The geomorphology and Late Cenozoic geomorphological evolution of the Cape Range – Exmouth Gulf region

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Abstract

The paper provides an overview of the geomorphology and Late Cenozoic geomorphological development of the Cape Range region. The broad scale geomorphology of the region is directly controlled by the structural geology and uplift history. The open anticline which forms the range has been deeply dissected on the flanking margins. The pervasive development of karst terrains and dissolution forms, at a variety of scales, reflect the dominance of carbonate lithologies. A series of emergent reef-complexes are striking elements of the geomorphology of the western side of the Cape Range. From these, new palaeontological evidence is presented which suggests that uplift in the area is likely to have been a feature of the late Tertiary, and that it did not extend into the Quaternary, as was previously thought. The coastal margin of Cape Range has seen the development of extensive alluvial fans. These interfinger and are associated with a series of marine-nearshore morphostratigraphic units of Middle (?)- Late Quaternary age. Deposits of Last Interglacial age are especially prominent elements of the geomorphology of the coastal margin.

Introduction

When viewed from the continental scale, the geomorphology of the western part of the Australian continent is generally seen as being characterised by areas of low relief, limited erosion potential, tectonic stability and a long history of subaerial denudation. The major elements of the geomorphology of the Cape Range region lie uncomfortably in this scheme. Much of the regional geomorphology of the area is Late Cenozoic in age, being dominated by geological structures which reflect the tectonic instability which the wider region has experienced in this time. Uplift has provoked a strong and distinctive erosional and depositional geomorphological response. In addition, the Cape Range region shares with other parts of Western Australia, the strong imprint that the global Late Cenozoic climatic and sealevel changes have left in the younger morphostratigraphic elements of the geomorphology and surficial geology.

The emphasis of this paper is on the general regional issues of geomorphology. Consequently, the account is largely descriptive and this, coupled with a regional perspective, inevitably pleads for more problem focused discussions. But our aim here is to provide a register of the results of work in this area, so that it may become readily available for use by others.

The regional-scale geomorphology and morphotectonics of the Cape Range-Exmouth Gulf region

The major components of the geomorphology of the region are shown in Figure 1. The regional setting of the geomorphology is dominated by a series of anticlines which find their surface expression in the Cape, Rough and Giralia Ranges. These anticlines have formed as

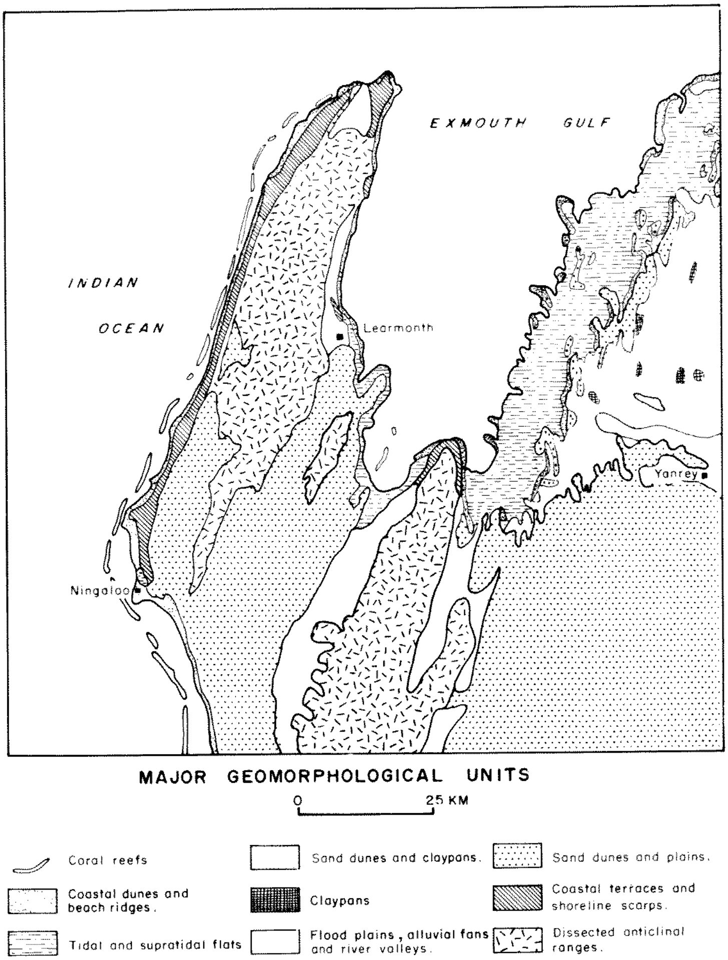


Figure 1. The regional geomorphological setting and general geomorphology of the coastal regions of the Cape Range- Exmouth Gulf area (adapted from van de Graaff *et al.* 1980).

the result of reverse movement on underlying normal faults (van de Graaff *et al.* 1980). These structures are part of a wider morphotectonic and structural province, which indicates that the coastal margins of the Carnarvon Basin have experienced considerable tectonic activity during the Cenozoic (Figure 2). The primary morphotectonic elements of the wider Cape Range region have exerted a fundamental control on the evolution of the geomorphology of the area, both at the general regional scale and at the scale of specific morphostratigraphic and geomorphological elements.

The geology of the area is dominated by the Cape Range Group, a sequence of marine Tertiary, mainly carbonate sediments spanning the Late Oligocene to Middle (? Late) Miocene. It comprises the Mandu, Tulki and Trealla Limestones and the Pilgramunna Formation, with the latter confined to the western side of the Cape Range anticline. A comprehensive discussion of the geology of the area is given by Hocking *et al.* 1987.

The uplift of the Cape Range peninsula is recorded dramatically by the series of well-preserved wave-cut erosion scarps, terraces and associated deposits, forming a "staircase"

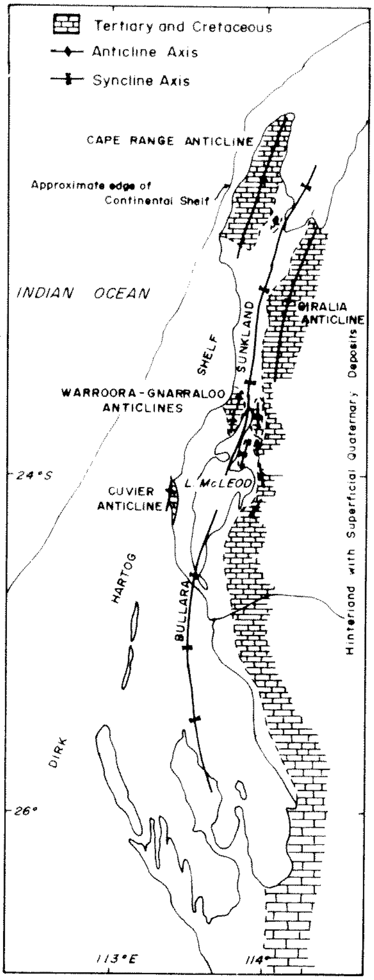


Figure 2. General structural geology context/control of the Exmouth Gulf - Cape Range region (after Logan *et al.* 1976).

arrangement, along the western margin of the range (Figure 3). The terraces have been incised into the Tulki Limestone and Pilgrammuna Formation and extend from Vlaming Head south to Wealjugo Hill, a distance of 90 km. These terraces are very much the geomorphological signature of the region and their ages hold the key to an understanding of the timing of uplift events.

The important work of van de Graaff *et al.* (1976) provided the first detailed study of these terraces, and also drew attention to the wider geomorphological importance of the region. But these western Cape Range terraces and their significance had been recognised by earlier workers (Condit 1935; Raggatt 1936). These earlier impressions are cited by van de Graaff *et al.* (1976: 62-63):

> "the slopes rise in several successive steps as elevated sea cliffs and wave-cut terraces ranging from about 20 feet above sea level up to 180 feet. The lowest forms a continuous coralline bench one half to one mile wide" (Condit 1935: 865).

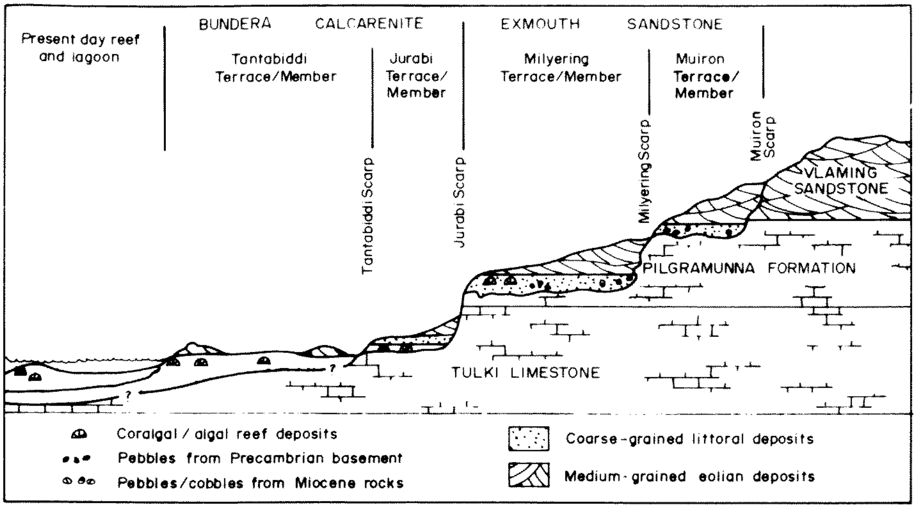


Figure 3. Uplifted coral reef complexes fringing the western flank of the Cape Range structure (after van der Graaff *et al.* 1976).

