CHAPTER 5

THE HERBERT RIVER DELTA

At the northern end of Halifax Bay the narrow coastal plain widens into the extensive deltaic plain of the Herbert River. The Herbert, with a catchment area of 3,400 square miles and a mean annual flow of 2.878 million acre feet, is a much smaller river system than the Burdekin and its delta is only about one third the size. However, though the rainfall of the delta area is approximately 80 inches per year, or twice that of the Burdekin, the climate, geology and physiography of the catchment of these two major rivers, are very similar. Unfortunately, a detailed analysis of the morphology and evolution of the Herbert delta is not possible for a number of reasons. Firstly, although this delta supports a vigorous sugar cane industry, with agriculture limited to the higher levee soils as in the Burdekin, there is a belt approximately 5 miles wide of mangroves and freshwater swamps along the coast which is almost completely inaccessible, except along three roads. Secondly, because of the higher rainfall, irrigation of the sugar cane is not necessary and there has not been the same intensity of drilling in the Herbert delta as in the Burdekin. The higher rainfall also means that the Herbert delta is much wetter than the Burdekin with large areas of swamp behind the levees, even back from the coast, and this too hinders access. For the same reason, vegetation is much more luxuriant and where uncleared is difficult to traverse on the ground, overgrows any stream bank sections and generally makes interpretation from the air more difficult.
Nevertheless, probably because of the simplicity of the Herbert delta, a satisfactory resume may be made of the more recent evolution of the morphology of the area. The lower Herbert is much more restricted than the lower Burdekin and occupies a funnel shaped embayment opening towards the south-east between the Cardwell Range to the north and the Seaview Range to the south. Both ranges are part of a Permo-Carboniferous igneous complex comprising porphyritic volcanics, various granitoid rocks and acid and basic dykes (De Keyser, Fardon and Cuttler, 1965). These rocks have a strong south-west to south-east trend and are cut by the major Palmerville fault which has a similar trend and is thought to underlie the Herbert delta. The Hinchinbrook Island massif further restricts the deltaic area to the north. Although the coast of the delta has an orientation south of east, this is not as open a coast as might be expected as considerable protection is given by the Palm Islands, 12 miles off-shore and by the smaller islands of Halifax Bay. Nevertheless, a strong south to north littoral drift exists which has swept material northwards from all the former distributaries of the Herbert.

Previous geomorphological work in the area has been sparse. The Cainozoic deposits are briefly described by De Keyser, Fardon and Cuttler (1965). Information of geomorphological interest is also contained in a number of local and State Government reports (Hinchinbrook Shire Council, undated Report on Stream Improvements; Report on Flooding in the Ingham District, 1967; Calvert, 1959). The report by Calvert on groundwater investigations of the Herbert River delta contains the only reliable borehole data. Unfortunately only 27 boreholes are recorded of which 11 reached bedrock. Macnae (1966, 1967) has described the mangrove ecology of the northern part of the delta at the southern end of the Hinchinbrook Channel.
Bedrock Morphology

The few borehole records available are limited in the area they cover and restrict the reliability of the map of bedrock morphology drawn from them (fig. 5.1). There are numerous rock outcrops in the lower delta which suggest that deltaic deposits are shallow to the north of the present course of the Herbert and also along the southern edge of the plain. The borehole evidence confirms this and also indicates the extension of a subsurface ridge northwards towards Trebonne. The gap between this ridge and the Mount Leach Range is narrow, less than 2 miles wide.

It is in this gap that the main bedrock channel is cut. Near Trebonne the bedrock channel apparently coincides closely with the present course of the Herbert, but whereas the present river swings north-eastwards at Ingham, the older bedrock channel continues towards the east probably crossing the coast just north of Allingham. The channel is surprisingly deep and gorge-like, having a depth greater than 250 feet below sea level beneath Ingham and in all probability greater than 300 feet before it crosses the coast. Two and a half miles north of Mount Mercer a bore reached 288 feet below sea level without finding bedrock. Even near Trebonne a borehole reached bedrock at 121 feet below sea level and it is likely that the channel here is over 150 feet deep.

South-west of Trebonne, bedrock was not reached at 106 feet. Apparently the Stone River also has a deeply incised channel which is a tributary to the main Herbert. Further east is another tributary channel trending north from the Seaview Range, this may be connected with the Stone River south of the northern-most outcrop which breaks the surface.
Fig. 51 Herbert River delta, bedrock contours.
Extension eastwards of the main channel brings it into the vicinity of the Palm Islands. Admiralty charts suggest three passages for the Herbert during Pleistocene low sea level phases. The most obvious is a channel between Brisk and Havanna Island, passing south of Great Palm Island. However, another channel leads northwards just west of Orpheus Island, whilst the deepest channel of all, meanders between the Palm Islands, passing out to sea between Fantome and Curacoa Islands.

The Deltaic Deposits

The deltaic deposits reach a maximum thickness of more than 315 feet in the Palm Creek area. Examination of borehole records indicates a complexity equivalent to that in the Burdekin delta. Two sections, figure 5.2 and 5.3, derived from Calvert (1959) are shown and serve to illustrate the salient features of the deposits. As in the Burdekin delta, weathering horizons may be recognised in the sequence as oxidised red or brown clays sometimes overlying or being replaced by cemented deposits. Several such horizons may be recognised in any one core, but only the uppermost appears to have any continuity. Following the analogy of the Burdekin delta, this is interpreted as the late Pleistocene deltaic surface (fig. 5.4). Owing to the paucity of records no details of this surface can be detected but the major channel of the Burdekin at the time appears to have followed a remarkably similar course to that of the bedrock channel, crossing the present coast just north of Allingham after closely paralleling the present river between Trebonne and Ingham.

Because the Herbert has apparently maintained more or less the same channel throughout the latter part of the
Fig. 5.2 Herbert River delta, north-south section at Ingham.

Fig. 5.3 Herbert River delta, east-west section at Allingham.
Fig. 5.4 Herbert River delta, late Pleistocene surface.
Quaternary, the coarser river deposits consisting of sands and gravels have been constrained to the one narrow belt. This is well seen in figure 5.2 where sands and gravels dominate beneath the present river and for about a mile to the south, within the late Pleistocene and bedrock channels. Outside these channels the quieter environments have experienced mainly fine grained sedimentation with coarse alluvials occurring only in lenses. The thick sand and gravel deposits occurring at the base of the northern-most bore of figure 5.2 are thought to belong to the streams issuing from the Cardwell Range, rather than to the main course of the Herbert. The widespread levee deposits north-east of Ingham in the present deltaic region are considered to be a comparatively thin veneer of recent date.

Figure 5.3 is an east-west section between Victoria Mill and Allingham. The Pleistocene surface here is between 20 and 30 feet below sea level, though dropping away fairly sharply about a mile inland from the coast. The transect is on the southern edge of the bedrock and late Pleistocene channels and clays tend to dominate the deposits. The latter part of the Holocene transgression is recorded in the deposits up to 2 miles inland. Mangrove muds containing roots and wood are found up to 35 feet below sea level and extend to 9 feet above this level. These figures relate to State Datum. Corresponding levels related to M.H.W.S. would be -38.6 to +5.4 feet. The higher level is generally beyond the range of mangrove habitats at present. It may indicate a higher Holocene sea level.

**Surface Deposits and Morphology**

The Herbert River enters the sea through an asymmetrical delta, the bulk of recent deposition being towards the northern edge of the delta. Although still partially
confined within the bedrock walls of the lower valley the characteristic cuspatate shape is maintained in part by the strong tidal scour which keeps open the Hinchinbrook channel. There is one major distributary but the lower delta contains a network of minor branching channels. The Seymour River, the lower course of which is a former major distributary, is connected with the main Herbert channel, and still carries part of the Herbert River flow.

Figure 5.5 depicts the surface morphology of the deltaic plain and lower valley below Herbert Vale. The map has been based largely on aerial photograph interpretation with ground checking in the more accessible parts of the delta. It is evident from the map that the Herbert in the past has occupied a number of channels to the south of the current distributary area. Two major distributary systems are apparent: one on the southern edge of the delta of which Trebonne and Cattle Creeks are the major channels, Trebonne Creek below the township of Trebonne being the former lower course of the Herbert; and between the southern deltaic area and the active delta, a system in which Palm and Victoria Creeks were the main channels and which branched off from the present Herbert in the vicinity of Ingham. Minor abandoned channels tend to interlock the levee distributary system though it is thought that each has operated more or less independently of the others. During floods the Herbert's flow may still be diverted through the old channels. Subaqueous deltaic sedimentation has occurred opposite the mouths of each of the old distributaries.

