell is complexly diffracted and refracted by the reefs and sediment is deposited in a less predictable manner. Flushing of lagoonal waters behind the reef either by longshore currents or offshore movement of water through breaks in the reefs appears to impede the formation of tombolos and provides an explanation for travelling versus stationary forms in the respective environments.

It has been shown that the development of these forms cannot be attributable to the length of the offshore obstacle or the distance of the obstacle offshore. Explanation of this requires further investigation of the combined oceanographic processes occurring leeward of the reef chains on the Central West Coast and on the Ningaloo Coast.

ADDITIONAL INDEX WORDS: *salient, cuspate foreland, tombolo, morphology, geometry, regional variation, Western Australia.*

INTRODUCTION

Cuspate forelands and tombolos were first described by GULLIVER (1896; 1899). Originally, the term foreland was applied to the Dungeness foreland in Britain. The term tombolo which is of Italian origin (JOHNSON, 1919), was applied to a spit of sand or shingle which joins an island to the neighbouring coast. It has since been recognised that low amplitude shoreline salients, cuspate forelands and tombolos are part of a hierarchy of coastal sedimentary landforms. Such landforms occur on the West and South Coasts of Western Australia and are common in three regions: on the Ningaloo Coast in association with an active, fringing coral reef; along the Central West Coast where semi-continuous Pleistocene reef formations shelter the shoreline; and on the South Coast in the vicinity of granitic islands (Figure 1). It was anticipated that a broad scale investigation of the shoreline features of the three regions would highlight geographical differences in the geometries of the forms and raise questions concerning the nature and intensities of processes affecting their formation.

COASTAL LANDFORMS IN WESTERN AUSTRALIA

No systematic and comprehensive study of the occurrence of salients, cuspate forelands and tombolos has been undertaken for Western Australia, although individual landforms have been described in detail. Further, there are few, if any studies of depositional landforms from the South Coast. However, a number of studies have examined sediment distribution, reef morphology and the relationship of the reef to inshore depositional features on the Rottnest Shelf between Busselton and Geraldton (SEMENIUK and JOHNSON, 1982; SEARLE, 1984; SEARLE and SEMENIUK, 1985; SEMENIUK and JOHNSON, 1985; SEMENIUK and SEARLE, 1986; COLLINS, 1988; and SEMENIUK *et al.*, 1988). They indicate that erosion

---

95144 received 23 May 1994; accepted in revision 30 May 1995.

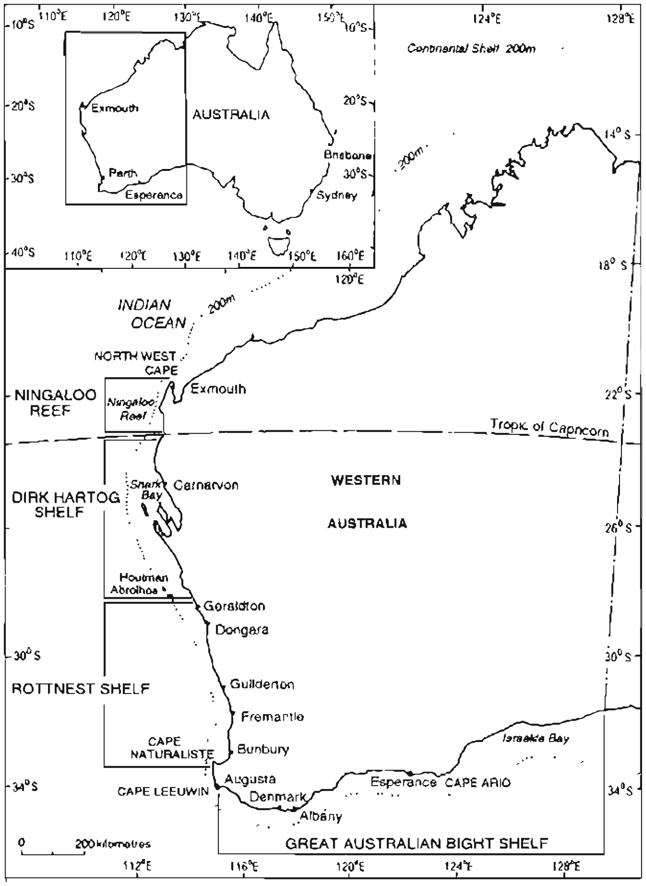


Figure 1. Regional Setting.

of reefs, particularly during the Holocene sea level rise, as well as the bioproductivity of existing reefs and seagrass banks, has substantially contributed, and continues to contribute, calcareous sandy sediment to beach and nearshore areas of the Central West Coast.

As described by SEARLE (1984) and SEMENIUK *et al.* (1988), the Central Southwestern Coast of Western Australia is protected by a broken chain of offshore reefs. The reefs dampen the effects of swell and give rise to an intricate pattern of wave refraction and diffraction in the lee of the obstacles. SEARLE (1984) concluded that Holocene sand accretion in the southwest of Western Australia has been controlled by interaction of the shelf wave climate with the complex and eroding ridge and depression bathymetry, abundant sources of sand and evolving bank structures. SEMENIUK *et al.* (1988) proposed that under the influence of prevailing southwesterly swell and wind waves, a net northward sediment transport has occurred along the exposed seaward faces of the mainland ridge and the first offshore ridge. Becher Point, a cuspate foreland on the Southwest Coast of Western Australia is discussed as forming as waves pass through the breach and impel sediment landward to form lobate submarine banks. Disruption of the swell and longshore transport by these structures caused progradation of a sandy cusp from the mainland toward the advancing bank. The mechanics of this are obscure and SILVESTER (1987) offered a counter explanation for the formation of the structure. He stated that, while some forelands may be formed by the above processes, Becher Point itself is maintained by the balance in wave energy from the south and the diffracted wave energy through the gap in the offshore reef.

Processes occurring in the Ningaloo reef system are similar to those on the Central West Coast. However their intensities are different as the oceanic and reef systems operate within different environmental settings. Headlands and zones of sediment accumulation in the Ningaloo lagoon are discussed by HEARN *et al.*, (1986). They are considered to form as a result of diffraction through breaks in the reef. Much of the energy of waves incident on the seaward reef slope is dissipated at the seaward face of the reef. However, overtopping of the reef by surf beat, wave and wind set-up and tidal activity drives water into the lagoon and establishes a lagoonal circulation. The resulting current contributes to longshore transport of sediment and usually exits the lagoon through breaks in the reef. Hence, development of cuspate forelands and salients in this region is controlled by a combination of wave generated currents, refraction and diffraction of waves, as well as by alongshore flow and large rip currents operating through breaks in the reef.

SOUTHWESTERN AUSTRALIA

Climate

Southwestern Australia encompasses a range of climatic conditions (GENTILLI, 1971) which establish a context for regional differences in depositional processes around the coast. Weather conditions in Western Australia are principally determined by movement of a belt of anticyclonic high pressure systems that move seasonally between latitudes 26°S and 45°S. Prevailing winds on the South Coast in summer are southerly to southwesterly and easterly on the Central West Coast. The Ningaloo Coast experiences quiescent weather conditions during summer but in winter the anticyclonic belt brings strong easterly to southwesterly winds. During winter, strong southerly winds on the South Coast and northwesterly to westerly winds on the Central West Coast are associated with winter storms. Strong sea breezes are experienced in summer on the South and Central West Coasts and in winter on the Ningaloo Coast.

Oceanographic Setting

Following tidal nomenclature described by DAVIES (1980), the Central West Coast and South Coast are in a microtidal environment which experiences a mixed mainly diurnal tidal regime (DEPARTMENT OF DEFENCE, 1993). Spring tidal ranges are generally less than 1.0m (Table 1). In contrast to this the Ningaloo Coast experiences meso-scale tides, with a spring tidal range at Exmouth of 1.8m (Table 1).

Incident wave energy is largely determined by the protection offered to the shore by offshore reef chains or islands. The South Coast is dominated by a persistent southwesterly swell which combines wave activity with more variable wind

Table 1 *Tidal ranges between Esperance and Exmouth*

Standard Port	Predicted Tidal Ranges (metres)					
	Neap Tides		Spring Tides		Highest Astron	
	MHLW	MLHW	MLLW	MHHW	LAT	HAT
Exmouth	1.1	1.7	0.5	2.3	0	2.8
Geraldton	0.4	0.9	0.3	1	0	1.3
Fremantle	0.7	0.7	0.5	0.9	0.1	1.3
Bunbury	0.7	0.7	0.4	0.9	0.1	1.3
Albany	0.7	0.8	0.5	1.1	0.1	1.5
Esperance	0.6	0.8	0.5	1.1	0.2	1.5

Source Department of Defence (1993)

(STEEDMAN, 1977; HEGGE, 1994). Its beaches are protected from the ocean swell by islands and the configuration of the coastline. In contrast to the South Coast, the West Coast is protected by a semi-continuous offshore reef barrier, including reefs of the Southern Rottnest Shelf, Houtman Abrolhos, the Dirk Hartog Shelf and the Ningaloo Reef System (HARRIS *et al.*, 1991). Wave energies incident on the shorelines of both the Central West Coast and the Ningaloo Coast are low due to the attenuation of incident swell wave energy by the offshore reef system (STEEDMAN and CRAIG, 1979; HEARN *et al.*, 1986).