> "The relics of wave-cut terraces at several levels, so beautifully exhibited on the west coast of North-West Cape, are eloquent testimony of the fact that the land has been rising in the recent past" (Raggatt 1936:166).

Arising from a more comprehensive field study and mapping of the area, van de Graaff *et al.* (1976) recognised and described four principal erosion terraces. Each of these was overlain by shallow in-shore and near-shore deposits and truncated to seaward by an erosion scarp. The deposits formed on the Muiron and Milyering Terraces, were assigned to the Exmouth Sandstone; those on the Jurabi and Tantabiddi Terraces constitute the Bundera Calcarenite. The three upper terraces have been clearly warped but, in the Cape Range region at least, there is no evidence of deformation of the Tantabiddi Terrace.

The ages of the Cape Range terraces

In addressing the difficult question of the ages of the Cape Range terraces, van de Graaff *et al.* (*ibid.*), concluded that the terraces are of post-Middle Miocene and probably post-Miocene in age. In the absence of other more positive evidence the authors initially assumed a probable Pleistocene age for all four terraces, assigning these and their associated sediments to supposed interglacial events ("Riss-Würm Interglacial" etc.) based on the classic German Alpine chronology. In light of the much more comprehensive understanding of global Quaternary climate events, that now exists, it is clear that the classical four glacial division of the Quaternary is invalid (see, for example, Martinson *et al.* 1987). But more important is the fact that, implicit in this attempt at "dating" the terraces, was the conclusion that uplift of the Cape Range structure was essentially achieved during the Quaternary.

At a more local level, van de Graaff *et al.* (1976) suggested a correlation between the Tantabiddi Member and the Bibra Formation of Shark Bay (Logan *et al.* 1970); a view that has since been essentially confirmed by uranium-series dating (Veeh *et al.* 1979; Kendrick *et al.* 1991). It now appears from this evidence that both units were formed during the Last Interglacial of the Late Pleistocene (oxygen isotope Substage 5e). The numerical ages obtained lie in the range of 132-127 ka BP. No numerical ages exist for the older terraces. The corals of the Jurabi Member have undergone intensive recrystallisation and no satisfactory numerical dates have so far been obtained.

Fossil evidence on the age of the Jurabi Member

An understanding of the ages of the three older terraces on the western Cape Range is clearly of considerable importance because of their direct bearing on the timing of uplift and hence on the geomorphological and biological (*e.g.* colonisation, speciation, endemism) processes that have generated the present Cape Range environment and biota. As the result of recent fossil finds, a step towards establishing the age of the older terraces can now be achieved.

Fossil shark teeth have been recorded from both the Mandu Calcarenite and the Jurabi Member. The Mandu Limestone contains *Carcharocles angustidens* Agassiz 1835 (WAM 68.9.1, Kemp 1992: pl.26 B; also possibly WAM 68.9.2), a large serrated tooth having basal denticles and a distinctly asymmetric outline. *C. angustidens* ranges in age in Australia from the Upper Oligocene to the end of the Lower Miocene (Kemp 1992), although in Europe and North America it appears by the start of the Oligocene following the disappearance of its precursor *C. auriculatus* (D. Ward, pers. comm. 1992).

A tooth of *Carcharocles megalodon* has been obtained from Shothole Canyon of the Cape Range area by Kemp (1992: pl. 28 D, WAM 68.9.3), although the exact stratigraphic location of the find is uncertain. However, other records of *C. megalodon* from the region have come from the Jurabi Member (WAM 87.3.2c, 92.10.1, also Department of Conservation and Land Management (CALM) collection). WAM 87.3.2c is a large tooth showing a minimum length of 69 mm, but estimated complete size would be around 81-83 mm. The edges are poorly preserved, but show that it lacks basal denticles and shows no distinct curvature as would be seen in *C. angustidens*. Therefore, based on its large size and apparently symmetrical shape it is referred to *Carcharocles megalodon*. Specimen 92.10.1 (Figure 4) has a crown height of *c.* 40 mm and a width across the base of the enamel of approximately 50 mm (estimated, slightly restored). Such proportions indicate a good example of a *C. megalodon* upper lateral tooth.

The known distribution of *C. megalodon* is global, being recorded from Miocene and Pliocene units in North America, Australia, Europe, New Zealand, Japan, India, the West Indies, Africa and South America (Capetta 1987). Although some workers believe that *C. megalodon* may have survived into the Pleistocene because teeth have been dredged up from abyssal red muds (Capetta 1987:103), there is no firm biostratigraphic dating yet published

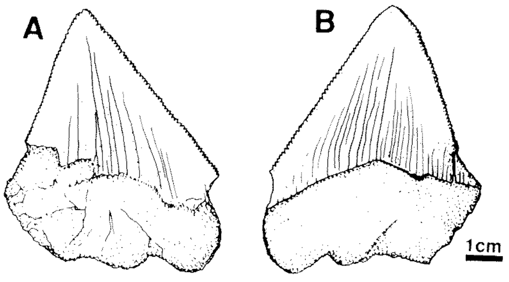


Figure 4. *Carcharocles megalodon*, speciment WAM 92.10.1, Jurabi Terrace Beds. A: lingual view; B: labial view.

which supports this hypothesis. We have examined extensive collections of Pleistocene fossils from Western Australia but have never observed teeth of *C. megalodon* in these collections.

The known age for *C. megalodon* in Australia is from early Middle Miocene to Late Pliocene, the youngest reliable occurrence being from the Upper Pliocene Cameron Inlet Formation, Flinders Island (Kemp 1992). *C. megalodon* is most commonly known from Miocene deposits in Australia, with only three Pliocene occurrences known (Kemp 1992; Pledge 1985). In the well-preserved Tertiary sequences of New Zealand, *C. megalodon* ranges in age from Whaingaroan (Early Oligocene) through to the Opoitian (lower half of the Pliocene), consistent with the upper age limit observed for the species in Australia (Fordyce 1992). Therefore, we believe the presence of *C. megalodon* in the Jurabi Member may be interpreted as evidence of deposition of the unit in late Tertiary times, most likely during the Pliocene Period.

If the Jurabi Member is not younger than late Pliocene (the minimum age consistent with the fossil evidence now to hand), then uplift would have essentially ceased by that time. This would cause some problems in terms of the Quaternary sealevel record as we presently understand it for the western margin of the continent (see Kendrick *et al.* 1991). This new scenario would require that the entire range of Quaternary coastal deposition along the western Cape Range be located on or seaward of the present Tantabiddi Scarp. We note however, that up to the present only one Pleistocene marine unit is known with certainty from the Tantabiddi Terrace (Tantabiddi Member, Bundera Calcarenite) and that this is of Late Pleistocene age.

Two observations of van de Graaff *et al.* (1976) may be relevant here. They state: "Locally an unnamed poorly developed terrace, a few metres higher than the surface of the Tantabiddi terrace deposits, has been carved into the Jurabi Member.."; and further, "In places an older terrace has been completely eroded during the cutting of a younger terrace. North of Yardie Creek for example, the Tantabiddi Terrace cuts across both the Jurabi and Milyering Terraces. Where this has happened, a single scarp up to 20m high is present ...".

We have noted the existence of a thin, weathered coquina plaster, overlying the Jurabi Beds. This deposit may be indicative of a Pleistocene marine member, but the evidence is poorly noted and the deposit requires further study. There are other shoreline deposits on the eastern margin of the Cape Range which may be Middle Pleistocene in age (see below). Therefore, there are suggestions of transgressive Quaternary events prior to the high sealevel stand of the Last Interglacial. It is possible that the Tantabiddi Member, as presently understood, bears evidence for more than one transgressive event, ranging back into the Middle Pleistocene.

The ages of the Milyering and Muiron Terraces remain problematic. Clearly, they are younger than Middle Miocene and older than Late Pliocene in age. But at this stage in our understanding of events we can offer no better estimate of their ages.

From this perspective we draw attention to the important observations of van de Graaff *et al.* (1976), concerning extraneous lithologies represented in a basal conglomerate of the Milyering Member near Vlaming Head. The pebble fraction of this unit has clasts of various types of quartz, chert, banded iron-formation, ?acid volcanics, tourmaline-quartz and felspar. This assemblage resembles the bedload of the present Ashburton River near Onslow. This pebble assemblage, evidently transported as river gravels into the Cape Range area, suggests that at some time during the Middle Miocene to Late Pliocene, during progressive deformation in the area, the lower course of the Ashburton River was in proximity to the Cape Range region.