The relationship of river, levees and floodplain is much the same as in the Burdekin. The Herbert is incised up to 50 feet into its levee deposits which range in height along the present banks from about 60 feet near Trebonne to 50 feet immediately north of Ingham and 30 feet near Halifax.
Fig. 5.5 Herbert River delta, geomorphology.
The heights of the levees of the abandoned channels have a similar range. The levees of Trebonne Creek a mile south of Trebonne are fractionally higher than along the adjacent parts of the Herbert River, and maintain their height to within a mile or two of the sea. Those of Palm and Victoria Creeks are slightly lower and are of a similar height to those of the present distributaries. The floodplain is generally some 20 feet lower than the levees and, except where artifically drained, is very swampy. It grades gently into the colluvial deposits of the delta's confining ranges.

In the more confined valley upstream from Trebonne the morphology of the valley floor is very reminiscent of that of the Burdekin near Dalbeg with a lower floodplain terrace generally less than a mile wide, overlooked by a terrace about 20 feet higher. The higher terrace merges imperceptibly into the slopewash deposits of the surrounding hills. The lowest area along the river where the two levels may be seen is around Trebonne where the old Trebonne Creek channel branches from the main Herbert. Unfortunately the morphology in this region is complicated by the confluence of the Stone River, a major right bank tributary, which also has at least one terrace higher than its present floodplain. However it would appear that the higher terrace level is the partially eroded levee system of the Trebonne Creek distributary system. The 1967 report on flooding indicates the river is currently widening its floodplain at the expense of the higher terrace above Trebonne. The relationship of the two terrace levels and of the levee system, together with the higher level of the Trebonne Creek-Cattle Creek levees close to the sea, may suggest a higher sea level at the time of this deposition. Unfortunately no sections have been observed in the deposits which could confirm this.
The relationship of the three distributary systems strongly suggests that the earliest deltaic area was the Trebonne-Cattle Creeks system and that the Herbert has subsequently migrated northwards. The relatively sheltered position of the delta has resulted in vigorous outgrowth of levee systems, with only moderate amounts of material being directed to shoreline development. Beach ridges have developed north of each of the distributaries under the influence of the south to north littoral drift. However, the northward migration of the Herbert together with the vigorous outward growth has meant that earlier beach ridge systems have generally been engulfed or at least fragmented by the later levees. The utilisation of the older channels during flood has maintained a narrow beach along the southern delta shores. The present distributary area, sheltered by Hinchinbrook Island has only a minimal development of sand ridges.

Development of sand ridges, largely in the form of recurved spits has not been as widespread as in the Burdekin delta. Much of the material which has been swept out to sea has been carried northwards, congesting the southern end of the Hinchinbrook Channel which is kept open by the strong tidal scour. The sand deposits making up the cuspate foreland of George Point on Hinchinbrook have been derived from the Herbert.

The sand spits have enclosed inter-tidal lagoons which have been readily colonised by mangroves. Macnae (1966, 1967) has described the mangrove sequences near Lucinda. Bruguiera forests are the most extensive, with B. parviflora and B. gymnohiza dominating and with scattered traces of Xylocarpus australasicum. Old channels and fringes of present channels are occupied by Rhizophora stylosa. Ceriops tagal occurs in higher areas, specially adjacent to the older
sand ridges which occur within the mangroves.

Around the present distributary area of the Herbert, and up the Hinchinbrook Channel the extensive mangroves have colonised the area enclosed by sand ridges and extend as fingers inland between the levee systems. A different location is noted for the older deltaic area of Trebonne and Cattle Creeks, where the mangroves tend to extend inland only up the abandoned channels. Inter-distributary areas are above the range of most tides and are occupied by salt marsh or freshwater swamp. Whilst the higher level of these areas in the south may be due to sedimentation, an emergence factor may have to be taken into consideration. It is notable that salt marsh increases rapidly in area in the south, occupying much of the environment colonised by mangroves further north. The effect of the lower rainfall will be discussed in Chapter 9.

Comparison with the Burdekin Delta

The Herbert River delta is considered a much less complex depositional area than that of the Burdekin River. This is due to a large extent to the confined nature of the lower Herbert basin which has restricted the river throughout most of its traceable history to more or less the same course. High and low sea level phases therefore have been similar in the Herbert, though the rapid progradation during the Holocene transgression has allowed the river to migrate from the confines of the low sea level incised course.

In many ways the Herbert delta has similarities with the eastern side of the Burdekin Delta, south of Cape Bowling Green. The orientation of both areas is identical though the Herbert delta appears to be in the lee of the
Palm Islands. It is not surprising, therefore, to find that both deltas have spits trending northwards from their former and present distributaries. However the more sheltered environment of the Herbert delta has produced generally smaller and narrower sand ridge barriers. Further similarities are found in the "crevasse" system of separately functioning distributary areas, and in the rapidly tapering wedge of Holocene sediments thinning towards the west.

There is great contrast in the more recent history of the two deltaic areas for, in spite of similar orientations and similar directions of longshore drifting, whilst the Burdekin has migrated steadily southwards during the last few thousand years, the Herbert over the same period has migrated northwards. The southerly migration of the Burdekin was determined by the blocking of all northerly exits by the vigorous development of spits creating long wide barriers, the height of which was reinforced by dune development. In contrast the more sheltered Herbert delta has experienced greater progradation than lateral movement of sediments. Barriers have been narrower, lower and shorter and each migration has merely moved the mouth northwards beyond the point of the then active spit. Moreover, the wetter climate has prohibited the development of dunes (see Chapter 9) and there has been little in the way of an aeolian cap to reinforce the ridges against a break through by the river. Migration northwards has therefore received no great opposition. The position of the present distributary area of the Herbert is in many ways analogous to that of the Burdekin at the stages of the systems of Sheepstation Creek or Kalamia Creek (prior to it coming under the full influence of the northerly drift of the east coast). Vigorous progradation is matched by weak development of shorelines; those which do occur within the mangroves are narrow, widely separated and apparently cheniers resting upon a clay or
mud base.

Summary Evolution of the Herbert Delta

1. The former Upper Burdekin was diverted to a more direct course to the sea to become the Herbert River system (see Chapter 1).

2. A narrow funnel shaped embayment formed the Herbert estuary, with the main channel to the south of the present river.

3. Incision occurred during Pleistocene low sea level phases to about 300 feet below sea level.

4. Aggradation occurred during high sea level phases of the Pleistocene, though even by the last interglacial, infilling of the embayment was not complete and the Herbert flowed out to sea by way of a partly filled estuary.

5. Aggradation and progradation have been rapid during the Holocene period, with migration of the shoreline at least two miles landwards of its present position.

6. Evidence in the Herbert delta suggests, though does not prove, a higher Holocene sea level, by the maximum of which the Herbert had over-topped the confines of the estuarine channel and occupied the Trebonne Creek-Cattle Creek delta.

7. Gradual migration northwards of the distributary area by way of the Victoria Creek-Palm Creek delta, to the present delta centered on Lucinda, has been the latest phase of development.
References


Hinchinbrook Shire Council, (undated), Preliminary Reconnaissance Report on Stream Improvements, Herbert River, Stone River, Trebonne Creek and Cattle Creek. 2 Parts.

Hinchinbrook Shire Council (undated), Herbert River after 1967 Flood.


CHAPTER 6

SOME CHARACTERISTICS OF BEACH MATERIALS

The coast within the research area is predominantly a depositional one. Great variety, however, is found in the beach environments and in the types of beach deposit. Variations also seem to occur with time. This chapter summarises the nature of the beach material and comments on the characteristics of distribution, and the processes of cementation.

Nature and Distribution of Beach Materials

Contrasts in beach materials occur between the following environments:

i) in close proximity to and away from river mouths which contribute sediments to the mainland coasts.

ii) in close proximity to and away from outcrops of solid rock on the mainland coast.

iii) with an open orientation to the south-east or east, and with orientation towards these directions restricted.

iv) between the mainland and island beaches in general.

Close to, and especially to the west or north of the river mouths, sand beaches of material contributed by the river predominate. The nature of the geology of the hinterland may determine the exact mineralogy of the beach sands, particularly in the heavy mineral assemblages, but the widespread occurrences of granitic rocks and acid volcanics
means that quartzose sands dominate, with minor contributions of feldspars. Estuaries of these streams provide limited environments for molluscan fauna and, with few nearshore coral reefs, the biogenic contribution to the beaches of these environments is low. Carbonate content of the beach sands is consequently small, generally less than 10% and often less than 5%.

Away from the river mouths, the amount of sand in the littoral zone decreases, indicating the predominance of fluvially transported terrigenous beach materials on the mainland littoral. The apparent response to these conditions is illustrated by the coastal deposits in front of the Muntalunga Range (fig. 4.1) and across to Cape Cleveland. Generally fine grained sedimentation will predominate in such an environment provided only low or medium energy conditions exist. Sorting occurs between the dominant clastic sediments of probable terrigenous origin and the small proportion of coarser fragments which are congregated together to form widely spaced cheniers. The origin of these coarser fragments is diverse. In front of the Muntalunga Range many are shell fragments (more than 80%, Appendix C). In general along this coast, the most favourable environment for a flourishing molluscan fauna is a rocky one. The presence of the Muntalunga outcrop not far removed from the present beach may indicate outcrops further out to sea which could contribute shell material to the present beach. The remaining 20% or less of the coarser beach materials is made up of angular quartz and feldspar fragments. These too may have originated from off-shore rock reefs, from occasional longshore drifting in a direction different from the normal or from sub-aqueous deposits which may not have been transported on-shore during the Holocene transgression. The calcareous nature of the cheniers seawards of the Muntalunga Range may be misleading. The total
amount of shell material on this coast may be no greater than on other fluvially dominated beaches, but the absence of other coarse material and the concentration of the coarser fraction into a few cheniers give these beaches their calcareous characteristics.