Geology and Sediments

The South Coast of Western Australia from Cape Leeuwin to Cape Arid consists of extensive areas of Pre-Cambrian and Cambrian crystalline cliffs and islands interspersed with sandy beaches (HARRIS *et al.*, 1991). The shoreline is characterised by rocky headlands, mainland coastal sand barriers and transgressive onshore dune systems. Occasional rock platforms and nearshore reefs occur along the exposed sections of the embayments (WOODS *et al.*, 1985). The massive headlands control much of the foreland and tombolo development while offering protection to the southeasterly facing bays. Beaches of the region are largely composed of quartzose sandy sediment, which tends to become increasingly fine grained in an easterly direction along the coast (HODGKIN and CLARK, 1990).

The Central West Coast, part of the Rottnest Shelf between Fremantle and Geraldton (Figure 2), supports onshore and offshore ridges of Pleistocene limestone running subparallel to the present coastline. The limestone outcrops as lithified dunes, chains of reefs and offshore islands (PLAYFORD *et al.*, 1976). Structural control is provided by the islands and broken reef chains (HARRIS *et al.*, 1991), contributing to the Holocene development of salients, cuspate forelands and tombolos along the coast. Sediments are mixed quartzose and calcareous sands, the latter derived from reworked limestones and bioproduction from extensive seagrass meadows (SEARLE and SEMENIUK, 1985; SANDERSON, 1992).

Further north, the fringing Ningaloo Reef tract runs parallel to the coastline from Gnarraloo Bay to Point Murat (280km) (Figure 3). The coral reef encloses a shallow sedimentary lagoon containing occasional patch and nearshore reef platforms. The shoreline is characterised by Pleistocene limestone outcrops interspersed with areas of Holocene sediment accumulation, mainly as deposits of calcareous sands and gravels (WYRWOLL, 1990).

The objectives of the project are to:

1. describe the distribution and form of salients, cuspate forelands and tombolos in the three coastal regions of Western Australia;
2. morphometrically examine the geometric relationships of the landforms with their associated structures; and
3. determine if morphometric variation between the three regions is greater than within each region.

PREVIOUS RESEARCH

The formation of coastal sedimentary accumulation forms have been reviewed by JOHNSON (1919), ESCOFFIER (1954), GUILCHER (1958), ZENKOVICH (1967), KING (1972), SUNAMURA and MISUZO (1987) and HORIKAWA (1988), and broad-scale classification of the forms have been reported by ZENKOVICH (1967) and KING (1972). The earlier authors distinguish between forelands and tombolos. More recent research including that by SUNAMURA and MISUZO (1987) and HORIKAWA (1988) recognise low amplitude accretionary features, shoreline salients, as part of a hierarchy of depositional landforms.

Much of the work on coastal accumulation forms has been geomorphological (JOHNSON, 1919; ESCOFFIER, 1954; GUILCHER, 1958; ZENKOVICH, 1967; KING, 1972; and SNEAD, 1982) dealing with the shape and genesis of the subaerial portion of the accretionary body. JOHNSON (1919) began a genetic study of coastal environments, and his work was followed by ESCOFFIER (1954) who examined "travelling" forelands, and by GUILCHER (1958) in a study of landforms which develop following erosion of coastal headlands or nearshore islands. ZENKOVICH (1967), DALLY and POPE (1986) and SILVESTER and HSU (1993) have examined contemporary processes maintaining sediment supply to the coastal area, and processes affecting erosion. Why some forms travel and others are stationary remains open to conjecture.

ZENKOVICH (1967) provided criteria by which cuspate forelands and tombolos may be classified. The criteria include: growth mechanism, degree of mobility, contemporary activity/processes, main processes involved in the supply of material, sources of supply, conditions of wave regime and stage of development. From field studies, DALLY and POPE (1986) describe combined refraction and diffraction processes These give rise to an alongshore difference in wave height in the lee of an island. The difference induces converging longshore currents, leading to the formation of salients, including cuspate forelands, and tombolos in the lee of the offshore structure.

In contrast to the geomorphic classifications and broad descriptions of formation some studies, particularly those from wave tanks (ROSEN and VAJDA, 1982; SUH and DALRYMPLE, 1987; and UDA *et al.*, 1988) have concentrated on the relationship between the dimensions of the offshore obstacle (island or reef) and the size and type of accumulation feature formed in its lee. For example, SUNAMURA and MISUZO (1987) examined the geometrical relationships of depositional forms on the shoreline in the lee of islands. In