Denudational modification of the uplifted cabonate terrain

The Cape Range has attained a maximum elevation of around 300m and is now intensively eroded with deep canyons dissecting the opposing dip slopes. The general appearance of the associated Rough Range is quite different. It is a relatively small feature with a maximum elevation of around 75 m which is attained within 5 km of the west coast of Gales Bay. The Rough Range has not been greatly dissected and the alluvial accumulations flanking it are relatively minor. The Giralia Range has been extensively dissected with significant alluvial fills flanking the sides of the anticline and extending into the coastal region.

The large canyons which have developed on both sides of the Cape Range are linked closely with the details of the lithological succession and structural geology. Different members of the succession exhibit different characteristics and susceptibilities to chemical weathering. Mass failure of bordering canyon slopes is clearly related to rock mass characteristics and lithological and weathering controls. Canyon development must also be related to wider weathering history and processes of the area, but the details of this have not been studied.

Given the pervasive carbonate lithologies of the area it is only to be expected that karst terrain dominates the Cape Range. However, we know very little about the details and history of weathering processes and karst development in the region. In fact, the present understanding of karst formation in arid areas is generally incomplete (see the recent review by Ford and Williams 1989). As in similarly arid karst areas, it is difficult to establish the extent to which present day karst development is an integral of past climatic events which were more conducive to karst development. The relevant palaeoclimatic information is summarized in a companion paper in this volume (Wyrwoll 1993).

In the case of the Cape Range region, an additional question which arises concerns the influence that relatively recent uplift has exerted on karst development. This may be of special importance as the timing of uplift is likely to have coincided with the change of climate to more drier conditions. Ford and Williams (1989: 438) recognise the direct principal effects: (i) the vadose zone expands but may be perched above valley bottoms, depending on the rate of valley entrenchment; and (ii) the phreatic zone moves downward into less karstified rock. These processes will clearly be linked with stream entrenchment and the incised canyon forms which are so prominent in the Cape Range.

Much of the Cape Range is devoid of a soil/regolith cover, and karst pavement with a variety of minor solutional pavement forms is dominant. Most striking are strong doline forms and associated cave systems, both vertical and horizontal, which have developed in some lithologies. Variable intensities of karst development are evident on the various lithotypes, according to lithology, age and duration of exposure. Different intensities of karst development are also evident on the various age-reef complexes. This is reflected most directly in the differences in drainage network development which characterise respective reef complexes. In the coastal zone, Quaternary sealevel fluctuations have influenced karst processes, an aspect that is readily apparent on outcops of the Tantabiddi Member.

The geomorphology of the coastal margins of the region

There is considerable variation in the geomorphology of the regions flanking the Cape Range structure. The geomorphology of these regions strongly expresses the imprints of Quaternary sealevel events, climatic variations and the erosional response to uplift. In order to provide a convenient overview of the environments, the major morphostratigraphic and

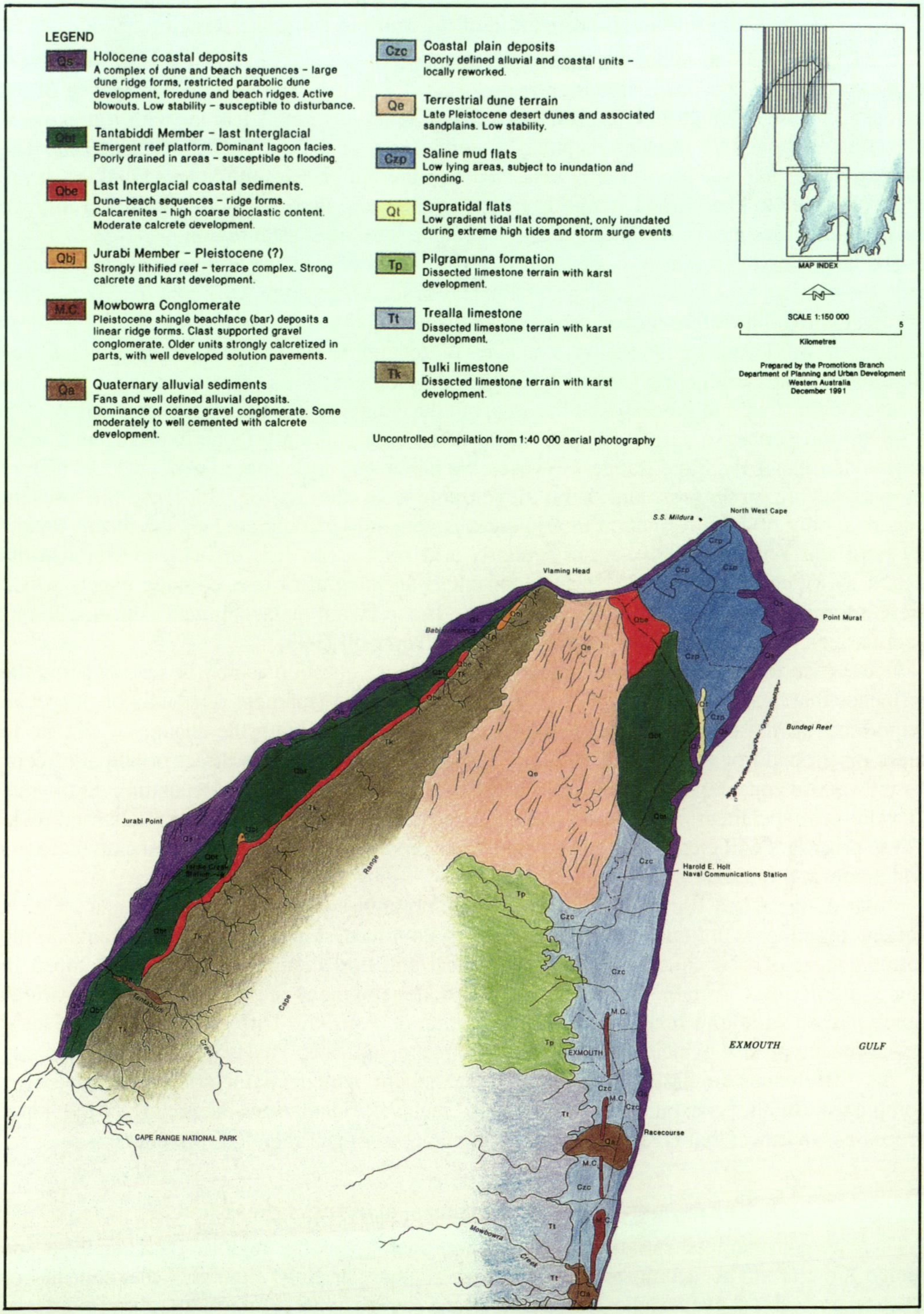


Figure 5. **a-c** The geomorphology and morphostratigraphy of the coastal region of the Exmouth Gulf - Cape Range area.