In general, however, beaches of fluvially derived sands predominate. The reasons for this are twofold. First, the coastal streams, though small and intermittent, are quite closely spaced; secondly, along most of the coast, a strong littoral drift occurs, strong enough to transport sediments along the shore between adjacent river mouths.

The importance of solid rock outcrops to the biogenic fraction of beach materials has already been indicated. High carbonate readings are generally found on the beaches of the headlands, though figures as high as 80% such as were recorded on the cheniers north of the Muntalunga Range, are rare, for though the total production of biogenic material may be considerably greater, it is combined with terrigenous material or sediments washed up from the sea floor, which lowers the carbonate reading in individual samples. However, beyond the headlands, in the direction of longshore drift, high carbonate readings may again occur as the lighter shell fragments are more readily transported. The best illustration is provided by the Range of Many Peaks area. Figure 4.3 indicates the carbonate content of the sands of the upper and lower beach around the headland. The overall average carbonate content of all samples is 15.75%, much higher than on any beach fed primarily by fluvial sands. Great

1. Collection and analysis of the samples was carried out by Mr. G.L. Dalton, third year honours student, University College of Townsville, under the supervision of the author.
variation in carbonate content occurs, within the range 0.1% to 91.8%, with a tendency for the higher readings towards the western end of the headland (longshore drift is from east to west).

Although the carbonate content of the present beach just east of the mouth of the Bohle is only modest, the cheniers behind are composed of almost pure shell grit, indicating the nourishment from the headland. A reading of 84.3% carbonate, with a residue of quartz grit was recorded for the first ridge. The reason for the lower content in the present beach is not known. However, the importance of the nourishment of the calcareous beaches from the headland is indicated by the change in nature of the present beach and the beach ridges in the west bank of the Bohle, where the sands have a carbonate content below 5.0%.

An interesting feature of the headland beaches is the contrast between the upper and lower beach relationships along rocky and sandy sectors of the shore. Where the present beach backs onto rock it is the lower beach which generally has the higher carbonate reading. Where beach ridges have accumulated, it is the upper beach which is more calcareous. The upper beach is invariably coarser than the lower beach owing to the strong action of the swash and weaker action of the backwash as a result of percolation (Bird, 1968, p.83). On the rocky shore the non-calcareous materials are normally of coarse sand calibre, larger than the shell fragments. On the sandy shores the shell fragments appear about the same size but the non-calcareous sands are finer apparently owing to transport along or onto the shore.

The logical pattern of beach sediments indicated by the Range of Many Peaks is not obviously repeated by the Muntalunga Range cheniers. Apart from the outer ridge,
beyond the solid outcrop, carbonate values are low, and whilst the boreholes may not consistently have gone deep enough to encounter beach sands, even for aeolian sediments the values are low. However, the environment of salt marsh with widely spaced ridges, which existed even when hard rock outcropped on the coast (as indicated by the older cheniers), is not conducive to a dense molluscan fauna. The sheltered habitat, in the lee of Cape Cleveland appears to have been the dominant factor. However, on other open beaches adjacent to solid rock, a proportion of broken shell is incorporated in the beach sands and carbonate values above 10% occur.

The importance of orientation towards the south-east or east i.e. towards an open aspect, is also related to the nourishment of beaches from off-shore sources. The only three areas where there is evidence to suggest the on-shore movement of barriers with a rising sea level or of previously deposited fluvial or deltaic sands are west of the Bohle estuary, south of Cape Cleveland in Bowling Green Bay, and between Cape Upstart and the Elliot River. All these areas have an open aspect with vigorous wave activity which has allowed the on-shore movement of sea floor sediments. More detailed analysis is needed to determine the full implications for the beach sands, but microscopic examination indicates that these sands have a much higher proportion of quartz sand, to the exclusion of biogenic material and more delicate minerals including feldspars, than do beaches fed more directly by fluvial sources and longshore drifting. Only the more resistant quartz appears to survive the constant abrasion which occurs during the long period of transportation. The rapid build up of beach ridges north of river mouths indicates that sands moving longshore, are probably subject to the abrasive activity of the breaker zone for a relatively
short period, before becoming stabilized within a beach ridge, hence the survival of more fragile beach elements.

The greatest contrast in beach materials is between the beaches of the mainland and those of the off-shore islands. Although high carbonate values may be recorded occasionally in the mainland beaches, they are the exception and the majority of beaches have values of 10% or less. The islands, however, consistently have high carbonate contents in their beaches derived from the erosion of the fringing reefs, and from an environment in which a dense molluscan fauna flourishes. In comparison, there are few stream courses, apart from incipient gullies, and provision of terrigenous material is dependent upon the erosion of the island cliffs. This is considered to be slow. Sediment yield from the sea floor is prevented by the steep front of the fringing reefs. The majority of samples analysed had carbonate values in the range 80% to 90% for both sand and fine coral shingle beaches. Typical are the values from the southern side of Curacoa spit (fig. 2.5) where the upper fine shingle beach of coral fragments had a value of 81.6%, the residue consisting of small lithic fragments, and the lower beach of coarse sand a value of 92.0%, the residue this time consisting almost entirely of quartz grains. The only island examined which had consistently lower values than those quoted was Great Palm Island, which has a few small streams supplying sand to the littoral zone. Carbonate values of 50% to 60% were common, the lowest value encountered being 33.2% just south of Wallaby Point (fig. 2.2). Even this value is much higher than is normally encountered on the mainland.
Comparison of Pleistocene, Mid-Holocene and Present Beach and Dune Materials

The common occurrence of stabilized boulder embankments on many of the off-shore islands has already been noted (Chapter 2). Boulder spits or beaches form the oldest identifiable Holocene features on Curacoa, Brisk, Havanna, Fly, Rattlesnake and Camp Islands, around or onto which the later deposits are laid. The boulder beaches at the base of the island cliffs also appear to be fossil features. On the mainland, a small number of similar boulder spits occurs on outcrops which, at the mid-Holocene stage, were undoubtedly islands. These include R.M. Point, Beach Mount and the Range of Many Peaks. Later sand beach ridges are attached to these features. In general the boulder embankments indicate a sea level as high as or higher than present and are all of mid-Holocene age.

Boulder beaches are not forming today, except in the few areas where older boulder deposits are being reworked, as on Camp Island. On the islands in particular, there is a great contrast between the boulder embankments and the biogenic sands and shingles of the present beaches. On the mainland the present sand beaches provide a similar contrast. Table 6.1 shows the carbonate values for deposits of different ages from several areas. Examination of beach rock samples from many of the islands indicates that though these are mainly calcareous the mid-Holocene deposits contain rock fragments, stones and boulders. Carbonate analysis was carried out on samples weighing between 25 and 50 grams, generally too small to include the larger lithic fragments. The values given therefore are generally only for the finer matrix. The Wallaby Point conglomerate is a good example, for the boulders here are estimated to form up to 90% of
Table 6.1  

Carbonate Values of Pleistocene and Holocene Beach  
and Dune Materials and Beach Rocks

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<th>Location</th>
<th>Sample</th>
<th>Age</th>
<th>Carbonate</th>
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</thead>
<tbody>
<tr>
<td>Muntalunga cheniers</td>
<td>Ridge 1, base</td>
<td>Late Holocene</td>
<td>88.8%</td>
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<td>Ridge 4, base</td>
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<tr>
<td>Cape Upstart</td>
<td>Present dune</td>
<td>Present</td>
<td>2.4%</td>
</tr>
<tr>
<td>Cape Upstart</td>
<td>Rear of outer barrier</td>
<td>Mid- to late Holocene</td>
<td>3.6%</td>
</tr>
<tr>
<td>Cape Upstart</td>
<td>Beach at base of red dune</td>
<td>Mid-Holocene</td>
<td>6.4%</td>
</tr>
<tr>
<td>Cape Upstart</td>
<td>Red dune sands</td>
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</tr>
<tr>
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<td>Present dune</td>
<td>Present</td>
<td>4.8%</td>
</tr>
<tr>
<td>Green Mount</td>
<td>Mid-Holocene beach</td>
<td>Mid-Holocene</td>
<td>3.6%</td>
</tr>
<tr>
<td>Green Mount</td>
<td>Pleistocene dune</td>
<td>Pleistocene</td>
<td>15.0%</td>
</tr>
<tr>
<td>Curacoa Island</td>
<td>Beach rock</td>
<td>Present</td>
<td>87.2%</td>
</tr>
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<td>Conglomerate</td>
<td>Mid-Holocene</td>
<td>10.0% (estimated)</td>
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<tr>
<td>Eclipse Island</td>
<td>Beach rock</td>
<td>Present</td>
<td>86.9%</td>
</tr>
<tr>
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<td>Beach rock</td>
<td>Mid Holocene</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>+lithic fragments</td>
<td></td>
</tr>
<tr>
<td>Herald Island</td>
<td>Beach rock</td>
<td>Present</td>
<td>91.0%</td>
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<th>Sample</th>
<th>Age</th>
<th>Carbonate</th>
</tr>
</thead>
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<td>Herald Island</td>
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<tr>
<td>Rattlesnake Island</td>
<td>Beach rock</td>
<td>Present</td>
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<td>94.7%</td>
</tr>
<tr>
<td>Wallaby Point, Palm Island</td>
<td>Beach rock</td>
<td>Present</td>
<td>65.5%</td>
</tr>
<tr>
<td>Wallaby Point,</td>
<td>Conglomerate</td>
<td>Mid-Holocene</td>
<td>10.0% (estimated) [or 85.2% for finer matrix only]</td>
</tr>
</tbody>
</table>
the material. The intervening matrix, however, has a 85.2% carbonate content, mostly fine shell grit and coral sand. In general, the carbonate values of the present beach rocks are similar to those of the cementing matrix of the mid-Holocene deposits.