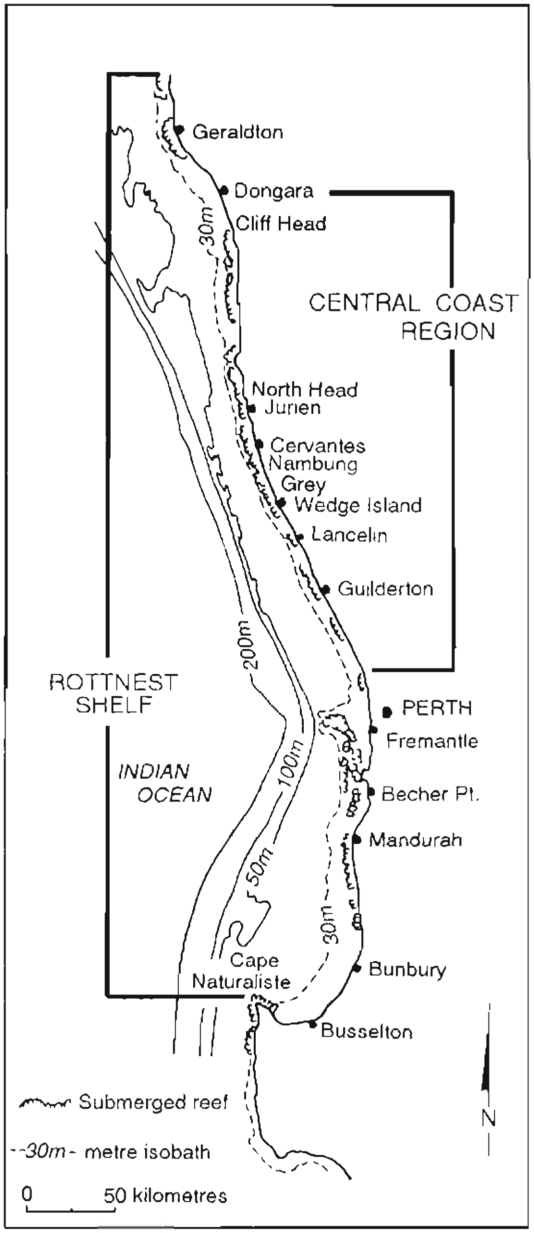


Figure 2 Central West Coast of Western Australia

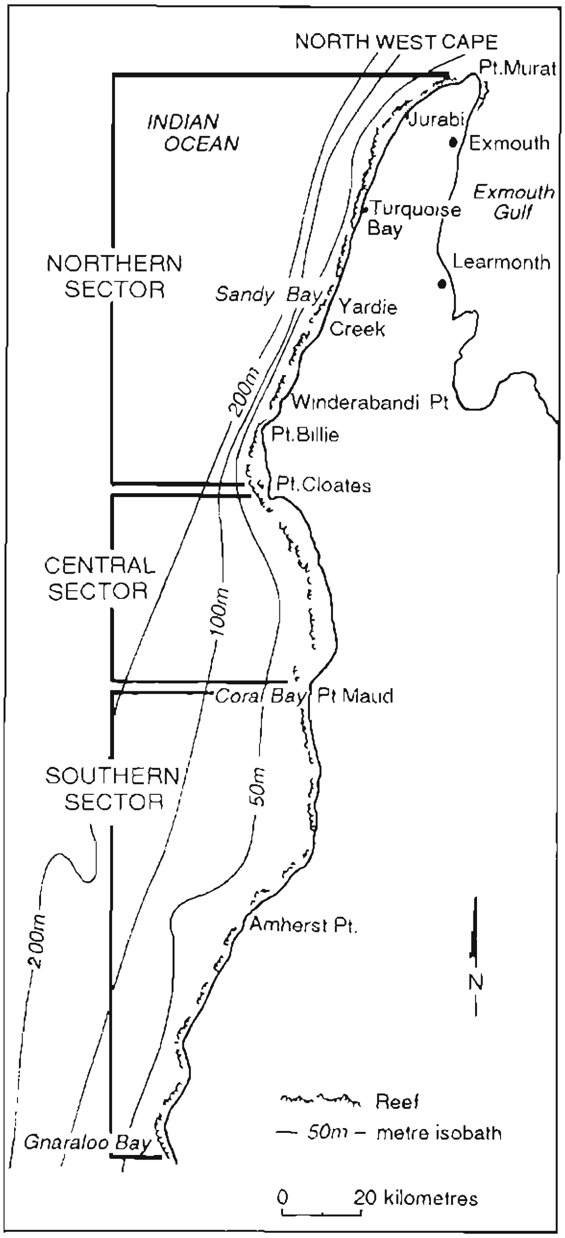


Figure 3 Ningaloo Coast of Western Australia

Figure 4, I is the island length, λ is the length at the root of a tombolo or salient, η is the projecting length, J is the offshore distance to an island and both η and J are measured perpendicular to the a-a' line. SUNAMURA and MISUZO (1987) found that a tombolo forms if $J/I < 1.5$, a salient develops if $1.5 < J/I < 3.5$ and no island influence appears if $J/I > 3.5$. This is demonstrated when η/λ or λ/I is plotted against J/I. These studies have been reviewed by SILVESTER and HSU (1993).

It was shown by HSU and SILVESTER (1990) that variables other than the island length (I) and its offshore distance (J) have little relevance to the accumulation feature forming behind a breakwater. SILVESTER and HSU (1993) showed that the distance of the salient from the obstacle (J-η) divided by I plotted against I divided by the original shoreline distance J provides a significant empirical relationship between the variables. They also extended previous studies by examining the planform of salients to determine its relationship to the formation of zeta-form embayments (HSU *et al.*, 1993). The observations of SUNAMURA and MISUZO (1987) and SILVESTER and HSU (1993) provide a basis to compare observations from the different coastal regions of Southwestern Australia.

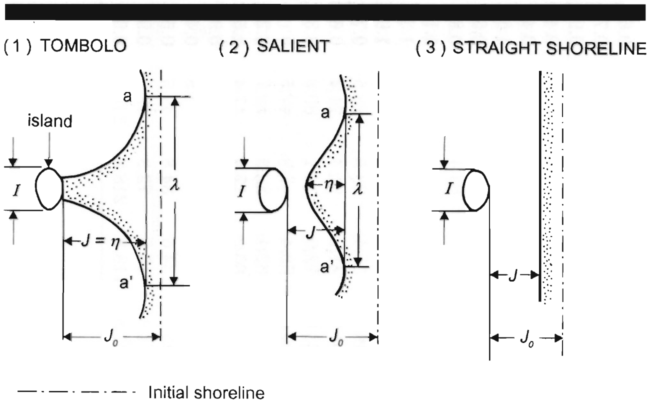


Figure 4. Geometry of salients and tombolos behind an offshore obstacle (after Horikawa, 1988: 155).

METHODS AND TECHNIQUES

Several steps were used to assess geographic difference in the occurrence of salient, foreland and tombolo forms of Western Australia. First, aerial photographs (Table 2) were interpreted to locate the sedimentary forms. Stereo-pairs were used to identify and describe the suite of landforms of each accretionary structure, and the overall dimensions of the structure were measured with a graticule overlay. The overlay gave an accuracy of +/− 0.25mm on the photographs, which converts to +/− 3.96m on the ground for the South Coast region, and +/− 5m in the Central Coast and Ningaloo areas.

The description encompassed morphological and genetic criteria, established by Zenkovich (1967) and King (1972). They included:

1) type of protection offered to the shore (none, reef, perforate reef);
2) shape of the feature (simple, double, triple);
3) type of connection with the coast (attached, looped, free, barrier, detached);
4) orientation of the landform (symmetrical, asymmetrical);
5) its position (open ocean, behind islands, in bays, on capes, paired);
6) size (ratio of length to width);
7) the possible causes of accumulation (estimated from the aerial photographs); and
8) stage of development (rudimentary, developed, decaying, relict, regenerated);

Each accumulation form was then classified according to both Zenkovich (1967) and King (1972). Forelands are classed as attached forms and tombolos as looped by Zenkovich (1967), while King (1972) affords both forelands and tombolos individual categories.

The dimensions of the cuspate forelands and tombolos included attributes such as alongshore length of the island or obstacle; width of the root of the foreland or tombolo; projecting length of the foreland or tombolo; and the offshore distance to the island or reef.

Third, geometrical attributes of the accumulation forms were analysed, using measured dimensions and graphing techniques similar to those described by Sunamura and Misuzo (1987) and Silvester and Hsu (1993). Graphs of η/λ vs J/I which compare the projecting length to foreland width ratio with the offshore distance to obstacle width, and λ/I vs J/I (width of the tombolo to length of the island against offshore distance to length of obstacle) for each of the three regions were compared with results from other authors. The geometric ratios for each of the three regions describing the relationship of the coastal accumulation form with the obstacle offshore, were then compared using analysis of variance techniques (Sokal and Rohlf, 1981). This was done to determine if the differences between the three areas was greater than the variation within each region.

RESULTS

The Accretionary Structures.

The South Coast of Western Australia is characterised by attached forelands and looped tombolos (after Zenkovich, 1967) apparently formed by the interaction of nearshore islands with prevailing swell waves. The islands are located less than 100m from the shoreline. Measurements of these South Coast accumulation features are shown in Table 3. Some double tombolos are found, for example Vancouver Peninsula near Albany. However these are not common. Where they do form, their dimensions broadly fit categories defined by Sunamura and Misuzo (1987).

The reef chain protecting the Central West Coast is located up to 15km from the shore. Close to the shoreline however, some reef is emergent or only partially submerged and these structures influence deposition of sedimentary material. The reefs are often discontinuous, and allow complex interference currents and wave patterns to form. Tombolos do not often form in this area, due to the broken nature of the offshore obstacles and the broad space between the reefs and the shore. Almost all forms in this region are classified as attached forelands (See Table 4). The accumulation forms generally project up to 150m from the shoreline, but there are significantly larger features such as the Cervantes foreland, Jurien Headland and Wedge Island (Figure 2). The dimensional relationships between the length of the projection and

Table 2. *Aerial photographs used in the analysis.*

Photograph Description	South Coast	Central West Coast	Ningaloo Coast
Job number	WA 944, Proj. E51	WA 2881(C), 900459	WA 2764, 890233
Run/photo numbers	5,148–5,156	Runs 1–7	Runs 1–5
Scale	1:15,840	1:20,000	1:20,000
Date	1965	27/6/90	12/8/89

Table 3. *Morphology and dimensions of salients, forelands and tombolos on the South Coast*