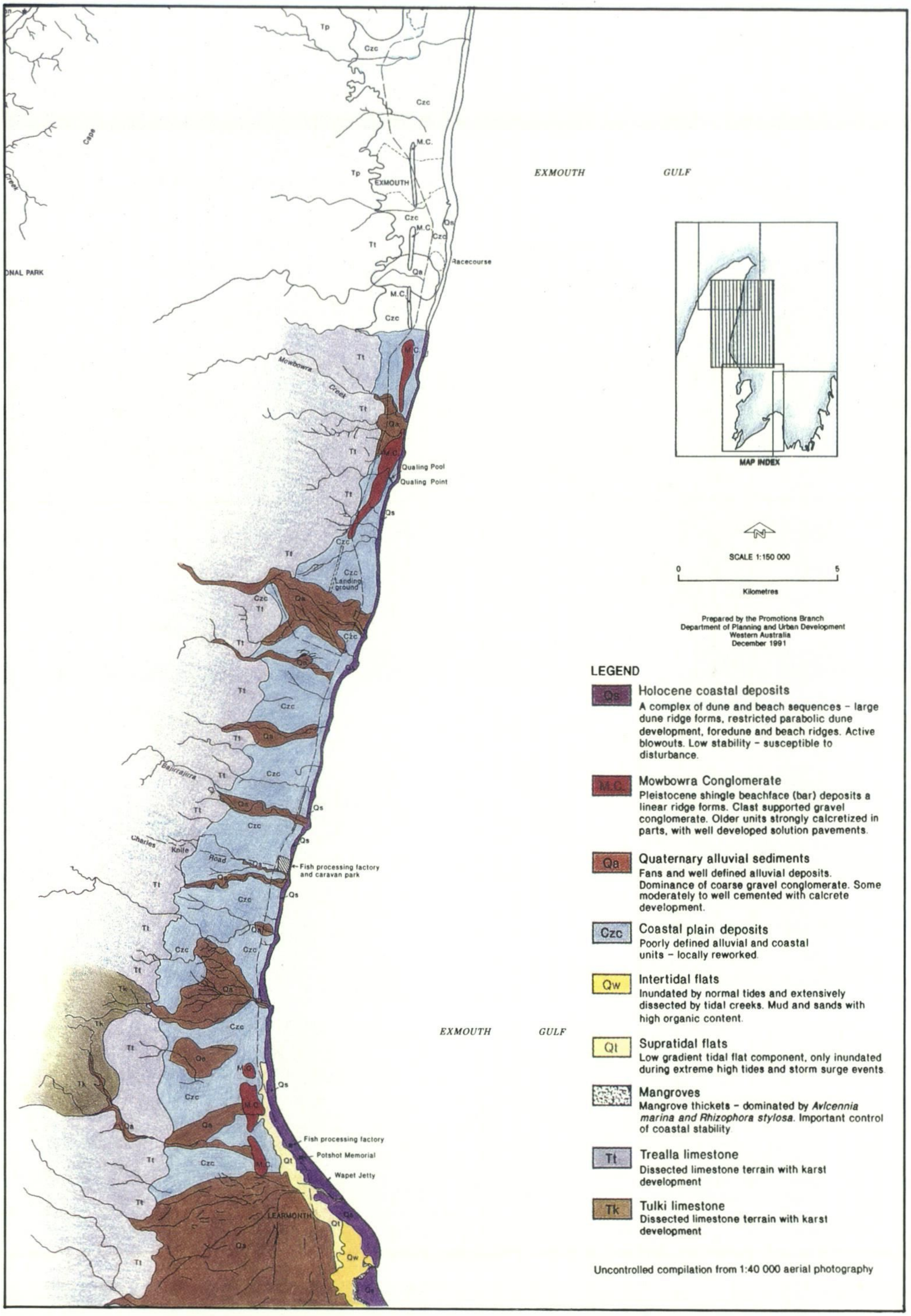
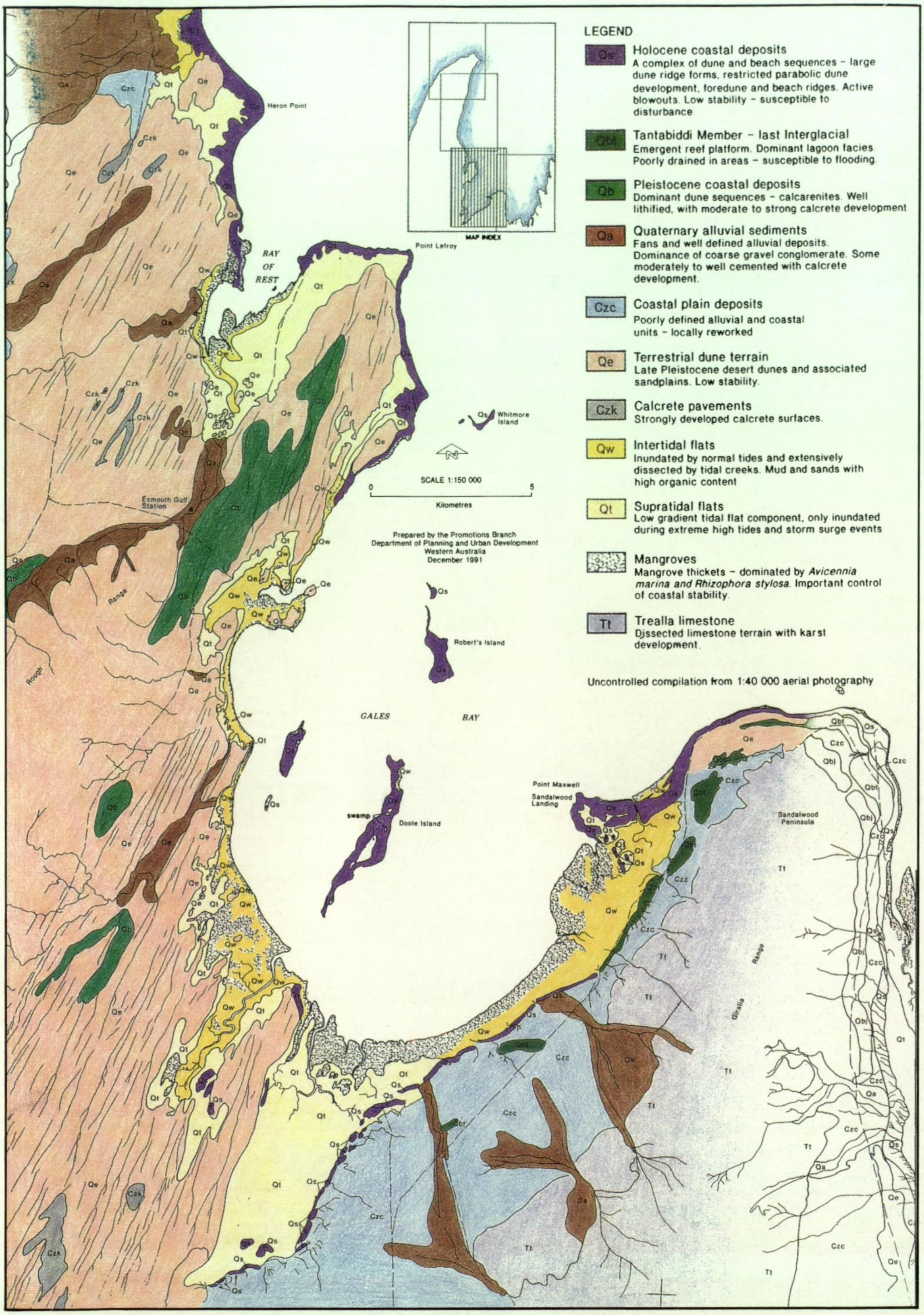

EXMOUTH GULF
EXMOUTH
Racecourse
Mowbowra Creek
Qualing Pool
Qualing Point
Landing ground
Charles Knife Road
Fish processing factory and caravan park
Fish processing factory
Potshot Memorial
Wapet Jetty
LEARMONTH
EXMOUTH GULF
MAP INDEX
SCALE 1:150 000
0
5
Kilometres
Prepared by the Promotions Branch
Department of Planning and Urban Development
Western Australia
December 1991
LEGEND
Qs Holocene coastal deposits
A complex of dune and beach sequences - large dune ridge forms, restricted parabolic dune development, foredune and beach ridges. Active blowouts. Low stability - susceptible to disturbance.
M.C. Mowbowra Conglomerate
Pleistocene shingle beachface (bar) deposits a linear ridge forms. Clast supported gravel conglomerate. Older units strongly calcretized in parts, with well developed solution pavements.
Qa Quaternary alluvial sediments
Fans and well defined alluvial deposits. Dominance of coarse gravel conglomerate. Some moderately to well cemented with calcrete development.
Czc Coastal plain deposits
Poorly defined alluvial and coastal units - locally reworked.
Qw Intertidal flats
Inundated by normal tides and extensively dissected by tidal creeks. Mud and sands with high organic content.
Qt Supratidal flats
Low gradient tidal flat component, only inundated during extreme high tides and storm surge events.
Mangroves
Mangrove thickets - dominated by Avicennia marina and Rhizophora stylosa. Important control of coastal stability.
Tt Trealla limestone
Dissected limestone terrain with karst development
Tk Tulki limestone
Dissected limestone terrain with karst development
Uncontrolled compilation from 1:40 000 aerial photography

Figure 5b.


LEGEND
Qs Holocene coastal deposits
A complex of dune and beach sequences - large dune ridge forms, restricted parabolic dune development, foredune and beach ridges. Active blowouts. Low stability - susceptible to disturbance.
Qbt Tantabiddi Member - last Interglacial
Emergent reef platform. Dominant lagoon facies. Poorly drained in areas - susceptible to flooding.
Qb Pleistocene coastal deposits
Dominant dune sequences - calcarenites. Well lithified, with moderate to strong calcrete development
Qa Quaternary alluvial sediments
Fans and well defined alluvial deposits. Dominance of coarse gravel conglomerate. Some moderately to well cemented with calcrete development.
Czc Coastal plain deposits
Poorly defined alluvial and coastal units - locally reworked
Qe Terrestrial dune terrain
Late Pleistocene desert dunes and associated sandplains. Low stability.
Czk Calcrete pavements
Strongly developed calcrete surfaces.
Qw Intertidal flats
Inundated by normal tides and extensively dissected by tidal creeks. Mud and sands with high organic content
Qt Supratidal flats
Low gradient tidal flat component, only inundated during extreme high tides and storm surge events
Mangroves
Mangrove thickets - dominated by Avicennia marina and Rhizophora stylosa. Important control of coastal stability.
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Djssected limestone terrain with karst development.
Uncontrolled compilation from 1:40 000 aerial photography
MAP INDEX
Heron Point
BAY OF REST
Point Lefroy
Whitmore Island
SCALE 1:150 000
0
5
Kilometres
Prepared by the Promotions Branch
Department of Planning and Urban Development
Western Australia
December 1991
Exmouth Gulf Station
Range
Rough
Robert's Island
GALES BAY
swamp
Doole Island
Point Maxwell
Sandalwood Landing
Sandalwood Peninsula
Giralia Range

Figure 5c.

geomorphological elements of representative coastal areas of the region are summarised in Figures 5a-5c.