On the mainland, there is not the same contrast between the older and recent Holocene sands. Carbonate values are generally too low even in the present beaches for significant differences to stand out. Beach deposits of all ages appear to be dominated by sands from fluvial sources. There is, however, the presence of the boulder beaches, in a few localities which leads one to suspect that they may be found beneath sand ridges in many other places close to solid rock outcrops. Evidence from the research area as a whole does little to invalidate the conclusions drawn from the islands that the rising Holocene sea level has reworked the regolith formed during the late Pleistocene low sea level phase, during which there is evidence for a period with a climate suitable for deep weathering (see Chapter 8). Investigations from elsewhere (for example Russell, 1967, p.104-106) have pointed out the reduction in sand volume of present beaches compared to those formed during the Holocene transgression. During the controversial period since the mid-Holocene, the stillstand or regression of sea has led to a diminishing sand supply. Erosion has occurred on beaches where the source of sand had been predominantly from the sea or from the weathered deposits of the old coastal plain upon which it encroached. In the area under consideration, the mainland beaches have been, and are, supplied with sand from fluvial sources and differences cannot be noted, and, on the off-shore islands, the rapid production of local biogenic material has always been great. Indeed, the late Holocene regression has exposed fringing
reefs to wave attack and increased the amount of beach material available.

Little can be concluded from the small number of Pleistocene samples analysed. In general terms they are comparable to present beach and dune samples, but exact comparisons are difficult as it is not always possible to determine if the Pleistocene feature belongs to the transgressive or regressive phase of the higher sea level. Presumably calcareous materials would increase in proportion (if not in actual amount) during the regressive phase. This probably explains the high carbonate content of the Inkerman and Green Hill ridges (see p.108).

**Beach Rock and Conglomerate**

There is a very extensive literature on descriptions and analyses of beach rock and hypothesis of formation, which, nevertheless, remains a controversial issue. In spite of observations dating back to Moresby (1835), Jukes (1847) and Dana (1852, 1853), discussion still centres around the origin and nature of the cementing carbonate.

One hypothesis for the origin of the carbonate is that it is precipitated from heavily charged groundwater which has acquired its carbonate by percolating through beach deposits with a high shell or other biogenic content. This hypothesis has been most recently proposed by Russell (1959, 1962, 1963, 1967) who indicates that the precipitation occurs at the water table, which, close to the beach approximates to sea level. Tidal fluctuations in sea level give the range over which precipitation will take place and determine the thickness of the beach rock. Numerous other authors (for example, Jukes, 1847; David, 1904; Field, 1920; Umbro, 1928; Gardiner, 1930; Yonge, 1930; Sewell, 1932;
Trichet, 1965; Bloch and Trichet, 1966) agree that the carbonate is precipitated from groundwater, but at the junction of freshwater and sea water below the water table. There is strong evidence to support both views but, as Stoddart and Cann (1965) have pointed out, well-developed beach rock occurs in arid areas such as the Red Sea where percolating groundwater can hardly have played a part in formation, and also on islands and atolls too small to support a permanent lens of freshwater, the evidence from the atolls of the Northern Marshall Islands suggesting that a freshwater lens does not develop where rainfall is less than 45 inches per annum.

A second hypothesis involves the precipitation in the pores of the beach sands of calcium carbonate from seawater which in the tropics is normally supersaturated in carbonates (Daly, 1924; Kuenen, 1933; Merrin, 1955; Ginsburg, 1953; McKee, 1956; Revelle and Fairbridge, 1957; Emery, 1962). Precipitation is promoted by an increase in temperature and evaporation, or by a decrease in hydrostatic pressure or a combination of these factors. Again, there is strong evidence against this hypothesis, one of the major arguments being the patchy and discontinuous distribution of the beach rock which is difficult to explain in any one region if the cementing agent is derived from the uniform mass of sea water.

Another major school invokes biochemical activity (Cloud, 1952; Nesteroff, 1954; Ranson, 1955a, b; Kaye, 1959; Maxwell, 1961). Cementation is caused either by precipitation under the promotion of micro organisms such as bacteria, which are abundant in the area of the water table, or, as Maxwell (1961) claims, through algal encrustation, green and blue-green algae flourishing within the littoral zone. However, confirmed reports of such encrustations are not
widespread and whilst lithification may be aided by biological agents, the major cementation process does not appear to be biochemical (Krauss and Galloway, 1960).

Conflicting reports from different environments in different climates and on different lithologies of cemented deposits and cogent objections to virtually all general theories of origin so far proposed may well indicate that beach rock can be formed by a number of processes, the importance of which tend to vary in different environments. This conclusion has also been reached by Kaye (1959), Guilcher (1961) and Stoddart and Cann (1965).

The exact nature of the cementing matrix also tends to lead to this conclusion. Aragonite, calcite and amorphous carbonate have been variously described as the cementing agent. Nesteroff (1954) showed that in the Red Sea beach rocks, the cementing agent changed its form with age. Earliest lithification was by amorphous calcium carbonate, but crystallisation then occurred in the form of aragonite needles and re-crystallisation into rhombohedrons of calcite. Geochemical analysis has indicated that salinity or degree of supersaturation may determine whether calcite or aragonite is precipitated (Higgins, 1968).

Detailed study of beach rock is outside the scope of the present research programme. Interest in lithified beach deposits has been mainly in the information which they can supply of past environments and present processes. However, a number of observations have been made which may confirm and add to the known facts on lithified beach sediments.

The rapidity of cementation described by many authors is confirmed in the Townsville region. A report by local residents indicates that a layer of beach rock formed over
a boat ramp on the northern side of Magnetic Island only six months after it had been completed. The beach sands involved were coarse shell grits. The amount of carbonate in the original beach deposit appears to be a strong influence on the rate of formation of beach rock. Whilst it is common on the islands where biogenic sands predominate, it is relatively rare on the mainland. Moreover, whilst the island beach rocks appear to form rapidly, even on recently formed and constantly shifting extensions of the lee side spits, on the mainland the few known beach rock locations are associated with older beach ridges and apparently rapid coastal retreat. Stabilization of the beach deposits long enough for the cementing matrix to build up appears essential. On the mainland this stabilization has to occur within vegetated beach ridges (with possibly humic acids helping to leach the carbonates down to the underlying water table). On the islands, in the much more calcareous environment, beach rock was forming not only in the ridges behind the present beach but apparently within the upper beach itself.

Exposed mainland beach rock is limited because it needs a high carbonate content in the original beach sand, combined with stabilization over a long period to allow cementation to take place, followed by a period of coastal erosion to expose the resulting lithified deposit. However, high carbonate content is found only around headlands and general observations indicate that beaches are most stable close to their anchoring points. Short term oscillations are not likely. Thus it is not surprising to find that beach rock is exposed in such situations only with a major beach recession and that the exposed beach rocks are comparatively old. At Balgal an age of 2,180 years ± 80 B.P. (Gak-1509) was indicated and at Shelly Beach, Range of Many Peaks an
age of 2,460 years ± 80 B.P. (GaK-1508). Just to the south of the research area at Dingo Beach near Bowen a similar age of 1,660 years ± 300 B.P. was obtained by the Bureau of Mineral Resources (Paine, Gregory and Clarke, 1966). The similarity in age of these deposits indicates that the erosion, which appears so widespread along the coast of North Queensland, has retrograded the littoral zone to its most landward position for 2,000 years.