Protection	Shape	Connection	Orientation	Position	Size	Accumulation	Development	King's Class	Zenkovich's Class	I (m)	λ (m)	η (m)	J (m)	J/I
none	simple	looped	asymmet	open/embay	2:01	lateral displ	rudimentary	tombolo-normal	looped tombolo	31.7	49.1	49.1	49.1	1.52
none	simple	looped	sl. asymm	open	1.5:1	lateral displ	developed	tombolo-normal	looped tombolo	?	?	?	?	?
none	simple	attached	symmet	open/behind isl	1:04	lateral displ	rudimentary	cuspate foreland	attached foreland	26.9	95	14.3	72.9	2.7
none	simple	attached	asymmet	open/behind isl	1:02	lateral displ	developed	cuspate foreland	attached foreland	15	57	9.5	30.1	2
none	simple	attached	symmet	open/behind isl	1.01	lateral displ	rudim-devl'd	cuspate foreland	attached foreland	18.2	47.5	6.3	42.8	2.35
none	simple	attached	symmet	open/embay	2:01	lateral displ	rudimentary	cuspate foreland	attached foreland	63.4	74.4	26.9	61.8	0.97
none	simple	looped	asymmet	open/behind isl	3:01	lateral displ	rudim-devl'd	tombolo-normal	looped tombolo	36.4	31.7	6.3	27.7	0.76
none	simple	looped	asymmet	open/behind isl	3:01	lateral displ	developed	tombolo-normal	looped tombolo	33.3	74.4	41.2	41.2	1.24
none	simple	looped	symmet	open/behind isl	2:01	lateral displ	developed	tombolo-normal	looped tombolo	15.8	31.7	9.5	14.2	0.9
none	simple	looped	asymmet	open/behind isl	1:02	lateral displ	rudim-devl'd	tombolo-normal	looped tombolo	9.5	23.8	4.7	17.4	1.83
none	simple	attached	asymmet	open/behind isl	1:03	lateral displ	rudimentary	cuspate foreland	attached foreland	17.4	36.4	9.5	44.4	2.55
none	simple	looped	asymmet	open/behind isl	1:01	lateral displ	developed	tombolo-normal	looped tombolo	19	36.4	20.6	20.6	1.08
none	simple	looped	asymmet	open/behind isl	1.02	lateral displ?	developed	tombolo-normal	looped tombolo	53.8	68.1	23.8	23.8	0.44
none	simple	looped	asymmet	open/behind isl	1:01	alongsh sed mvt	developed	tombolo-normal	looped tombolo	53.9	90.3	44.4	44.4	0.82
none	simple	attached	symmet	open/behind isl	1.01	lateral displ	developed	cuspate foreland	attached foreland	50.7	142.6	47.5	72.9	1.44
none	triple	looped	asymmet	open/between isls	2:01	lateral displ	devl'd/devl'ing	tombolos-normal	looped tombolos	142.6	28.5	60.2	60.2	0.42
										23.8	34.8	7.9	7.9	0.33
										82.4	74.4	25.3	25.3	0.31
none	simple	looped	asymmet	open/behind isl	1:01	lateral displ	developed	tombolo-normal	looped tombolo	23.8	39.6	26.9	26.9	1.13
none	simple	looped	asymmet	open/behind isl	1:02	lateral displ	developed	tombolo-normal	looped tombolo	23.8	50.7	15.8	15.8	0.66
none	double	looped	asymmet	open/behind isl	?	lateral displ	developed	tombolos-normal	looped tombolos	45.9	74.4	36.4	36.4	0.79
										28.5	30.1	26.9	26.9	0.94
none	simple	attached	symmet	open/behind reef	1:03	lateral displ	rudimentary	cuspate foreland	attached foreland	17.4	28.5	6.3	7.9	0.45
none	simple	looped	asymmet	open/behind isl	1:01	lateral displ	developed	tombolos-normal	looped tombolos	80.8	95	34.8	34.8	0.43
										23.8	41.2	25.3	25.3	1.06
none	simple	looped	asymmet	open/behind isl	1:02	lateral displ	developed	tombolo-normal	looped tombolo	26.9	47.5	15.8	15.8	0.59
none	simple	looped	asymmet	open/behind isl	2:01	lateral displ	well devel	tombolo-normal	looped tombolo	72.9	103	63.4	63.4	0.87
none	simple	attached	asymmet	open/behind rock	1:02	lateral displ	developing	cuspate foreland	attached foreland	12.7	47.5	12.7	14.3	1.13
none	double	looped	symmet	open/behind isl	1:01	alongsh sed mvt	developed	tombolo-normal	looped tombolo	25.3	71.3	33.3	33.3	1.32
none	simple	attached	symmet	open/behind rock	1:02	lateral displ	developing	cuspate foreland	attached foreland	30.1	55.4	12.7	31.7	1.05
none	double	looped	asymmet	open/behind rock	1.02	lateral displ	developed	tombolos-normal	looped tomobolos	38	55.4	28.5	28.5	0.75
										31.7	41.2	21.4	21.4	0.68
none	simple	attached	symmet	open/behind isl	1:03	lateral displ	developed	cuspate foreland	attached foreland	23.8	72.9	11.1	80.8	3.39
none	simple	attached	symmet	open/behind isl	1:03	lateral displ	developed	cuspate foreland	attached foreland	9.5	82.4	7.9	47.5	5
none	simple	attached	asymmet	open/behind isl	1.04	lateral displ	developed	cuspate foreland	attached foreland	15.8	82.4	29.3	50.7	3.21
none	simple	looped	asymmet	open/behind isl	1:02	lateral displ	developed	tombolo-normal	looped tombolo	11.1	60.2	17.4	17.4	1.57
none	simple	attached	asymmet	open	1:02	diffrcation	developed	cuspate foreland	attached foreland	47.5	63.4	44.4	44.4	0.93
none	simple	looped	asymmet	open	1:02	lateral displ	developed	tombolo-normal	looped tombolo	34.8	53.9	15.8	15.8	0.45
none	simple	?	asymmet	open/behind reef	1:03	lateral displ	developing	cuspate foreland	attached foreland	95	134.6	34.8	47.5	0.5
none	double	looped	asymmet	open	1:04	?	developed	tombolos-normal	looped tombolos	74.4	15.8	72.9	72.9	0.98
										221.8	118.8	218.6	218.6	0.98

Table 4. *Morphology and dimensions of salients, forelands and tombolos on the Central West Coast.*

Protection	Shape	Connection	Orientation	Position	Size	Accumulation	Development	King's Class	Zenkovich's Class	I (m)	λ (m)	η (m)	J (m)	J/I
reef	simple	attached	asymmet	behind reef	1·04	wave converg	developing	cuspate foreland	attached foreland	126.7	126.7	25.3	85.5	0.67
reef	simple	attached	symmet	behind reef	1:02	refraction	developing	cuspate foreland	attached foreland	41.2	82.4	23.8	49.1	1.19
reef	simple	attached	asymmet	behind reef	1·01	lateral displ	developed	cuspate foreland	attached foreland	95	134.6	53.9	98.2	1.03
reef	simple	attached	symmet	behind isl	1:02	lateral displ	developing	cuspate foreland	attached foreland	47.5	69.7	14.2	71.3	1.5
reef	simple	attached	symmet	behind isl	1·02	lateral displ	developing	cuspate foreland	attached foreland	64.9	103	26.1	91.9	1.42
reef	simple	attached	asymmet	behind reef	1:02	lateral displ	developing	cuspate foreland	attached foreland	26.9	55.4	11.9	30.1	1.12
reef	simple	attached	symmet	behind rock	1·01	wave converg	developing	cuspate foreland	attached foreland	66.5	82.4	22.2	71.3	1.07
reef	simple	attached	asymmet	behind reef	1:02	lateral displ	developing	cuspate foreland	attached foreland	79.2	110.9	33.3	91.9	1.16
reef	simple	attached	asymmet	behind reef	1·04	lateral displ	developing	cuspate foreland	attached foreland	126.7	134.6	36.4	63.4	0.5
reef	double	attached	asymmet	behind reef	1.03	lateral displ	developed	cuspate foreland	attached foreland	110.9	103	31.7	71.3	0.64
reef	simple	attached	asymmet	behind reef/isl	1:01	refraciton	developed	cuspate foreland	attached foreland	90.3	112.5	47.5	84	0.93
reef	simple	looped	asymmet	behind isl	1.01	lateral displ	developed	tombolo-normal	looped tombolo	14.3	44.4	17.4	17.4	1.22
reef	simple	attached	asymmet	behind rock	1.02	lateral displ	developed	cuspate foreland	attached foreland	128.3	142.6	23.8	31.7	0.25
reef	simple	attached	asymmet	behind reef	1·02	lateral displ	developed	cuspate foreland	attached foreland	71.3	87.1	20.6	53.9	0.76

the width of the obstacle do not fit the general model put forward by SUNAMURA and MISUZO (1987).

The Ningaloo Coast consists of a fringing reef barrier at varying distances from the shore. The reef is more continuous than that of the Central Coast, but closer to shore and broken by deep channels that aid in flushing of the shallow lagoon. The exchange of water between the ocean and the lagoon aids formation of a distinctly different suite of accumulation forms. They project from 100m to over 1.7km from the shore, and consist of attached forelands and travelling forelands (Table 5). The travelling forelands are similar to those described by ESCOFFIER (1954) from the USA. Again the dimensional relationships of the forelands do not fall into the categories described by SUNAMURA and MISUZO (1987).

Geometrical Attributes

Sediment accumulation occurs in the lee of an island or reef structure primarily as a result of wave refraction processes, and secondarily in response to movement of sediment by nearshore currents. Many people have examined this phenomenon; for example see NOBLE (1978), DALLY and POPE (1986) and the review by SILVESTER and HSU (1993). Most authors acknowledge the importance of the length of the offshore structure parallel to the shore and its distance offshore as primary variables affecting the basal size and distance the landform protrudes from the original shoreline.