Alluvial fans of the coastal margins - depositional response to uplift

A direct response to uplift has been the development of the associated alluvial fans which emanate from many of the canyons. The fans cover a large part of the coastal plain. Large fan-conglomerate sequences have been deposited at the canyon mouths throughout the Cape Range and, in places, grade into small fan-delta systems. Some older fan-delta complexes have been uplifted and erosional remnants are associated with the older terraces. The fan-conglomerates of the Cape, Giralia and Rough Ranges, include the Walatharra Formation (Condon 1968). In its type section the Walatharra Formation consists of a well cemented, thick, conglomerate sequence which is steeply dipping and which was clearly involved in the uplift of the Giralia Range.

In the areas adjacent to the Cape Range, alluvial fans have developed at the mouths of many of the gorges. Although, on the northeastern side of the structure, the alluvial deposits take more the form of inset alluvial fills, with younger units set into an older alluvial sediment body. The eastern side of the Rough Range is bordered by an alluvial apron. This apron attains a significant thickness and extends into the coastal zone. Similarly, the Giralia Range has a well defined alluvial fringe, which borders the immediate coastal area.

The size of the alluvial fans is directly related to the catchment area of the associated stream. Such a relationship has long been known from work in other areas (Bull 1962; Leece 1991). Where streams have a large drainage area, or where a number of major streams drain into adjacent areas, they can give rise to enormous accumulations of sediments, such as at Learmonth. Generally, larger fans are more developed along the eastern coast of the Cape Range, while those found along the northwest section of the coast are relatively limited in size.

There is also a pronounced difference in the overall morphology and drainage network characteristics of the fans on the opposing sides of the Cape Range. On the western side of the range, the fans take a more linear form, with some being quite irregular in their planform. These fans exhibit simple channel networks, essentially consisting of one major channel - which can bifurcate. Along the west side of the Cape Range, small scale fan-delta complexes are found.

On the east side of the Cape Range the fans are generally well entrenched at the fan head. Towards the apex of the fan a complex network of low order channels develop and emanate from this foci. These are partly abandoned former "main" channels, but are also small lower order channels which act as "spillways" during extreme discharge events. The network recombines further down the fan, leading to the formation of well entrenched major channels over the leading edges of the fan. There is a tendency for the major streams of some fans of the east side of the Cape Range, to become more incised downstream. However, in some cases the main channel dies out along the long axis of the fan.

The sediments of the fans are dominated by pebble to cobble sized conglomerates - some of the Tertiary limestones supply already well prepared "conglomeritic" clasts which require relatively minor stream abrasion to attain full conglomerate characteristics. Clast size varies between streams and is clearly related to drainage area via stream discharge. Some very large clasts, suggestive of very large discharges and exceptional stream competence, are found in some of the larger channels.

While no discharge data are available, an indication of the nature of likely flood stream discharge events can be obtained from calculated precipitation recurrence intervals (Institute of Engineers 1977). The 12-hour duration, 50-year recurrence interval intensity is 20 mm/hour. The 72-hour duration, 50-year recurrence interval rainfall intensity is 6.0 mm/hour. These figures, coupled with the catchment geology and geomorphology of the region, make it clear that high magnitude flood events can be expected; a fact reflected in the stream channel characteristics and gravel and boulder clast-sizes.

The gravel clasts are rounded to sub-rounded, polymodal and crude imbrication is evident in places. The deposits are crudely to horizontally bedded, with many massive units. There are very isolated planar tabular crossbedded beds, which are interpreted as representing large scour infill in the former channel; analogues of this mode of deposition can be seen in the present channels. Stratification consists of beds of clast supported, matrix filled conglomerate interbedded with finer textured sand beds containing matrix supported clasts.

Channel mesoforms are evident and, as expected, these vary with channel size. Channel pavements characterise stretches of channel. Well defined longitudinal bars with frontal and lateral slip faces are found in some small fan streams. These are usually associated with pebble and small cobble sized material. Geometrically less well ordered hummocky and other irregular channel forms are present. Channel mesoforms appear to be absent in large cobble and boulder sized material.

The alluvial architecture of the fans is expressed most clearly in road sections along the east side of the Cape Range. These sections generally show a complex depth variable palaeochannel channel form. Palaeochannel cross-sections are wide and thin with isolated deeper sections. The palaeochannels show some stacking, with the gravel channel trains separated by sand beds. However, the stacking of gravel units, of clearly different channels, without intervening sand beds also occurs.

As is to be expected, there is quite a strong difference between distal and proximal lithofacies of the fans, with a noticeable increase in fines away from the range front. In proximal sections there is a predominance of massive or crudely stratified, clast-supported gravels generally bimodal or poorly-sorted. Down fan this changes to clast supported matrix filled beds with some interbedded sand. In some distal reaches the sediments consist of matrix supported clast frameworks, with a greater dominance of fines and finer textured beds. These lithofacies changes are not evident in the fans of the western side because of their restricted long-axes extent. Similarly, a clear contrast exists between the alluvial deposits of the Cape Range (strong conglomerate lithofacies) and the Rough Range (less conglomerate) and the Giralia Range (more sand textured sediments).

The only real chronostratigraphic control that is presently available for the fans is provided by the Quaternary coastal units. It is evident from calcrete horizons that discrete time-stratigraphic units are present in the fans. But, so far, it has not proven possible to establish a regionally valid event stratigraphy based on packages of genetically related stream gravel/facies bounded by unconformities.

The Late Quaternary stratigraphic framework which is available makes it clear that the alluvial fans saw active deposition during the Last Interglacial and at times prior to the Mid-Holocene. Deposition is active on the alluvial fans today. But during the last 15 years there has not been one discharge event of sufficient magnitude to move the very large boulder material that is present in some of the channels (e.g. at Mandu Mandu).

The fanglomerates are potentially of enormous palaeoclimatic significance as they relate to large discharge events. Given the important contribution that tropical cyclones make to the mean annual precipitation (Wyrwoll 1993), it is likely that fanglomerate deposits could serve the role of a proxy indicator of tropical cyclone activity. However, this could only be achieved if high resolution numerical age control is available.

Pleistocene desert dune terrain

Pleistocene desert dune terrain is found in two major areas: the extreme northern part of the peninsular and the southern part of Exmouth Gulf (Figures 5a, c). Clearly defined dune bedforms are present in both areas, and the two dune fields indicate a significant climate change in this area to more extreme arid conditions. At North West Cape, the dunes overlie Last Interglacial marine deposits and must post-date that event. During early work in this region preliminary attempts were made to establish the age of the dunes by obtaining ^{14}C dates on the pedocalcic horizons which have developed in some dunes. Not surprisingly, given the geochemical setting of the deposits, problematic dates were obtained. Any ^{14}C date from this region obtained from soil-carbonates must be viewed with suspicion. More recently two thermoluminescence dates (Table 1) were obtained on the dunes at the northern end of the peninsula (Figure 5a) and these yielded a Last Glacial Maximum age.

The sediments of the desert dune assemblages differ significantly between areas. The dunes of the northern part of the Cape Range the southern and eastern Exmouth Gulf, consist of red siliceous sand, while those of Gales Bay also include dunes with more carbonate rich sediments. Little pedological differentiation occurs in the profiles of red siliceous dune sediments. In the paler, more carbonate rich sediments, pedological differentiation is evident with quite well developed profile horizonation. The upper part of the dune consists of loose, pale-chocolate brown coloured sand, with an irregularly, crumbed structure and pervasive roots and burrows. The upper part of the profile grades downwards, with a diffuse boundary, into a moderately compacted pale sand with carbonate segregations, which become less evident down the profile.

Much of the southern part of the Gulf is bordered by extensive desert sand dune terrain. The dunes and associated sandplains have played an important role in controlling the characteristics of Holocene tidal flat development. The Yanrey Tidal Flat (see below) overlies, and is the present coastal extension of this older longitudinal dune and sandplain terrain. Dune remnants form islands within the tidal flat and have acted as nuclei for high-level supratidal accumulations giving rise to very distinct ecological zonations. Hope Island provides an excellent example of this, being dominated by a core of large linear dunes.

Table 1. Details of the thermoluminescence dates obtained from the desert dunes on North West Cape *sensu stricto*.

Specimen number	Reference	Temperatures (°C) Plateau	Analysis	Accumulated dose (Grays)	[1]K content (%)	[1]Rb content p.p.m.	[2]Moisture content (%)	[3]Alpha activity (counts $ksec^{-1}cm^{-1}$)	[4]Annual radiation dose ($mGy\ a^{-1}$)	[5]Age (ka)
W738	Ex1-1988	300-425	375	29.6	0.71	25.3	1.7	0.18	1263	23.4 ±6.7
W739	Ex2-1988	300-500	375	14.08	0.47	17.3	0.9	0.118	881	16.0 ±1.7

[1] Potassium and rubidium levels were determined by means of x-ray fluorescence. [2] Corrections were made for moisture content as measured from specimen supplied. [3] The alpha activity of the specimen was measured using "thick source" alpha counting. [4] The A.D.R. values were computed assuming there to be no disequilibrium in the U and Th decay chains. [5] The errors shown represent one standard deviation of the measurement made. In these determinations no correction has been made for residual surface TL.