The actual carbonate content of beach rocks is illustrated by a number of results given in Table 6.1. In general the beach rocks of the islands have carbonate values around 90%, not far removed from the values for the adjacent beach. In contrast, the Shelly Beach sample had only 46.1% carbonate, a reflection of the generally lower values of the mainland beaches. However, the adjacent beach, although calcareous, has only a 10% carbonate content, indicating the degree of enrichment during cementation. The known occurrences of beach rock on the mainland all appear to have a similarly low carbonate content, except for the example in the Pleistocene beach ridge trending south from Mount Inkerman (Chapter 3) and exposed in the bank of Yellow Gin Creek. This had a carbonate content of 89.2%, but this beach ridge is highly calcareous throughout: further north it contains the Inkerman calcarenite.

Exact carbonate values for beach rocks elsewhere are not indicated in the literature. However, general descriptions indicate that the majority of beach rocks in other areas though containing boulders and mineral sands, have a higher calcareous content than those on the Townsville region mainland. Russell and McIntire (1965) have attempted to set temperature limits on beach rock formation. Rainfall is considered to be another important factor. If it is too low, then leaching of carbonates in groundwater may be
slow and require a high carbonate content in the original material. Whilst beach rock may still form through other processes, it is considered that downward movement of carbonates is the most rapid type of formation. If the rainfall factor is high then the leaching factor may also be high, with unsaturated and still aggressive groundwater reaching the inter-tidal zone during low water, and preventing cementation from taking place. As seen from the island spits, a higher rainfall certainly prevents the preservation of raised beach rock. From observations in North Queensland and in eastern Papua-New Guinea (Hopley, in press) a much higher carbonate content is required in beach sands for cementation to take place in the wetter tropics than is needed in tropical areas with a long dry season. In general in areas with a rainfall of 80 inches or more per annum, only coral island beaches have a sufficiently high carbonate content to become cemented. Even beaches consisting of 80% or more coral sand, if combined with terrigenous sediments, may show no evidence of lithification taking place. The climate of the Townsville area may well be close to the optimum for beach rock formation.

Beach rock as an indicator of sea level at the time of formation has been one of the major interests in lithified deposits in the current research programme. In general, the literature on the subject is in agreement that beach rock is an inter-tidal feature, though Russell does suggest that the cemented surface may rise inland with a rising water table. However, in all the examples examined in North Queensland the apparently modern beach rock is most definitely found between tide levels, the upper level being at or just below M.H.W.S. Where beach rock higher than this is found inland, the water table does not show a corresponding gradient and the beach rock is interpreted as fossil. Indeed, on the off-shore island spits, there is apparently
no permanent freshwater (Ghyben-Herzberg) lens and in the coarser materials involved the water table is closely related to sea level.

The upper surface of beach rock is thus horizontal, truncating the bedding of the sands. The lower surface of the cemented zone is also reported as being equally abrupt and level (Kuenen, 1933). The thickness of beach rock should reflect the local tidal range. The older beach rocks of the off-shore islands display thicknesses of up to 16 feet, much greater than the present tidal range. However, the regression of the sea from the mid-Holocene maximum level would have transferred the zone of cementation downwards and, whilst the materials in the beach rocks may belong to the mid-Holocene period, their cementation in the lower portions, may be younger. This may well explain why a younger date was obtained for the beach rock at the base of the Herald Island outcrop compared to the date from near the top (Chapter 2). Whereas a single shell was submitted for dating from the top, the lower sample contained some of the cementing matrix.

Once removed from the cementation zone, by either a change in water table level or by exposure on the beach, the beach rock undergoes erosion. This may be through wave attack, biological activity (McLean, 1967a, b), freshwater run-off corrosion (McLean, 1967c) or, most extensively, through solutional effects (Reville and Emery, 1957). All forms of erosion have been observed in North Queensland. The opening of joints in the beach rock appeared to facilitate the disintegration. Most rapid erosion appeared to be in the inter-tidal zone where all methods of attack are operating. Raised beach rock however, seems to be eroded only slowly, mainly through corrosion. The porosity of the material appears to retard most solutional processes
and may explain the survival in a comparatively fresh state, of mid-Holocene and even late Pleistocene beach rocks.
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CHAPTER 7

DISCUSSION OF THE EVIDENCE FOR SEA LEVEL CHANGE

Former shorelines some of which indicate sea levels higher than that of present, have been described from all parts of the research area. It is intended here to correlate the evidence from the region as a whole and to give an absolute chronology for the sequence of sea level changes in North Queensland. In addition, the question of the tectonic stability of the coast will be discussed in relation to possible warping of shorelines. The significance of the results and their correlation with those obtained from elsewhere in Australia and other parts of the world will be indicated.

Late Pleistocene Shorelines

A shoreline marked by dunes and beach ridges composed of weathered and oxidised sands and by older, emerged, beach rocks has been described from the whole of the research area. Only one of the off-shore islands, Camp Island, contains a feature which can definitely be ascribed to the Pleistocene. Here, a beach rock plateau composed of cemented coral fragments rises to 15.2 feet above M.H.W.S. and a radiometric date of 20,200 years ± 600 B.P. was obtained for this. On the mainland, interrupted shorelines can be traced from Cape Upstart in the south, to Rollingstone Creek in the north. This shoreline is much less continuous than the Holocene outer barrier of dunes and beach ridges behind which it is found. However, it is sufficiently well
preserved for it to be compared to the inner barrier of the coast of south-eastern Australia (see for example, Hails, 1968). South of Cape Upstart this shoreline consists of a 60-foot high dune of red oxidised sands, resting on a mottled clay surface 4 feet above M.H.W.S. Between Cape Upstart and the southern edge of the Burdekin delta, the Pleistocene shoreline can be traced as a series of ridges associated with which is a similar clay surface separated from the lower salt flats by a salting cliff. This surface also rises to 4 feet above M.H.W.S. South of Mount Inkerman, one of the ridges contains dune calcarenite, dated at 25,150 years ± 1,050 B.P. and beach rock rising to 6 feet above M.H.W.S. and giving dates of 26,900 years ± 900 B.P. and 28,900 years ± 2,800 B.P. In the Burdekin delta, the indications are that the inner barrier has been buried beneath Holocene deltaic sediments. South of Cape Cleveland, the older ridges reappear, sediments with characteristics diagnostic of beach sands rise to 17 feet in one of the ridges near Storth Hill. This is thought to indicate a sea level of approximately 15 feet above present. The inner barrier can be traced in the Townsville area from south of the Ross River to the mouth of the Bohle River. A section in the bank of the Bohle River indicated beach rock rising to 8 feet above M.H.W.S. Carbonate nodules from above this gave an age of 14,680 years ± 310 B.P. North of Townsville only isolated remnants of the Pleistocene shoreline remain. However, the inner barrier has been recognised further north in the Tully area (Bird and Hopley, 1969).

The evidence suggests that the Pleistocene sea level stood at between 4 and 15 feet higher than that of present. The possibility of tectonic warping being the only reason for this discrepancy must be dismissed as both 4-foot and 15-foot levels occur within close proximity of each other.
For example, the Camp Island beach rock is located only 3 miles from the Cape Upstart dune. There is no evidence to suggest such a highly unlikely pattern of local warping. Two further possibilities exist: that the two levels represent two completely different shorelines, one of approximately 15 feet the other of 4 to 8 feet; or that the remnants of the Pleistocene shoreline all belong to more or less the same period, the higher remnants belonging to the maximum of the transgression, the lower ones to the regression phase from this level.

The possibility of two separate transgressions must be given serious consideration as a casual examination of the deposits involved apparently indicate two series, one oxidised and red in colour the other weathered, clayey and bleached. However, a detailed analysis indicates that these variations are related to the nature of the original beach and dune materials rather than age. What is almost certainly the same shoreline south of the Burdekin delta, is composed of red sands near Green Mount and of bleached deposits further north. Similarly, in the Townsville area the Pleistocene shoreline near the mouth of the Bohle is composed of white sands, but changes to brown sands near Mount St. John and to red oxidised sands in what is considered to be the same feature south of the Ross River. The absence of the higher level can be explained by erosion which can take place even during the regressive phase (Bird, 1968, p.101). It is unfortunate that the full range of levels of the Pleistocene shoreline is not available in any one sequence. However, the ridge south of Mount Inkerman appears to indicate a 6-foot level, those further seawards a 4-foot level and no obvious discontinuity is indicated between them. The conclusion to be drawn from this evidence is that the Pleistocene shorelines all belong to the one higher sea
level phase, both the maximum and regressive stages being indicated.

The age of the Pleistocene shoreline is controversial. The morphology of the area indicates that without doubt it belongs to the latest high level stage prior to the Holocene transgression. The radio-carbon assay results are spread over a wide range from 14,680 years ± 310 B.P. to 28,900 ± 2,800 B.P. However, the younger date is for secondary carbonate and gives a minimal figure only. One other date, that of 25,150 years ± 1,050 B.P. from the dune calcarenite is also from secondary carbonate and again can be considered as minimal. Of necessity the samples had to be taken from a highly calcareous environment and contamination from younger carbonates is very likely. The date from the raised beach rock on Camp Island (20,200 years ± 600 B.P.) is certainly too young. There remains the two dates from the beach rock at Yellow Gin Creek which are compatible at 26,900 years ± 900 B.P. and 28,900 years ± 2,800 ± 1,700 B.P. It is also interesting to note that the secondary carbonate of dune calcarenite was dated at about 2,000 years younger.