SUNAMURA and MISUZO (1987) have suggested that their results indicated that tombolos and salients could be distinguished on the basis of the ratio between the length of the offshore structure (island or reef) and its distance offshore. Measurements from the three coastal regions of Western Australia (Figure 5a–5f), do not significantly support these findings. However, in observations from the South Coast, tombolos all have J/I ratios of less than 1.83, which is close to the 1.5 ratio indicated by SUNAMURA and MISUZO (1987).

SILVESTER and HSU (1993; 350) have demonstrated that three geometric variables, namely I, J and η, best define the apex position of a salient. Their reanalysis of published information describes a curvilinear relationship between length of the offshore structure relative to its distance offshore (I/J) and the difference between offshore distance and the ratio of salient protrusion to island length (J-η/I), such that:

$$I/J = 0.6784(J - \eta/I)^{-1.211}$$

In this relationship, $J - \eta/I = 0$ for tombolo landforms that, by definition, reach the structure and tie it to the shoreline. Their approach offers a basis for regional comparison since the constant and exponential function may be reasonably expected to vary for landforms in different phases of development or which have been developed under different environmental conditions.

Accordingly, morphometric data from the three coastal regions of Western Australia have been plotted according to the methods of SILVESTER and HSU (1993) (Figure 6) to determine whether the attributes of the salients:

a) conform with SILVESTER and HSU'S (1993) findings; and
b) provide a basis to distinguish between the landforms of each region.

Table 5. *Morphology and dimensions of salients, forelands and tombolos on the Ningaloo Coast.*

Protection	Shape	Connection	Orientation	Position	Size	Accumulation	Development	King's Class	Zenkovich's Class	l (m)	λ (m)	η (m)	J (m)	J/I
reef	simple	attached	symmet	behind reef	1:04	current converg	developed	cuspate foreland	attached foreland	4,000	3,200	800	3,000	0.75
reef	simple	looped	asymmet	behind isl	1:02	lateral displ	developed	tombolo-normal	looped tombolo	60	420	150	150	2.5
reef	simple	attached	asymmet	behind reef	1:04	alongshore currents	developed	cuspate foreland	attached foreland	4,000	1,500	500	2,400	0.6
reef	simple	attached	asymmet	behind reef	1:04	alongshore currents	developed	cuspate foreland	attached foreland	4,000	1,200	240	2,200	0.55
reef	simple	travelling	asymmet	behind reef	1:03	alongshore currents	developing	cuspate foreland	attached foreland	5,000	620	180	2,200	0.44
reef	simple	attached	asymmet	behind reef	1:02	?	developed	cuspate foreland	attached foreland	4,000	400	100	1,000	0.25
reef	simple	travelling	asymmet	behind reef	1:02	alongshore currents	developed	cuspate foreland	attached foreland	3,000	1,000	460	1,300	0.43
reef	simple	attached	asymmet	behind reef	1:04	?	developing	cuspate foreland	attached foreland	1,200	1,000	180	760	0.63
reef	simple	attached	symmet	behind reef	1:01	diffraction	developing	cuspate foreland	attached foreland	2,000	500	140	1,100	0.55
reef	simple	attacjed	symmet	behind reef	1:01	diffraction	developing	cuspate foreland	attached foreland	4,000	480	280	1,300	0.32
reef	simple	attached	symmet	behind reef	1:04	diffraction?	developed	cuspate foreland	attached foreland	1,700	1,200	200	1,440	0.85
reef	simple	attached	asymmet	behind reef	1:04	diffraction	developed	cuspate foreland	attached foreland	2,200	1,300	200	2,200	1
reef	simple	attached	asymmet	behind reef	1:04	current convergence	developing	cuspate foreland	attached foreland	4,000	900	330	2,800	0.7
reef	simple	attached	asymmet	behind reef	1:04	current convergence	developed	cuspate foreland	attached foreland	2,500	1,600	360	1,800	0.72
reef	simple	attached	asymmet	behind reef	1:01	spit development	developed	cuspate foreland	attached foreland	4,000	2,200	1,700	2,600	0.65

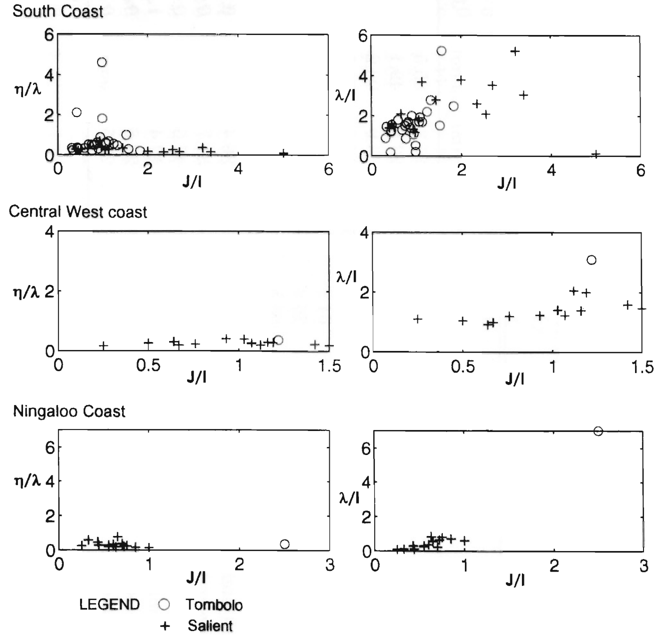


Figure 5. Geometric relationships of depositional landforms behind an offshore obstacle.

Separate graphs have been compiled for all observations from Western Australia as well as for each region (Figure 7) to indicate geographic differences. Regression of the ratio of J − η/I against I/J for all observations of salients results in equation $I/J = 0.7285(J - \eta/I)^{-0.657}$ where the constant is close to that used by SILVESTER and HSU (1993) and the exponent is significantly smaller. A full range of salients occurs along the South Coast, as indicated by the distribution of points along the curve from $I/J < 0.5$ to $I/J > 3$ (Figure 7) and this yields the empirical relationship $I/J = 0.4119(J - \eta/I)^{-0.546}$. In contrast to this, the graphs from the Central West Coast and Ningaloo Coast show a more restricted distribution. The salients from the Central West Coast range

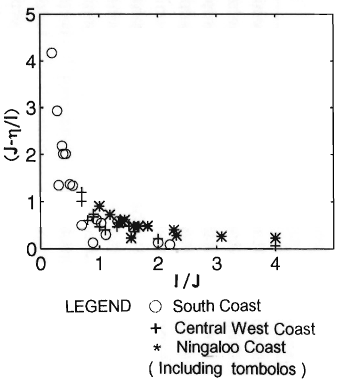


Figure 6. Relationship between I/J and J − η/I including data from salients and tombolos (after SILVESTER and HSU, 1993).

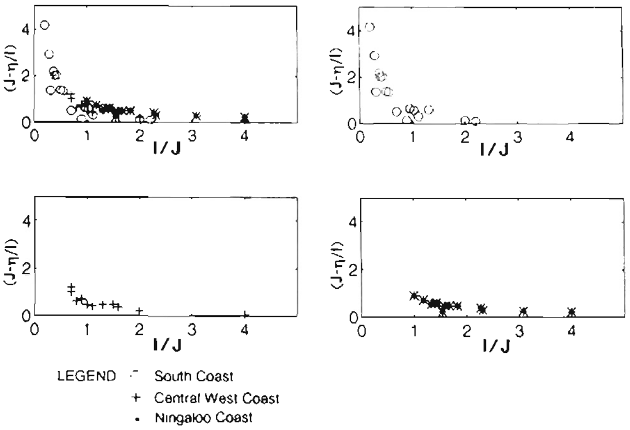


Figure 7 Relationship between I/J and J − η/I for salients in each coastal region.

from I/J = 0.5 to 4.0; whereas those from the Ningaloo Coast range from I/J = 1.0 to 4.0. The empirical formula are $I/J = 0.7362(J - \eta/I)^{0.614}$ and $I/J = 0.984(J - \eta/I)^{-0.713}$ from the Central West Coast and Ningaloo Coast respectively

Results presented here are more consistent with those from observations presented by SILVESTER and HSU (1993) than those from SUNAMURA and MISUZO (1987). However, in contrast to SILVESTER and HSU's (1993) results there is a scatter of observations when J η/I is plotted against I/J for all three coastal regions in Western Australia (Figure 6) and this remains true when tombolo forms are excluded from the classification. The scatter of data on the graphs is apparently wider than that reported by SILVESTER and HSU (1993: 350). However, this may be due to errors involved in taking measurements directly from aerial photographs, inclusion of a range of forms that are not necessarily in static equilibrium with local wave and nearshore current conditions and sediment supply, or some combination of these two. Nevertheless, the results generally agree with those reported by SILVESTER and HSU (1993).