The stratigraphic context of the dunes of the Yanrey Tidal Flat is similar to the classic dune sequences of the Fitzroy Estuary (Jennings 1975), and provide evidence for arid-zone extension and desert dune advance into the present onshore region during the Late Pleistocene. The dunes overlie older coastal and alluvial plain deposits, the latter having developed through stream displacements and provide the geomorphological infrastructure of the eastern margin of the Exmouth Gulf. It is to be expected that the dunes have been repeatedly reworked during various Pleistocene arid phases. An extensive program of thermoluminiscence dating of the dunes, which is presently underway, should clarify the age structure of the erg.

Coastal geomorphology and sealevel change

The range structures of the region are bounded by a very distinctive coastal fringe. The geomorphology and morphostratigraphy of this coastal zone has been largely controlled by Quaternary sealevel events. The significance of the coastal marine Quaternary succession of the area needs to be seen in the context of our wider knowledge of Quaternary sealevel events along the western margin of Western Australia. A summary of Pleistocene sealevel events for the western margin of Western Australia is given by Kendrick *et al.* (1991). For a detailed discussion of the sealevel history of the Last Interglacial, reference should be made to Zhu *et al.* (1993). An up to date discussion of Holocene sealevel events and controls along the coast of Western Australia is provided by Lambeck and Nakada (1990) and Eisenhauer *et al.* (1993). For the convenience of the reader, a summary of Late Quaternary sea level events is given in Figure 6.

The Pleistocene marine morphostratigraphic units of the coastal plain

The known Late Pleistocene coastal units of the western and northeastern margins of the Cape Range constitute the Tantabiddi reef complex (together with associated beach and dune morphostratigraphic units) and the Mowbowra Conglomerate which represents a series of shingle beachface (bars) sequences. The latter have resulted from the injection of fanglomerates into the nearshore zone, where they have been incorporated into beachface and shoreface sequences. Such deposits are especially pronounced in the eastern part of the Cape

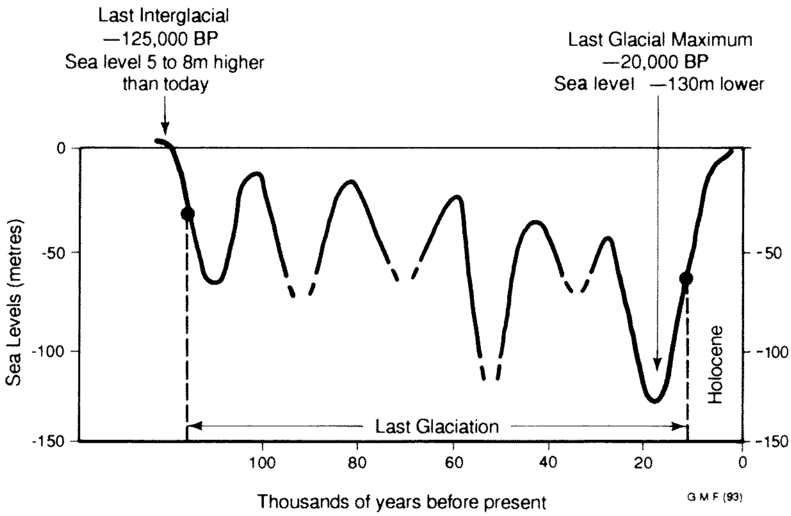

Figure 6. The record of Late Quaternary sealevel variations.

Range, where both Holocene and Pleistocene shingle-storm ridges (bars) constitute a significant portion of the coastal plain and core some of the Holocene coastal dunes.

The difficulties of dating the component elements of the Mowbowra Conglomerate are formidable, and from field relationships we consider it likely that some units of the Mowbowra Conglomerate are older than Late Pleistocene. Similarly, there are some field indications that some units attributed to the Tantabiddi Member (see below) may, in fact, be Middle Pleistocene in age.

The Tantabiddi Member

The Tantabiddi Member of the emergent reef complexes dominates the coastal geomorphology of the western and northern parts of the Cape Range and has been a major control on the pattern of Holocene geomorphological development in this area. The Tantabiddi Member is also evident in the geomorphology of the northern part of the Giralia Range. Three U-series dates were originally obtained by Veeh *et al.* (1979) — 111±6 ka BP, 120±7 ka BP and 138±7 ka BP — indicating a Last Interglacial age. More recently a more extensive series of U-series dates also give a Last Interglacial age for the Tantabiddi Members and associated morphostratigraphic units (Kendrick *et al.* 1991).

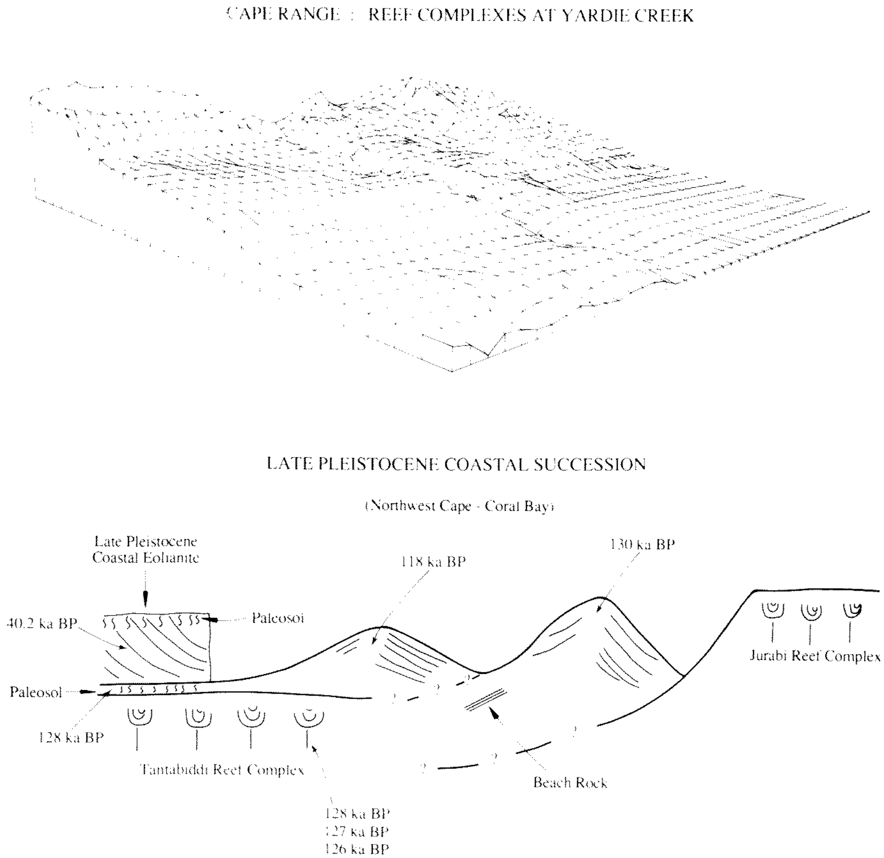

Figure 7. Schematic summary of the Late Quaternary coastal succession of the western margin of the Cape Range.

A strong geomorphological expression characterises the Tantabiddi Terrace/Member in the form of a continuous coastal plain which is strongly developed along the northeastern and western sides of the Cape Range; locally this may attain a width of up to 5 km. The deposit represents a former fringing reef and associated lagoonal environment, analogous in some respects to the modern Ningaloo lagoon and inshore reefs. The Tantabiddi Terrace has no connection to any coeval offshore barrier reef; presumably that persists as a foundation to the modern barrier.

At its seaward margin, the Tantabiddi rises to little over 1m above modern high water mark. Heights of up to 5.5m above low water mark were recorded for *in situ* corals by van de Graaff *et al.* (1976: Table 21). At its seaward margin the Tantabiddi is widely overlain by Late Pleistocene and Holocene dune and beach units (Figure 7). The inshore margin of the Tantabiddi Terrace is indicated by the conspicuous and well-preserved Tantabiddi Scarp, the result of shore erosion of the Jurabi Member. Occasional small sea caves occur here. Associated dune and beach units mark the position of the Last Interglacial shoreline and in places, extend on to the Jurabi Terrace.

A section through this sequence on Pilgramunna Creek shows at the base a medium-textured, rubefied and moderately indurated calcarenite. Above this is a low angle, planar cross-bedded, medium-textured calcarenite containing shells and coral debris. This is interpreted as an intertidal beach face/ beach rock deposit. Above this is an aeolian calcarenite, with large scale cross-bedding. Large solution pipes penetrate this dunal deposit from a strong surface calcrete. A uranium-series age for transported coral from the beach rock unit here was 130±6 ka BP (Kendrick *et al.* 1991: 428, Table 1). The full extent to which the Late Pleistocene shoreline actually extends to the Tantabiddi Scarp is something that remains to be determined. The presence of other older Pleistocene units associated with the Tantabiddi Terrace cannot at present be ruled out.