Although there is little published information on the rates of formation of dune calcarenite, Jennings (1968) has indicated that the whole series of the extensive calcarenites of southern Australia reach well back into the Pleistocene. Veeh (1966) and Teichert (1967) give a radiometric Th 230 age of 100,000 years ± 20,000 B.P. for coral underlying calcarenite in Western Australia. Gill (1967) quotes an ionium date of 125,000 years for the younger of two calcarenites in Western Victoria. Blackburn (1966) quotes radio-carbon ages of 24,950 years ± 300 B.P. and 30,600 years ± 450 B.P. and two dates beyond the range of carbon dating for materials overlying concretionary
layers only 6 inches thick.

The stage of accumulation indicated by the 25,150 year old date is obviously not known, though the sample dated came from almost the centre of the exposure and it would not be unreasonable to expect that the secondary carbonate accumulation was well developed by this stage. The radiocarbon dates thus suggest that considerable accumulation of calcarenite had occurred in approximately 2,000 to 3,000 years, but this does not appear compatible with the rates of formation intimated from the southern Australian calcarenites. Whilst it is quite possible that, under the different climatic conditions of north Queensland, formation of calcarenite is much more rapid, the contrast in rates would appear to be too great. Another possibility must therefore be considered, that of contamination of the Yellow Gin Creek beach rock samples, and the compatibility of the two dates being coincidental.

The maximum age measurable by the Gakushuin University (Tokyo) radio-carbon laboratory, using the method by which the samples submitted were assayed, is 30,000 years B.P. The dates of the Pleistocene beach rock are thus close to the maximum possible. It would require only a minute amount of modern carbon contamination to produce a date of 25,000 years to 28,000 years (as quoted) for material which was actually beyond the range of dating. Contamination of the order of 1% would probably be sufficient. Although great care was taken in the collection of the sample, there can be no guarantee that the sample was as sterile as is needed for dates of the magnitude obtained. The calcarenite date may possibly suggest that an age of about 28,000 years B.P. is much too young.

The problem reflects the controversy found in the literature dealing with the ages of late Pleistocene
shorelines. The point of issue lies in the possibility of an interstadial sea level as high as, or higher than, present during the Würm, the alternative being that the latest high sea level phase prior to the Holocene occurred during the Riss-Würm interglacial (Eemian or Sangamon). The main evidence in the controversy has been recently summarised by Guilcher (1969), who concludes that a high intra-Würm sea level is possible but points out that large differences in the figures found for the age of the supposed interstadial (ranging from 20,000 to 35,000 years B.P. or more) are an additional difficulty against its acceptance. Nevertheless, a number of authors appear firmly convinced that a high sea level existed approximately 30,000 years ago and correlate it with the Gottweig or Paudorf interstades. The greatest support for this date comes from Milliman and Emery (1968) whose evidence comes mainly from the Atlantic coast of the U.S.A. However, similar conclusions have been reached by others from widely separated areas, for example Shephard (1963) at Oahu, Hawaii and Hoyt (1967) from Georgia and West Africa.

Although a number of dates older than 25,000 years B.P. have been obtained for shoreline deposits in Australia (Gill, 1956-7, 1961), they have generally been accepted only with caution. Walker (1962), however, indicates a date of 29,000 years B.P. for the beginning of pedogenesis on a terrace associated with a 20 to 25-foot sea level, but the attitude of Jennings (1961) to a date of 37,500 years + 1,900 B.P. for driftwood from an older shoreline is possibly more typical of Australian attitudes to the controversial interstadial:

"... and it is impossible to infer no more than that the Old Shorelines belong either to the last (Sangamon) interglacial or to a subsequent inter-
stadial older than all the Wisconsin glacial drift of North America". More recently Dury (1968), has doubted the existence of a high interstadial level during the Würm, placing the Würm I/Würm II interstadial at no more than 50,000 years ago and indicating that even during this period of glacier recession, temperatures were still below those of the present day.

Palaeo-climatic evidence does suggest that a warmer phase may have existed 28,000 to 35,000 years ago (Karlstrom, 1966). From an examination of trace elements in cave soils from various parts of the tropical Pacific, Sabels (1966) indicates that a warmer phase existed about 35,000 years ago. Radio-carbon dates occurred in sequences and were related to rates of accumulation and there seems little doubt as to the validity of these older dates here. However, a warmer phase need not necessarily have been warm enough, or warm for a long enough period, for a glacio-eustatic rise in sea level to above that of present. In Senegal and Mauretania, Faure and Elouard (1967) describe deposits in the range 2 to 7 metres and date them at around 31,000 years B.P. However, they indicate that tectonic uplift of the land is probable and estimate that the higher sea level reached only 10m. below the present level. This agrees well with Curray's (1961, 1965) findings in Texas where he places an interstadial sea level a few metres below present at around 30,000 years B.P.

These estimates for the interstadial are more in keeping with the palaeo-climatic data of Emiliani (1955), Maarleveld and Van der Hammen (1959) and Van der Hammen et al (1967) and reported by Guilcher (1969). Their information indicates that no large variation in climate existed 30,000 years ago sufficient to cause a higher sea
level than present, though possibly a 5°C rise in temperature is indicated (in the Netherlands). However, a 15°C rise was necessary to produce the Holocene transgression.

The balance of the evidence would seem to weigh against a high interstadial sea level within the range of radio-carbon dating, suggesting that where such evidence is forthcoming, contamination of the samples dated is very probable. More recent use of radio-active isotopes other than carbon 14 almost certainly supports this view. Newell (1961) compares the dates obtained on dune calcarenites in the Caribbean using radio-carbon compared to those obtained from uranium and ionium isotopes. Material dated at between 20,000 and 30,000 years B.P. by radio-carbon gave ages of 70,000 to 160,000 years using the greater ranging isotopes. More recently, similar results have been recorded in Australia. For example Veeh (1966) and Teichert (1967) discuss $^{230}\text{Th}/^{238}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ages of 100,000 and 140,000 years for raised corals associated with a 15-foot emergence in Western Australia. In Victoria, shell from calcarenite gave an ionium dating of 125,000 years (Gill, 1967).

Russell (1964) has shown that a shoreline immediately preceding the late Pleistocene lowering of sea level, is a feature found in most parts of the world, at about 15 feet (5m). The late Pleistocene shoreline in North Queensland corresponds well with this feature elsewhere, and a last interglacial age is indicated. Although a radio-carbon age of around 28,000 years B.P. is indicated, the possibly anomalous compatibility of the age from the secondary carbonate of the aeolianite together with the consensus of opinion in the literature would favour an age in the order of 80,000 years B.P. The North Queensland shoreline may thus correlate with the Lower Normannian deposits of Western Europe, the Hoxnian deposits of Britain, the Princess Anne
shoreline in eastern U.S.A. and the Epi-Monastirian of the Mediterranean, all of Eemian or Sangamon age.

The Low Sea Level Phase

Little is known of the last glacial low sea level phase in North Queensland. The major streams became incised and the coastline was certainly far east of its present position. Maxwell (1968a, b) has recognised strand lines at 16 fathoms (96 feet), 22 fathoms (132 feet) and 32 fathoms (192 feet) along the whole of the Great Barrier Reefs province. The rise of sea level during the latter part of the Pleistocene and the early Holocene is documented elsewhere in Australia, particularly in Victoria (Gill, 1968). In North Queensland it is indicated probably by the sub-aqueous delta of the Burdekin River in Bowling Green Bay, the onshore movement of coastal sand barriers, especially south of Cape Upstart, and by cemented deposits which lie below present sea level. Those of Curacoa Island have already been noted (Chapter 2) but others occur, as indicated by the washing up of beach rock fragments on the beaches apparently from submerged outcrops. Only one has been located with any certainty and this lies near the dredged channel into Townsville harbour at a depth between 32 and 35 feet below L.W.M.

The Mid-Holocene Transgression

Although the early stages of the Holocene transgression are not well documented in North Queensland the maximum of the transgression is very clearly recorded. On the off-shore islands of the Palm Group, in Halifax Bay and in the southern part of the research area at Camp Island, cemented beach rocks and conglomerates indicate a higher sea level between
6 and 16 feet higher than present within a range of 3,900 to 5,250 years B.P. On the mainland the evidence is equally convincing. South of Cape Upstart and near Green Mount in Upstart Bay are sheltered environment beaches indicating Holocene sea levels 10 feet higher than present. At Beach Mount Beach and on Rita Island in the Burdekin Delta, mangrove peats possibly formed when sea level stood 4 to 5 feet higher than present, give radio-carbon dates of 3,200 and 3,680 years B.P. Sections in the Burdekin delta display inter-tidal deltaic deposits 10 feet above M.H.W.S. giving a radio-carbon date of 3,820 years B.P. In the same area Holocene beach sands rest on fluvial grits 6.5 feet above M.H.W.S. South of Cape Cleveland beach sands rise to 9 feet above their present maximum level of accumulation. In the Townsville area beach rock occurs in older dune ridges about 12 feet above M.H.W.S.