An examination of the geometric differences between each coastal region was undertaken using analysis of variance techniques. Each of the geometric ratios, J/I, η/λ, λ/I, I/J and J − η/I were tested by non-parametric one-way analysis of variance using the Kruskal-Wallis test (SOKAL and ROHLF, 1981) to determine which ratios showed significantly greater differences between than within coastal regions. A 5% level was adopted for determination of significance. The analysis of variance for each ratio was conducted twice. First for the complete data sets, including tombolos and salients, and second for data sets excluding tombolos.

Results (Table 6) showed that at the 5% significance level there are significant differences between the coastal regions for most ratios when tombolos are excluded from the data sets. Only λ/I, the ratio of the length of the root of the salient to the length of the obstacle showed significant differences between the coastal regions when tombolos were included in the data sets. The ratio of η/λ, the projecting length to the length of the root of the salient, was not significantly different between the coastal regions. In all instances, I (length of the offshore obstacle), J (distance to the offshore obstacle) and J − η (distance between the offshore obstacle and the apex of the salient) remain significantly different between coastal regions when tombolos are excluded from the data sets.

Table 6. *Results from analysis of variance.*

Geometric Variable	Tombolos Included	Tombolos Excluded
J/I	P = 0.098, F = 2.41	P = 0.001, F = 8.175
η/λ	P = 0.199, F = 1.65	P = 0.451, F = 0.813
λ/I	P = 0.021, F = 4.11	P = 0.000, F = 20.86
I/J	P = 0.095, F = 2.436	P = 0 002, F = 7.102
J-η/I	P = 0.955, F = 0.046	P = 0.010, F = 5.184

Differences are significant when $P < 0.05$

It follows that the forms of salients, cuspate forelands and tombolos on the Rottnest Shelf and Ningaloo Coasts are markedly different. Although much work has been conducted on the cuspate forelands of the Central and Southern Western Australian Coast, the models of their formation remain localised and cannot be applied to the Ningaloo Coast where the reef structure and nearshore processes differ greatly. The relative simplicity of the formation of the South Coast cuspate forelands and tombolos can be accounted for by the lack of reef control and the direct relationship between offshore island and sedimentary accumulation. With the complex, broken reef chains that exist on the West Coast it is anticipated that a combination of processes including swell diffraction and refraction, sediment distribution, nearshore circulation, current flow and local weather conditions will each have an effect on the resulting development of the coastal sedimentary features. These processes require further investigation in the field.

DISCUSSION

General Morphology

Initial analysis of the aerial photographs of the three areas indicated that there are distinct differences between the South Coast and the reef protected West Coast. The development of accumulation forms on the South Coast is directly attributable to the offshore granitic islands, and changes in bathymetry. Offshore reef protection is very limited, and thus the sediment accumulates directly behind nearshore obstacles. Cuspate forelands and tombolos which are characteristic of the South Coast are illustrated in Figure 8. Type A forms are tombolos which link a rocky outcrop with the mainland. The coastline typically changes orientation at this point and the headland is flanked by long sandy beaches. Type B tombolos occur where a large granitic outcrop is found close to a sandy beach. A small amount of material is then needed to link the island with the mainland. These forms are usually large (800–1000m width) and are situated within a sandy beach environment. Type C tombolos are very similar to type B but smaller in scale. They are quite common due to the frequent occurrence of small islands close to the shore and occur on average with a frequency of approximately 5 every 100km. Type D sedimentary forms are cuspate forelands that

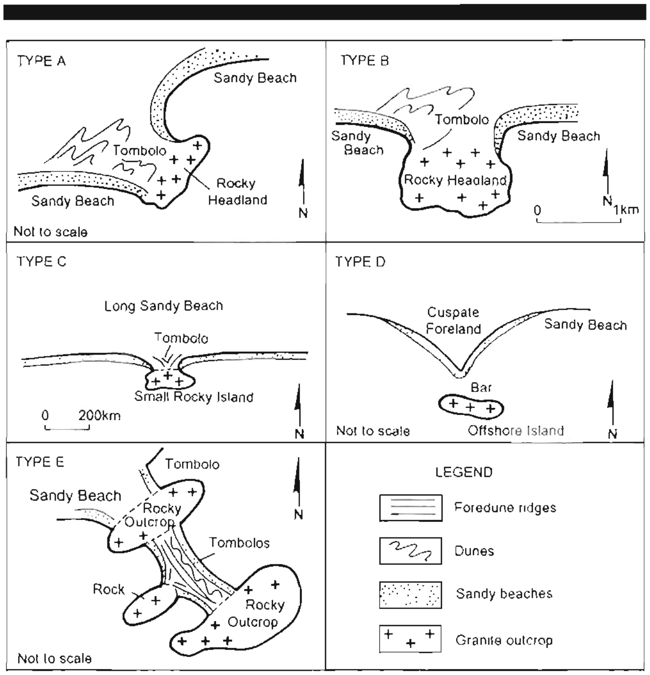


Figure 8. Types of cuspate forelands and tombolos characteristic of the South Coast.

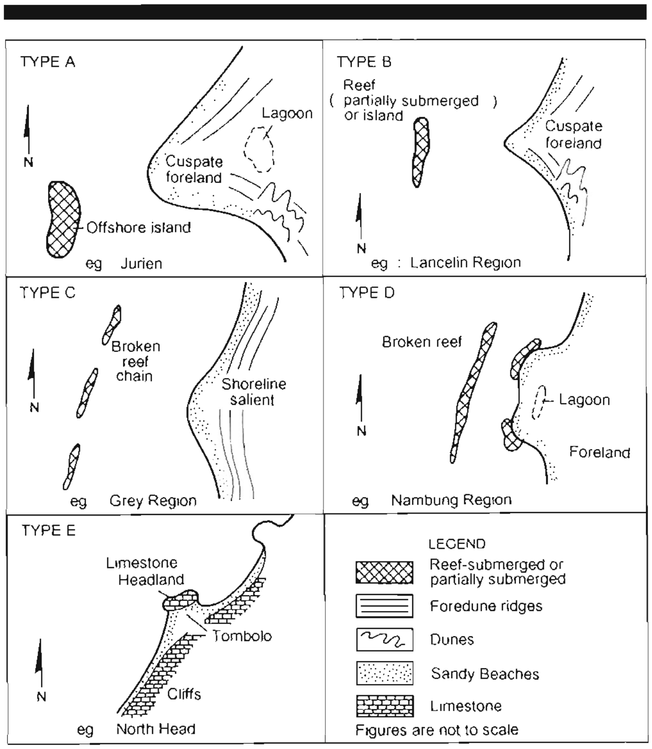


Figure 9. Types of salients, forelands and tombolos characteristic of the Central West Coast.