Exposures of the Tantabiddi Member are generally poor, being restricted for the most part to surfaces, where the outcrop is often covered by other surficial sediments. Thus details of the facies relationships within the overall reef-lagoon complex are not readily available. Sections along the present coastal margin show that hermatypic coral frame can be the predominant structure, with coralline algal encrustations generating strong boundstone development. Other lithofacies include calcarenites and calcirudites; some conglomerates record former stream-gravel injections into the Tantabiddi lagoon. Small lagoonal patch-reef coral clusters occur in the more central - offshore parts of the platform, an example of which is located at Mangrove Bay. Forty eight species of molluscs from the Mangrove Bay outcrop are listed in Kendrick *et al.* (1991: 439, Appendix 3).

Studies of the Tantabiddi molluscs from Mangrove Bay indicate that most are species represented in the modern Ningaloo lagoon fauna. A notable exception to this is the turbinid gastropod *Astralium rhodostomum* (Larmarck) which, in modern seas, is not recorded south of the Kimberley coast, a difference of some 6 degrees of latitude. The species, with its strong, southerly Late Pleistocene expansion and subsequent contraction, exemplifies a widespread pattern of distributional change during and since oxygen isotope Substage 5e of the Last Interglacial. This topic is discussed further by Kendrick *et al.* (1991).

The Tantabiddi Member records a Last Interglacial sealevel which was some *c.* 5 - 6m higher than present. The wider importance of the Tantabiddi Member lies in:

(1) It is suggestive of two discrete sea level events during the period *c.* 125-140 ka BP. The global importance of this problem has been discussed by a number of authors (Moore 1982;

CLIMAP Project Members 1984; Pillans 1987) but despite this, uncertainty still remains (most recently, Li *et al.* 1989; Chen *et al.* 1991 and Zhu *et al.* 1993).

The problem was also addressed by Veeh *et al.* (1979) in their work in the Cape Range - Lake McLeod area. From their data they concluded that neither the stratigraphic separation nor the dates obtained allowed them to unequivocally state that there was a dual peak during the Last Interglacial — "although the results would be consistent with such a hypothesis" (Veeh *et al.* 1979: 289). The dual "barrier" stratigraphy associated with the Tantabiddi Member suggests the possibility that there were two sea level events during Stage 5e and this is supported by conventional uranium-series dates. However, the evidence is not convincing and high resolution mass spectrometric uranium series dates (see Zhu *et al.* 1993) are now being obtained.

(2) The stratigraphy and supporting dates for the Tantabiddi Member give no evidence of sea level reaching its present height (or above) during the later part (i.e. after Substage 5e) of the Late Pleistocene (cf. Vacher and Hearty 1989). The only evidence for a transgressive event approaching modern sea level comes from an aeolian dune unit widely seen to overlie a palaeosol. A section featuring this unit at Bolman Hill, on the coast south of the Cape Range, is discussed by Kendrick *et al.* (1991: Figure 7). This dune unit, with a thermoluminescence age of *c.* 40 ka BP, shows that sea level was high enough and the shoreline close enough for aeolian dunes to have reached the present shoreline.

The bathymetry of the continental shelf in this region makes the area especially suitable for registering such evidence. The shelf is very narrow (*c.* 10 km) between North West Cape and Coral Bay and this brings the shelf break closer to the coast than at any other location in Australia. It is not surprising therefore that the coastal stratigraphy registers a Late Pleistocene high sea level event - in the form of a coastal dune unit - the question as to the height at which the transgression peaked, remains open. Some care has to be exercised when ascribing a Holocene age to the beach ridge - dune sequences of the northern part of the peninsula; in parts some of the dunes may be Late Pleistocene in age or partially reworked Late Pleistocene sediments.

The Mowbowra Conglomerate and other Pleistocene coastal units of the Exmouth Gulf

The identification of the Pleistocene coastal succession is more difficult along the eastern side of the Cape Range because of limited sections and more extensive development of a surficial cover of stream deposits. The Tantabiddi reef platform which fringes the western and northeastern coast of the Cape Range is absent from much of the Exmouth Gulf, with the exception of the northern part of the Giralia Range. The only date so far obtained for the Late Pleistocene members of the Exmouth Gulf, is that of Veeh *et al.* (1979) who obtained a U-series date of 111±6 ka BP for a shoreface coral-rich facies exposed at the mouth of Mowbowra Creek. Consequently, the chronological framework proposed for the Exmouth Gulf sequences discussed below is tentative, being based on general field relationships and correlation with the dated sequences of the west side of the Cape Range.

A possible Last Interglacial unit is present south of the Exmouth townsite, on the landward side of large Mowbowra Conglomerate deposits. The unit is a medium to coarse calcarenite containing an abundance of molluscs, corals and bryozoa skeletal materials. A nodular soil carbonate profile, similar to that developed over the landward beach/dune unit associated with the Tantabiddi Member, has developed in the upper part of the unit. No coastal dune eolianite sediments overlie the marine sediments. The marine sediments overlie a beachface, shingle

(Mowbowra Conglomerate) - indicating a transgressive sequence of events. Late Pleistocene fanglomerates overlie the marine units.

The Mowbowra Conglomerate is a major unit of the Exmouth Gulf coastal plain. Its type section is located along the lower course of Mowbowra Creek. Here, a number of large shingle beach (bar) units of Pleistocene age can be distinguished. These take the form of large, composite "linear mounded-ridge forms", the most landward of these has a height of *c.* 8 m. The formation is characterised by a clast supported gravel-shingle, with isolated lenses of coarse calcarenite. The clasts of these sediment bodies are characteristically smooth disc and spherical cobble shaped, well sorted, often with an imbricate fabric. Abraded corals and molluscs occur throughout the deposit and form lags along some bedding planes.

The deposits are composite with an upper member separated from a lower member by a strong calcrete. Cementation in the lower part of the deposits is poor and individual clasts can be picked out by hand. The surface of the outcrop is strongly calcretised with a well developed solution pavement. The 'shingle unit' is underlain by a clayey sand containing matrix supported gravel clasts. These clasts are more rounded and have none of the disc shaped characteristics of swash worked clasts, and are likely to be a stream deposit.

The deposits are stratified, with indications of planar bedding and inclined beds. At the eastern margin of the outcrop, beds dip to the east at angles of 18^0. These beds are sand dominant and interbedded with thick shingle beds. At the mouth of the creek the beachface facies - shoreface facies transition can be clearly distinguished.

The Mowbowra Conglomerate has a wide distribution and the outcrops show various intensities of karst and calcrete development. Some of these may be of Middle Pleistocene age but this suggestion requires further study and the development of an absolute chronology for the formation.

Towards the southern part of Exmouth Gulf, longitudinal desert dunes overlie some coastal deposits, limiting access. Outcrops are more isolated and detailed examination of the Quaternary succession has yet to be completed.

The Holocene coastal sequences

The dominant Holocene element of the coastal geomorphology of the region is the Ningaloo Reef, which bounds the west of the region. The reef has a strong barrier expression, is partly breached and exhibits a distinctive lagoonal circulation pattern and associated sediment transport regime. There are no data on the Late Pleistocene - Early Holocene growth history of the barrier. In fact, essentially no work has been undertaken on the geomorphology and geology of the extant reef system.

It is largely due to the work of Brown (1988) and his co-workers (Clifton 1974; Caldwell 1976; Logan *et al.* 1976; Murray 1976) that the Holocene geology and geomorphology of the Exmouth Gulf is reasonably well known. There is a stark contrast in the sandy beach/dune dominance of the northern parts of the Exmouth Gulf and the strong tidal flat - mangal development of the southern and eastern parts. In the areas of strong tidal flat development there is a strong relationship between the biota and the sediment facies. This occurs at a variety of spatial scales, ranging from biotopes (*e.g.* mangal) to microbial mats.

The details of the Holocene sealevel history for this region, while known from general field evidence, remain to be dated and their significance fully evaluated. Using two different "ice-mantle" models, Nakada and Lambeck (1989) predicted a Holocene (at 6 ka BP) sealevel high stand for the Exmouth Gulf of 0.9 -1.5 m.

In the Exmouth Gulf the large tidal range, the nature of the coastal environments and the likely influence of storm surges make it difficult to reconstruct Holocene sea levels. Storm surges associated with tropical cyclones are triggers of coastal instability and leave their imprint on the coastal geomorphology. Clear evidence of storm surge activity can often be found, such as on Simpson Island, where the cliff line, some 4 m high was breached and evidence for overwash deposition was widespread. Along much of the northern and western areas evidence of storm uprush occurs within the dune areas. The Holocene shingle beach deposits of the Exmouth Gulf also attest to high energy conditions. Logan *et al.* (1976) note evidence for very high tides (at least 5 m above normal HWS) in the southern Exmouth Gulf and southward directed wave-trains are indicated by extensive strandline accumulations resultant on cyclone occurrence. There is clear field evidence along the western margin of the Cape Range that sea level was higher than present (by possibly 1-2 m) at some time during the Early-Middle Holocene.