In contrast, beach rocks and peat which appear related to present sea level give radio-carbon ages no greater than 2,460 years B.P. The radio-carbon dates obtained for the research area and quoted in Chapters 2 to 5 which can be related to sea level, are plotted on figure 7.1. Those derived from beach rocks can be related very closely to sea level, but those from peats can be shown only approximately. A number of other dates shown in the graph may need correction factors as indicated. These are:

i) the date for shell dredged from an older barrier and deposited in the 10-foot beach south of Cape Upstart;

ii) the date for the beach rock summit on Herald Island which may indicate a level related to a water table above the sea level of the period;

iii) the date for beach rock from Rattlesnake Island which is probably too young due to incorporation
Fig. 7.1 Radio-carbon dates related to sea level changes in the research area.
of younger calcareous cement;
iv) the anomalous date for raised coral reef from
Eclipse Island, probably contaminated from
overlying coral shingle of a younger age.

However, a fairly lucid picture of the mid-Holocene trans-
gression and the late Holocene regression is indicated.
Sea level 5,000 years ago was about 6 feet higher than
present and still rising, reaching a maximum of 10 or 11
feet about 4,200 years ago. The maximum level was not
maintained for long. By 3,500 years ago, a level of about
5 feet above present is indicated, the present land-sea
relationships being reached about 2,500 years ago. Since
then there appears to have been little variation in level.

The postulated variations in sea level have a close
fitting relationship with all the evidence of higher sea
levels presented in the research area. Three other carbon
dates are known for coastal deposits in North Queensland.
At Byrne's Creek near Babinda, 85 miles to the north of
the Herbert River delta, a mangrove log in marine mud
9 feet above present mangrove level gave a radio-carbon
date of 3,720 years \( \pm 85 \) B.P. (Grant-Taylor and Rafter,
1962) and in the same area, a mangrove peat a few feet above
H.W.M. dated 6,270 years \( \pm 120 \) B.P. (Fergusson and
Rafter, 1959). Both these dates would deviate little from
the postulated curve of figure 7.1. Further north at
Karumba on the Gulf of Carpentaria, Twidale (1956) quotes
a date of 3,320 years \( \pm 125 \) B.P. for beach rock 70 feet
thick with an upper surface lying at about 20 feet. The
datum to which this level is related is not indicated but
a higher level may be expected on this coast as tidal ranges
are greater than at Townsville.

The question of a higher Holocene sea level is one of
the most controversial issues of Quaternary studies today.
In spite of a wealth of material available, including numerous radio-carbon dates, there is no general agreement on the changes in sea level over approximately the last 6,000 years. Results may be deformed by movements of the land during the period studied, but many authors claim that their research area is a stable one (for example, Thom, Hails and Martin, 1969; Scholl and Stuiver, 1967; Shepard et al 1967) or that they are able to take into account a geo-synclinal or loading isostatic depression factor (e.g. Jelgersma, 1961; Coleman and Smith, 1964) or a glacial isostatic unloading factor (e.g. Morner, 1969a, b). Nevertheless, disagreement still exists.

The numerous hypotheses on Holocene eustatic shorelines have been discussed by Jelgersma (1966), Guilcher (1969) and at the INQUA meeting in Paris 1969 where data from all parts of the world were presented (Jelgersma, 1969; Davis, 1969; Fujii, 1969; Richards, 1969; Hopley, 1969). Basically the hypotheses fall into three groups:

i) The Holocene transgression is marked by many oscillations in sea level, some of which may have taken sea level above that of present. The best known of these hypotheses is probably that of Fairbridge (1961) who indicates rapid oscillations in the Holocene with higher levels at 6,000 to 4,600 B.P. (Older Peron 10 to 15 feet), 4,000 to 3,400 B.P. (Younger Peron, 10 feet), 2,600 to 2,100 B.P. (Abrolhos, 5 to 6 feet) and 1,600 to 1,000 B.P. (Rottnest, 2 to 3 feet). However, Fairbridge's data were taken from many different environments and from many different parts of the world and errors may have been incorporated not only from the radio-carbon technique but from the
use of contrasting materials and datum. More recently Morner (1969a, b) has presented evidence of similar though not identical oscillations from Scandinavia, claiming to have taken into account the glacial isostatic uplift factor. Several of his oscillations reach or just exceed present sea level, the maximum of 0.4m (1.25 feet) occurring 3,600 to 3,350 years B.P.

ii) The Holocene transgression is marked by a steady rise in sea level 5,000 to 3,000 years B.P. by which time it had reached that of present and since which it has remained steady. Evidence for this hypothesis comes mostly from the Gulf Coast region of the U.S.A. (Fisk, 1951; Gould McFarlan, 1959; Le Blanc and Bernard, 1954; McFarlan, 1961; Coleman and Smith, 1964). However, these findings are paralleled by those of Godwin, Suggate and Willis, (1968).

iii) The Holocene transgression is marked by a steady rise of sea level continuing right up to the present day. This concept was first conceived by Shepard and developed by Shepard and other authors (Shepard and Suess, 1956; Shepard, 1960, 1961, 1963, 1964; Shepard and Curray, 1965).

The problem is epitomised by the Australian region. Figure 7.2 shows the level of the sea in relation to radiocarbon dates available in the literature. Great variations exist in the evidence, and its interpretation, from state to state and even within the one region. Thus in the Perth area of Western Australia high sea levels of about 16 feet are indicated from about 5,500 to 3,800 B.P. (Fairbridge,
Fig. 7.2 Radio-carbon dates related to sea level in the last 11,000 years in Australasia.
1961) though at least part of this evidence has been questioned by Russell (1964). 450 miles to the north, at Shark Bay, emergent marine strata formerly considered to belong to the Holocene have now been allocated to the late Pleistocene (Logan, 1967) but shelly marine beds including articulated pelecypods indicating a higher sea level to about 4 feet, have been dated at between 4,000 and 5,000 years B.P. (Logan, 1968).

Although Holocene tectonic activity is suspected in South Australia higher Holocene sea levels have been interpreted as eustatic. A 6-foot level was dated at 4,330 years in Holocene sand ridges apparently unwarped near Robe and a 7-foot level is quoted for emerged shell beds at Port Germain (Blackburn, 1966).

The structurally complex coast of Victoria, consisting of a series of horts and grabens, provides convincing evidence of a higher Holocene level. Concentrating research on undisturbed still water marine facies over the whole length of coastline, Gill (in press) has indicated that a higher sea level of 6 to 10 feet existed along the whole coast within the age bracket 4,000 to 6,500 years B.P. The importance of these results is their constancy over 500 miles of coast and across 5 major tectonic provinces which have been active during the early Quaternary. If earth movements are considered as influencing the emergence of these shell beds then the movement has been similar over the whole coast and has taken no account of recently active structural weaknesses. Moreover, the rate of movement will have been almost 200 times more rapid than the average rate of movement calculated since the beginning of the Oligocene. An upward movement would also be envisaged for areas in which the Tertiary movements have undoubtedly been downward.
In contrast to Victoria, it is surprising to find that in New South Wales, no convincing evidence of higher Holocene sea levels incorporating radio-carbon dates has been reported. In the Shoalhaven delta, marine deposits of about present sea level date at 4,470 years + 150 (Langford-Smith, 1968) and are overlain by freshwater fluvial deposits. Similarly in the Macleay delta, on the north coast, marine deposits do not extend above sea level (Hails, 1968). Hails (1965) has summarised the evidence on sea level changes in eastern Australia, though his conclusion that no high Holocene sea levels exist in eastern Australia should be restricted to the N.S.W. coast: Thom, Hails and Martin (1969) discuss further the absence of higher Holocene levels though their definition of eastern Australia, might be more accurately termed N.S.W. Rather surprisingly in view of the evidence presented in Chapter 2, they quote evidence which suggests that sea level has not risen above the present during the Holocene in the Burdekin delta, though they do suggest that the nature of evidence from northern Queensland requires further study.

It may be significant that, in N.S.W. where the higher level has not been found, gentle down-warping of the continental shelf in at least the central coast area around Sydney, has been postulated in the Quaternary (Phipps, 1967) and it has been suggested that the Lapstone monocline, which forms the front of the Blue Mountains west of Sydney, attained its present form during movements which post-date the middle Pleistocene (Brown, Campbell and Crook, 1968).

The evidence from North Queensland very strongly indicates that a higher Holocene sea level has existed in the area studied. The heights and dates quoted agree well with those from elsewhere in Australia, and though there is no firm evidence of any great oscillations in the sea
level movements, there are suggestions of such oscillations in the variations in height of beach sands in the Cape Cleveland beach ridges. Although the hypothesis of Bloom (1967) allows for the co-ordination of the hypotheses of a continuing rise of sea level to the present and of present sea level being reached several thousand years ago, by introducing a water loading isostatic factor on the continental shelf, which will vary with the width of the continental shelf, it can do nothing to help in the explanation of evidence for higher Holocene sea levels.