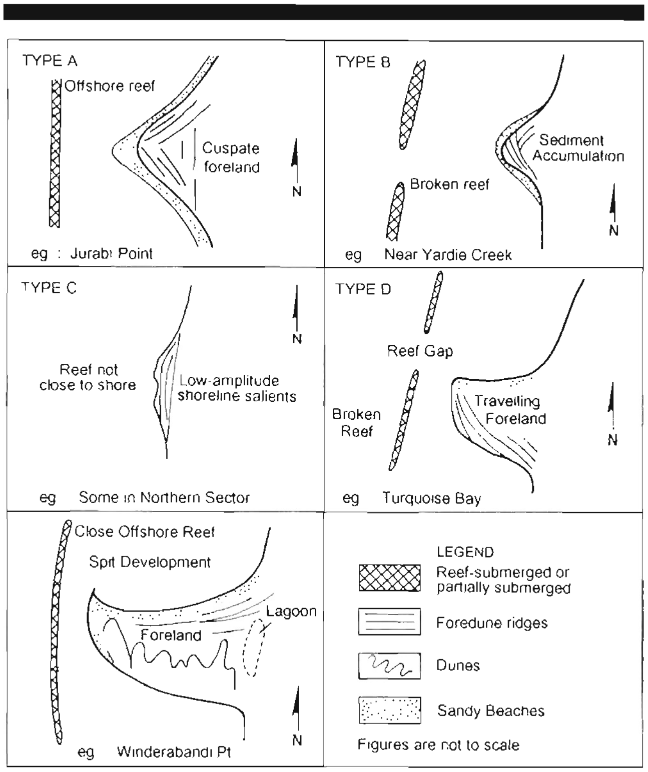
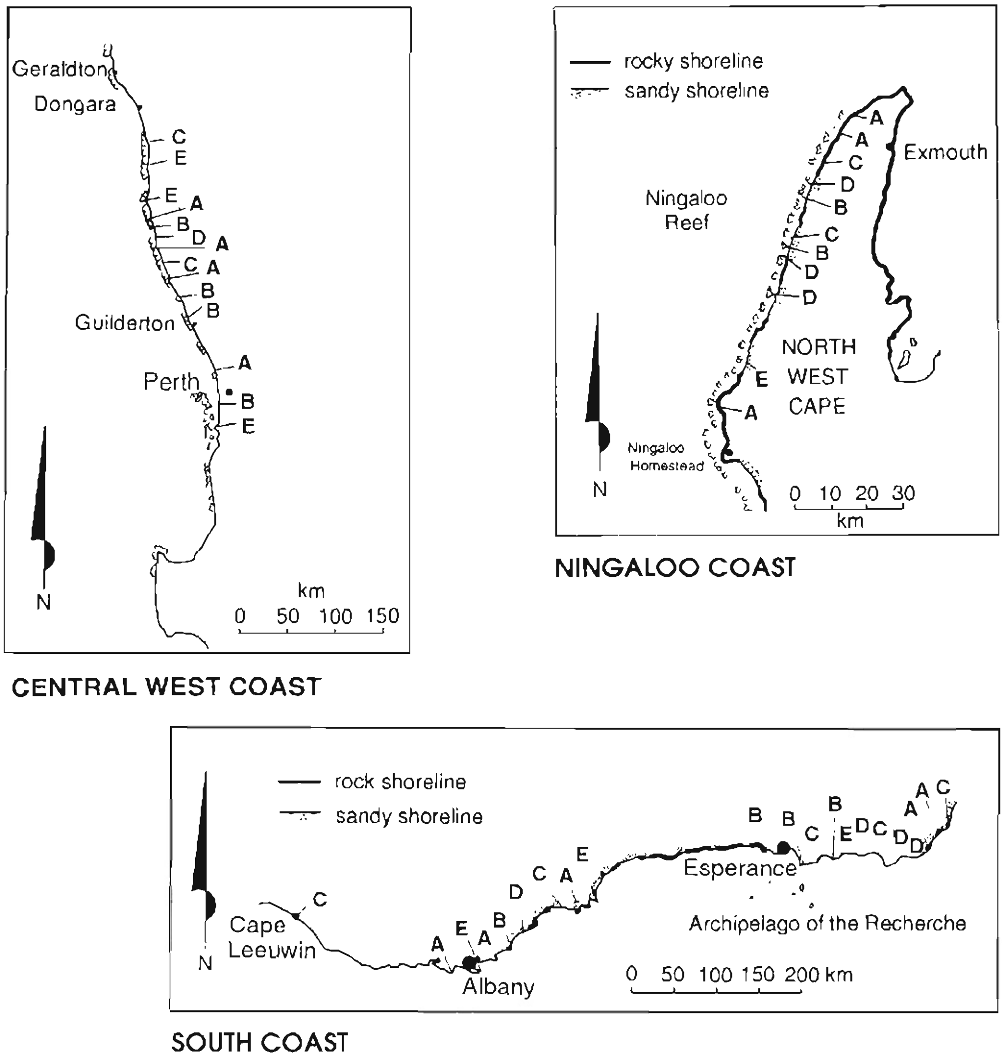


Figure 10. Types of salients and forelands characteristic of the Ningaloo Coast.

form behind islands that outcrop a greater distance offshore than those of type C. The foreland is often symmetrical, or slightly asymmetrical, and apparently is formed by diffraction of waves around the island. The geometry of each of the types found on the South Coast generally fits the models described by SUNAMURA and MISUZO (1987). Type E coastal accumulation forms are complex double or triple forms. The sediments accumulate between offshore islands linking one to another and to the mainland. The areas are characterised by granitic outcrops with few sandy beaches or onshore accumulations of sediments.

In contrast, the protection offered by the broken reefs to both the Central and Ningaloo Coasts allows complex interaction of swell waves, wind waves and longshore currents, causing sediments to accumulate in areas which are not directly landward of the offshore reef but skewed to the direction of longshore transport. Closer examination of the Central Coast and Ningaloo reef systems shows that these two regions are different to those of the South Coast and from each other. The reef of the Central Coast is discontinuous and the nearshore bathymetry is irregular, leading to complex circulation patterns. Sedimentary accumulation forms typical of the Central West Coast are illustrated in Figure 9. Type A are the large cuspate forelands which form behind offshore islands and reef chains. The island is usually quite large (100–200m long) and part of a longer reef. Although 2–3km offshore, it still exerts a considerable influence on the local sediment transport. These cuspate forelands are found at


CENTRAL WEST COAST

NINGALOO COAST

SOUTH COAST

Figure 11. The locations of the sedimentary accumulation forms described in Figures 8, 9 and 10 on the coast of Western Australia.

such areas as Jurien, Cervantes and Wedge Island. Type B forms are smaller scale cuspate forelands occurring behind islands or extensive areas of partially submerged reef. Type C forms are low-amplitude salients which form when sediments accumulate behind broken reef chains. Type D forelands develop behind broken and partially submerged reef outcrops. The perforate nature of the reef allows wave energy to cross the reef and impede development of the foreland. A lagoon is often enclosed by the foreland as the flanks have accumulated. Type E forms are tombolos which are formed by accumulation of sediments behind limestone headlands. Longshore transport appears to significantly contribute to development of these forms. Very few of these coastal accumulation forms have dimensions which are comparable to those of the South Coast.

Ningaloo Coast accumulation forms are significantly different to those of the South Coast and to those of the Central West Coast. Wave diffraction and refraction through breaks in the reef is important, water driven across the reef by tides and waves significantly contributes to circulation within the flat lagoon. In particular the wave driven water appears to be associated with the longshore transport of sediment, and with the movement of water in and out of the breaks in the reef. It combines to form distinct coastal accumulation forms (Hearn *et al.*, 1986). The characteristic salients and forelands of the Ningaloo Coast are shown in Figure 10. The type A foreland is similar in scale to the type A forelands of the Central Coast. It is formed, however, behind reef with no island influence and consists of extensive barrier development including development of relic foredune plains. Type B salients are 200–300m in width and are found behind broken offshore reef. Further contributing factors are not easily identified from the aerial photograph analysis. Type C accumulations are small scale forms occurring on the shoreline in areas where the reef is a considerable distance from the shore. Travelling forelands are classified here as type D forelands. They form behind broken reef chains close to the shore and are influenced by longshore currents operating within the lagoon. Type E forms are large forelands (2–3km length) which project out to the close inshore reef. The foreland does not form a tombolo, and spit development is observed at the offshore extremity. In some instances, a lagoon has been enclosed by the development of the foreland at some time during the Holocene.

From the broad classification of coastal accumulation forms described it is evident that different coastal environments give rise to different types of salients, forelands and tombolos. Due to the irregular nature of the West Coast reefs and complex interaction of oceanographic processes, full classification and description of processes forming the forelands and tombolos can only be undertaken following a wider examination of associated wave and current processes and sediment characteristics. The locations of the landform types described above is shown in Figure 11.

Regional Variation

It is apparent from analysis of the aerial photographs that there is significant disparity between the landforms of the South, Central Western and Ningaloo Coasts of Western Australia. Most of the South Coast forelands and tombolos are formed by the deposition of sediment resulting from the convergence of swell behind an obstacle, nearly always a granite headland or island, whereas on the Central West and Ningaloo Coasts the submerged reefs provide an offshore barrier to incoming swell waves which would normally transport sediments onshore. The swell is then complexly diffracted and refracted by the reefs and sediment is deposited in a less predictable manner. The distance of the reef offshore, the degree of continuity of the reefs, and the bathymetric variations are the most prominent differences between the two regions, and these then lead to the different types and dimensions of the forelands and tombolos forming behind them. Flushing of the lagoonal waters behind the reefs either by longshore currents or offshore movement of water through breaks in the reefs appears to impede the formation of tombolos and provides an explanation for travelling versus stationary forms in the respective environments.