In terms of the coastal geomorphology a distinction can be drawn between the dune ridge and beach sequences of the western and northern parts of the peninsula and western Exmouth Gulf and the tidal flats of the southern and eastern Exmouth Gulf. In the discussion of the stratigraphy of the Tantabiddi Member attention was drawn to a coastal dune unit dated at *c.* 40 ka BP. Although, it has so far not proven possible to identify this unit in the northern part of the Ningaloo Reef tract, there is a possibility that parts of sequences thought to be Holocene may be (reworked?) Late Pleistocene in age.

Dune ridge and beach sequences

The Holocene depositional pattern of coastal dune and beach deposits along the Ningaloo Reef tract, is widely controlled by the circulation of the lagoon. The circulation of the lagoon is driven by wave pumping across the reef and wind and tidal forcing. Incident wave energy is dissipated on the seaward reef slope. The reef is the source of most of the sediments incorporated into the Holocene sand deposits. Consequently, the Holocene history of the dune/beach units is closely related to the Holocene history of reef growth and evolution and, more generally, carbonate productivity. It is not surprising therefore, that stratigraphic evidence indicates more dominant mangrove environments during the early part of the Holocene transgression.

Along the western margins of the Cape Range, the development of many of the major zones of Holocene deposition can be directly related to reef morphology. For instance, large cuspate foreland development, such as Jurabi Point, is directly related to wave diffraction through reef breaks. The resultant circulation and sediment redistribution is clearly indicated by large transverse bedforms which stand at an acute angle with the shore.

The overall depositional pattern controlling major foreland development was that of shore parallel dune and beach ridge structures, which aligned themselves with the opposing limb of large lagoon circulation gyres. Jurabi Point, provides the best example of this, and is related to reef breaks both to the north and south. Less well defined, but nevertheless, significant foreland accumulations are found south of the mouth of Tantabiddi Creek and at Bajarrimannos. In both cases the lagoon circulation controlling growth is more complex than at Jurabi Point, but the importance of reef structure is still obvious.

Much of the rest of the western coast has a relatively narrow Holocene dune-beach fringe, often composed of one or two major dune ridges. In some cases the original shore parallel dune ridge morphology has been destroyed by more recent dune instability and the development of large blow-outs with the resultant transgressive lobes burying the northern extension of the eroded ridge forms.

The northern margin of the Cape consists of a large single dune ridge, but with a braid in its central section, in which some large blowouts and unstable areas have developed. It is clear from the stratigraphic evidence, that much of the northern part of the Cape Range peninsula was a shallow lagoon during the Middle Holocene. A major foreland has developed at the northeastern side of the peninsula, focused on Point Murat. A notable feature of this area are parabolic dunes, which in part, are transgressive over older dune and beach ridges.

The overall development of the foreland in this area, may be related to the controlling influence of the underlying Pleistocene geomorphological structures, and especially that of Bundegi Reef. South of the reef, a complex of crenulate shore-parallel bars occur in the nearshore zone. These grade northwards into a sandflat, without major bedforms, which lies between the reef and the shore. Broad, 3D bar forms, with an acute angle to the shore, have developed at the northern margin of the northern most part of the reef. A sediment plume streams northwards from Point Murat, towards the Cape. It is clear that the foreland development is related to the trapping of a northward directed sediment train, and is also facilitated by the shelter given by the northward extension of the Ningaloo Reef and the wave diffraction and refraction processes associated with this.

Point Murat forms the major Holocene beach/dune body along the western margin of the Exmouth Gulf. South of this, the Holocene coastal sequences become more simple, more restricted in width and in parts, with ill defined topography. In its more narrow sections the Holocene is little more than a single dune beach-ridge. In other sections of the coast, the Holocene deposits form a wider coastal fringe, consisting of a complex of beach-dune ridges.

Further south of the Exmouth townsite, shingle beds make up a large part of the volume of apparent dune ridges. Similar stratigraphies were also observed at a number of other locations, as far south as Learmonth. At the mouth of some creeks large active shingle beachface (bars) are present. These extend well into the backbeach environment and are in places, covered by a thin veneer of dune sand. Limited volume and restricted extent are characteristics of the Holocene dune/beach deposits of much of the western Gulf. This is related to both limited sediment supply and a low energy environment. Although, the occurrence of high energy cyclone events is well registered by the Holocene coastal stratigraphy.

Tidal flats

The most extensive areas of tidal flats occur in the southern part of the Exmouth Gulf, where the Yanrey Tidal Flat forms the major tidal flat in the region. More minor occurrences of tidal flats are found in other parts of the Exmouth Gulf, with those at Gales Bay and Bay of Rest being the most prominent. There is evidence from the northern most part of the peninsula and from the west side that mangroves have been much more extensive along the coast during the Middle Holocene (6-4 ka BP). This is indicated by the lithostratigraphy and the presence of concentrations of fossils (including midden material) of mangrove - associated gastropods such as *Terebralia palustris* (Linnaeus) in areas now remote from extant populations.

In fact, some of the clearest evidence for higher sealevel stands during the Holocene comes from small tidal-inlets and larger lagoons which formerly supported mangrove stands. Kendrick and Morse (1990) describe one such former lagoon from the Point Maud area, which exemplifies the formerly more extensive mangrove occurrence along the west coast. At Point Maud a palaeolagoon is defined by two richly fossiliferous shell beds. The younger is an extensive pale sandy coquina. Shells of the large cardiid bivalve *Acrosterigma dupuchense* from this younger unit, yielded a radiocarbon age of 5230±60 years BP. This date is thought to represent the approximate time of cessation of marine exchange.

It is likely that the decline in mangrove extent in this area may in part be a response to a more sand dominated coastal depositional environment over the last few thousand years. At present the reef generates most of the sediment of the nearshore zone. During the early part of the Holocene transgression it is likely that less reef generated sediment was available. A similar decline in mangrove stands has been recognised widely throughout northern Australia (e.g. Woodroffe *et al.* 1986).

The tidal flats show distinctive biotic and sedimentological zonation. Mangrove growth is widespread, and the mangal separates a lower tidal flat from the higher zones. *Avicennia marina*, is the dominant mangrove species. In more sheltered situations patches of *Rhizophora stylosa* are well represented. The mangrove thickets and the adjacent immediate landward areas are affected by normal tides, but beyond that there is a very low gradient supratidal flat. The tidal flats are dissected by meandering tidal creeks which are incised below the mangal, in places exposing the underlying Pleistocene formations. Brown (1988) has undertaken a detailed study of tidal flat characteristics and the descriptions that are given below are based largely on his work.

(i) Lower tidal flat sedimentation: the range extends from the margins of the mangal to low water spring level, so that it corresponds essentially in the intertidal area. It consists of sand, shelly sand and muds and sandy muds. The lower tidal flat is characterised by a variety of bedforms ranging from ripple structures through dune to large bar forms. Intense bioturbation is characteristic of much of this zone. Algal mats are strongly developed in some areas.

(ii) Middle tidal flat sedimentation: the vertical range of this zone incorporates the mangal and extends to approximately midway between high water neap and high water spring tide level. The zone is dominated by mangrove thickets and is dissected and borders tidal creeks. The mangal has a sharp seaward boundary with more of a transitional boundary at its landward margin. The mangal acts as a roughness element for the water flow and hence forms an important buffer during storm and surge events. The sediments consist of muds and sand with a very high organic content and in which there is pervasive bioturbation. More sandy textured sediments are often found at the landward margin of this zone, which can take the form of quite well defined beach ridge structures.

(iii) Upper tidal flat and supratidal flat sedimentation: dark green to black coloured, blue-green algal (cyanobacteria) mats are developed within the upper intertidal zone. Mat development continues upslope in the form of reddish-brown sheets that are extensively impregnated with sediments. The uppermost rim of the flat is demarcated by halophytes. The supratidal flat is up to 15 km wide and is mostly salt encrusted. Landward of this, occurs a beach ridge margin, with chenier development in places. The beach ridges probably formed during cyclones when the effective shoreline was landward of the supratidal flats. The extent of the supratidal flats and chenier - beach ridge units are, in part, likely to be related to the higher sea levels of the Middle Holocene. But storm surges associated with tropical cyclones would also be responsible for sediment deposition well above the normal strandline.

Conclusions

The paper has aimed to provide a register of the aspects of the geomorphology/surficial geology of the Cape Range - Exmouth Gulf region, as they are presently known to us.

Although, the information we have provided is selective and incomplete, we hope that we have provided some of the background relevant to an understanding of the natural history of the area and that this information can be readily used by others. The challenge that remains to all, is to integrate our understanding of the biology and geology/geomorphology of this region in such a way that it amounts to a true geoecology. For, in few areas is the relationships between geology/geomorphology and biology so strong as it is in the Cape Range-Exmouth Gulf region. If we want to understand the natural history of the region, in an explanatory sense, this integration has to be achieved.

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