CONCLUSIONS

Shoreline salients, cuspate forelands and tombolos of the South and West Coasts of Western Australia have been identified, described and broadly grouped in terms of their similarity of form. Characteristic types of forelands and tombolos are identified for each area which highlight differences between the regions. The accumulation forms of the South Coast are formed behind granitic outcrops due to the diffraction of approaching swell waves around islands and the subsequent deposition of sediment. The reef chain which flanks the Central West Coast and Ningaloo Coast of Western Australia provides protection to the shoreline and leads to complex diffraction and refraction patterns inside the lagoon region. Measurements of the forms from the three coastal regions of Western Australia do not significantly support the findings of Sunamura and Misuzo (1987) however in observations from the South Coast tombolos all have J/I ratios of less than 1.83 which is close to the 1.5 ratio indicated by Sunamura and Misuzo (1987). Empirical equations derived for each of the three regions demonstrate a curvilinear relationship that is similar to that reported by Silvester and Hsu (1993) but which have different constants and exponential values. Significant differences have been shown to exist between the three coastal regions for the geometric variables I, J and J η when tombolos are excluded from the data sets.

It has been shown that the development of these forms cannot be directly attributable to the size of the offshore obstacle or the distance of the obstacle offshore. This leads to the need for further investigation of the combined oceanographic processes occurring leeward of the reef chains. Onshore geochronologic work combined with an examination of nearshore currents, circulation, sediment distribution and type would lead to a more complete understanding of the geomorphic development of these Holocene features. This is currently being conducted for landforms on the Central West and Ningaloo Coasts as part of an ongoing research program.

LITERATURE CITED

Collins, L.B. 1988. Sediments and history of the Rottnest Shelf, southwest Australia: a swell-dominated, non-tropical carbonate margin. *Sedimentary Geology*, 60: 15–49

Dally, W R. and Pope, J. 1986. *Detached breakwaters for shore protection.* Technical Report, Coastal Engineering Research Centre, Waterways Experiment Station, CERC-86-1, 62pp.

Davies, J.L. 1980. *Geographical Variation in Coastal Development.* Longman, London, Second Edition, 212pp.

Department OF Defence. 1993. *Australian National Tide Tables 1994: Australia, Papua New Guinea and Antarctica.* Australian Govn. Publishing Service, Canberra. pp 355.

Escoffier. F.F. 1954. *Travelling forelands and the shoreline processes associated with them.* Bulletin, US Beach Erosion Board, 9: 11–14.

Gentilli, J (Ed) 1971 *Climates of Australia and New Zealand.* Elsevier, Amsterdam.

Guilcher, A. 1958. *Coastal and Submarine Morphology.* Methuen and Co Ltd., London. 274pp.

Gulliver, F.P. 1896. Cuspate Forelands. *Bulletin Geol. Soc. America*, 7

Gulliver, F.P. 1899. Shoreline Topography. *Proc. Amer. Acad. Arts and Sciences*, 34, 189.

Harris, P.T., Baker, E.K. and Cole, A.R. 1991. *Physical Sedimentology of the Australian Continental Shelf: With Emphasis on Late Quaternary Deposits in Major Shipping Channels, Port Approaches and Choke Points.* Ocean Sciences Institute, Report No. 51, The University of Sydney, December, 1991

Hearn, C.J., Hatcher, B.G., Masini, R.J. and Simpson, C.J. 1986. *Oceanographic Processes on the Ningaloo Coral Reef, Western Australia.* Centre for Water Research, Uwa, Environmental Dynamics Report ED-86-171.

Hegge, B.J., 1994. *Low Energy Sandy Beaches of Southwestern Australia: Two-Dimensional Morphology, Sediments and Dynamics.* PhD Thesis, Department of Geography, University of Western Australia.

Hodgkin, E.P. and Clark, R. 1990. *Estuaries of the Shire of Albany.* Estuarine Studies Series No. 8, November, 1990. Environmental Protection Authority, Western Australia.

Horikawa, K. 1988. *Nearshore Dynamics and Coastal Processes: Theory, Measurement and Predictive Models.* Univ. of Tokyo Press.

Hsu, J.R.C. and Silvester, R. 1990. Accretion behind single offshore breakwater. *Journal Waterway, Port, Coastal and Ocean Engineering., Asce.* 116(3): 362–380.

Hsu, J.R.C., Uda, T. and Silvester, R. 1993. Beaches downcast of harbours in bays. *Coastal Engineering*, 19, 163–181.

Johnson, D.W. 1919. *Shore Processes and Shoreline Development*. New York: Wiley, 584pp.

King, C.A.M. 1972. *Beaches and Coasts*. Edward Arnold, London. 570pp.

Noble, R.M. 1978. Coastal structures' effects on shorelines. *Proceedings of the 16th International Conference on Coastal Engineering*, American Society of Civil Engineers, 3:2069–2085.

Playford, P.E., Cockbain, A.E. and Low, G.H. 1976. *Geology of the Perth Basin, Western Australia*. Western Australian Geological Survey, Bulletin 124.

Rosen, D.S. and Vajda, M. 1982. Sedimentological influences of detached breakwaters. *Proc. 18th Inter. Conf. Coastal Eng., Asce* 3: 1930–1949.

Sanderson, P. 1992. *Alongshore Compartmentalisation and Distribution of Beach Sediments on the Central Coast of Western Australia: Guilderton to Cliff Head*. Unpublished Honours Thesis, Department of Geography, University of Western Australia.

Searle, D.J. 1984. *A Sedimentation Model of the Cape Bouvard to Trigg Island Sector of the Rottnest Shelf, Western Australia*. PhD. Thesis, Univ. of Western Australia.

Searle, D.J. and Semeniuk, V. 1985. The natural sectors of the inner Rottnest Shelf Coast adjoining the Swan Coastal Plain. *Journal of the Royal Society of Western Australia* 67 (3, 4): 116–136.

Semeniuk, V. and Johnson, D.P. 1982. Recent and Pleistocene beach/dune sequences, Western Australia. *Sedimentary Geology* 32: 301–328.

Semeniuk, V. and Johnson D.P. 1985. Modern and Pleistocene rocky shore sequences along carbonate coastlines, southwestern Australia. *Sedimentary Geology* 44: 225–261

Semeniuk, V. and Searle, D.J. 1986. The Whitfords Cusp—Its geomorphology, stratigraphy and age structure. *Journal of the Royal Society of Western Australia* 68 (2): 29–36.

Semeniuk, V., Searle, D.J. and Woods, P.J. 1988. The sedimentology and stratigraphy of a cuspate foreland, southwestern Australia. *Journal of Coastal Research* 4 (4): 551–564.

Silvester, R. 1987. *Environmental Review and Management Programme for Westport, Vols I and II Nov. 1986. Review of Findings.* Report and Recommendations by the Environmental Protection Authority, Western Australia, Bulletin 281, May 1987.

Silvester, R. and Hsu, J.R.C. 1993. *Coastal Stabilization: Innovative Concepts*. Prentice Hall, New Jersey, 578pp.

Snead, R.E. 1982. *Coastal Landforms and Surface Features: A Photographic Atlas and Glossary.* Hutchinson Ross, Pennsylvania, 247pp.

Sokal., R.R. and Rohlf, F.J. 1981. *Biometry and the Principles and Practice of Statistics in Biological Research*. Freeman and Co., New York, 2nd Ed., 859pp.

Steedman, R.K. 1977. *Mullaloo Marina: Environmental Investigations and Physical Oceanographic Studies for the Shire of Wanneroo.* Job 048, R.K. Steedman and Associates, Perth, 210pp.

Steedman, R.K. and Craig, P.D. 1979. *Numerical Model Study of Circulation and Other Oceanographic Aspects of Cockburn Sound.* Job 063, Report 64. Unpub. Report for Department of Conservation and Environment, Perth, Western Australia.

Suh, K. and Dalrymple, R.A. 1987. Offshore breakwaters in laboratory and field. *Journal Waterway, Port, Coastal and Ocean Engineering., Asce* 113(2): 105–121.

Sunamura, T. and Misuzo, O. 1987. A study on depositional shoreline forms behind an island. *Ann. Rep., Inst. Geosci., Univ. Tsukuba*, 13, 71–73.

Uda, T., Omata, A. and Yokoyama, Y 1988. On the formation of artificial headland beach using detached breakwater. *Proc. 35th Japanese Conf. Coastal Eng.*, 26–30.

Woods, P.J., Webb, M.J. AND Eliot, I.G. 1985. Western Australia. In Bird, E.C.F., Schwartz, M.L. (Eds). *The World's Coastline.* Van Nostrand Reinhold Company, pp 929–947

Wyrwoll, K-H. 1990. *The Geomorphology and Geomorphological Evolution of the Coast of the Cape Range Exmouth Gulf Region.* Unpublished Report, Department of Planning and Urban Development, Western Australia.

Zenkovich, V.P. 1967. *Processes of Coastal Development.* Oliver and Boyd, Edinburgh, London, 738pp.