It is proposed that the evidence presented here is significant in that beach rock heights as indicators of former sea level are possibly more exact than shore platforms, peat levels or unconsolidated deposits. However, the writer must agree with the conclusions of Kuenen (1955) that:

"It must be admitted that the problems connected with sea level as datum are not yet in a satisfactory stage of development. Random observations will not bring much advancement. What is needed are accurate altitude measurements of well dated terraces in widely separated localities made by observers realising the difficulties involved. Only this will be possible to distinguish between glacial-eustatic and general eustatic movements and to assess the role played by coastal warping".

The examination of the coastal area between North Queensland where higher Holocene sea levels are found, and northern New South Wales where possibly they are not, may well help to solve the problem at least in Australia. In particular, extension of the research on raised beach rock terraces would seem to be indicated.
The Question of Warping in Study Areas

Beach rock is an ideal agent for indicating the heights of past sea levels, but the rapidity with which cementation can take place means that even minor oscillations may have beach rock indicators. As indicators of warping, therefore, beach rock levels are not ideal. Thus a level of 10 feet at one place and of 12 feet at another may give similar radio-carbon dates and suggest warping. However, the two samples may each have error dates of the order of ± 200 years which could easily place them 400 years apart. It is suggested that beach rock may be too fine an indicator of sea levels in relation to the error of the age to allow for interpretation of warping trends.

Shore platforms on the other hand are formed much more slowly and may indicate only major stillstands. Thus platforms cut at different eustatic sea levels but in similar climates and lithologies should remain the same vertical distance apart, assuming that no tectonic movements take place. The question as to what height the platforms are cut in relation to sea level and lithology (see Bird and Dent, 1966; Gill, 1967) should not enter the problem. Slight variations in exposure in response to a different sea level may not be experienced evenly over the whole area being examined and could give small anomalies in the height differences of platforms, but these are considered too small drastically to affect the results.

Mention has been made in the regional chapters of platforms occurring at various levels in the research area. A partial analysis of these was made by Driscoll and Hopley (1968) who concluded that platform notches occurred at mean heights of 0.2 feet, 4.8 feet and 14.8 feet (their heights have been related to M.H.W.S.). The upper platforms is
fragmentary and not found in all localities and interest
in this study has centred on the two lower platforms. That
at 0.2 feet is well within the reach of modern wave activity
and shore platform processes in general but cemented
conglomerate occurs on this platform in places and in a
number of localities (for example Havannah Island, Wallaby
Point on Great Palm Island and Camp Island) the conglomerate
is almost certainly of mid-Holocene age. Moreover, this
platform at or just above M.H.W.S. in many places appears
to be suffering erosion, being consumed by a lower notch not
much above L.W.M. The platform is therefore interpreted as
mid-Holocene, though it may be a composite feature cut
during both the transgressive and regressive phases of the
Holocene high sea level as the indications are that the
actual maximum level was of too short duration to allow a
significant platform to develop. The higher 4.8-foot
platform is older and more weathered and being destroyed at
present by solution pitting within the spray zone. It
appears to be the next oldest of the platforms and is there­
fore allocated a late Pleistocene age. The relationship
between the mean heights of platforms and assumed maximum
sea levels at time of formation are remarkably similar.
The 0.2-foot platform is associated with an 11-foot sea level
(10.8-foot difference), the 4.8-foot platform with a 15-foot
sea level (10.2-foot difference). Variations of at least
this magnitude may be explained in terms of local
irregularities in platform heights which limit the accuracy
of the survey method.

Using the data published by Driscoll and Hopley (1968)
and extending the platform survey over a much greater area
of the research region, an attempt has been made to indicate
the degree or lack of warping in the coastal zone in the last
100,000 years. The areas surveyed include from north to
south:

i) Palm Island, composite figures from Great Palm, Fly and Havannah Islands.

ii) Mount Douglas.

iii) Range of Many Peaks.

iv) Muntalunga Range.

v) Beach Mount, Burdekin delta.

vi) Camp Island.

All the platforms were poorly developed, the majority being cut in granite, the remainder in rhyolite or gabbro. Examination of current processes suggested that the platforms were cut at about the same level in all lithologies. Table 7.1 shows the mean heights and height relationships of the two platforms in the different localities. Variation at each level appears due to variations in exposure.

The height differences range from 4.4 feet to 8.4 feet. The range appears great and possibly indicates warping though it may also reflect the difficulty of identifying the notch at the rear of the higher platform. In Table 7.1 there appears to be no logical pattern to the differences in spacing of the platforms.

The amount of data is too small for the use of statistical techniques to identify any significant pattern. However, of necessity, the information points are located in linear fashion along the coast in a direction which parallels the regional structure and in particular the line of main Tertiary uplift from north-west to south-east. Figures 7.3a and 7.3b show regression lines for the height differences plotted against distance along a base line, in figure 7.3a the base line being parallel to the regional structural trend (i.e. parallel to the coast), in figure 7.3b it being transverse to the regional structural trend. The results indicate a degree of warping upwards from north-
Table 7.1

Mean heights of shore platforms in the Townsville area

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean height lower platform</th>
<th>Mean height higher platform</th>
<th>Height difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm Islands</td>
<td>0.8 feet</td>
<td>7.3 feet</td>
<td>6.5 feet</td>
</tr>
<tr>
<td>Mount Douglas</td>
<td>-1.3 &quot;</td>
<td>3.2 &quot;</td>
<td>4.5 &quot;</td>
</tr>
<tr>
<td>Range of Many Peaks</td>
<td>2.0 &quot;</td>
<td>6.4 &quot;</td>
<td>4.4 &quot;</td>
</tr>
<tr>
<td>Mungalunga Range</td>
<td>2.3 &quot;</td>
<td>7.9 &quot;</td>
<td>5.6 &quot;</td>
</tr>
<tr>
<td>Beach Mount</td>
<td>5.2 &quot;</td>
<td>13.6 &quot;</td>
<td>8.4 &quot;</td>
</tr>
<tr>
<td>Camp Island</td>
<td>-0.3 &quot;</td>
<td>6.2 &quot;</td>
<td>6.5 &quot;</td>
</tr>
</tbody>
</table>
Fig. 7.3A  Regression line indicating warping parallel to the coast.

Fig. 7.3B  Regression line indicating warping transverse to the coast.
west to south-east at a rate of 1 foot in 58 miles. This is not considered significant in view of the small amount of data available and the difficulties and possible errors involved in its collection. The other graph (7.3b) indicates a much greater degree of warping, as would be expected across the regional structural trend. A rate of warping upwards from the coast of 1 foot in 6.5 miles is indicated. This appears more significant but in view of the same difficulties must be treated with caution. Nevertheless it is possible that warping along the coastal zone has continued into the late Pleistocene.

The amount of warping indicated is not great but it may have accompanied vertical movements of much greater magnitude. Thus the significance of the results to the late Pleistocene and mid-Holocene shorelines cannot be judged. The figures indicate warping in the time span between these two shorelines, at rates which if continued since the mid-Holocene period, would not noticeably affect the mid-Holocene level. The degree of vertical movement and the influence such a movement has had on these emerged shorelines cannot be gauged, though it is suggested that, in the absence of further evidence, the mid-Holocene level must be considered as eustatic rather than tectonic. The general agreement between the level of the late Pleistocene 15-foot shoreline in North Queensland and probably the same feature from other presumably stable areas in Australia and elsewhere in the world, would suggest that the amount of vertical movement over the region as a whole has been negligible in the last 100,000 years.

Assuming that the conclusions reached from figure 7.3b are correct and that the tilting is continuing the same trends as the major late Tertiary movements, then the axis of tilting in the Townsville area is shown to be seawards
of the present coastline.

Conclusions from North Queensland on Sea Level Changes

1. The oldest identifiable littoral deposits in the research area belong to a transgression with a maximum sea level height of 15 feet occurring in the late Pleistocene. A last interglacial age of 80,000 years or greater is allocated to this transgression in preference to a Wurm interstadial. The results from North Queensland closely agree with those obtained elsewhere in Australia and in other areas.

2. Little information is available on the Wurm low sea level phase, though shorelines identified 96 feet, 132 feet and 192 feet below sea level many indicate stillstands during the late Pleistocene.

3. Submerged beach rocks possibly 30 to 35 feet below M.H.W.S. may correlate with a stillstand during the Holocene transgression.

4. The mid-Holocene transgression culminated at about 4,250 years B.P. with a maximum sea level of approximately 11 feet. Close agreement is found between these results and from elsewhere in Australia, though not from New South Wales.

5. The maximum level was not held for long. By 2,500 years B.P. sea level had fallen to approximately its present position and has remained at about this level ever since.

6. Analysis of mid-Holocene and late Pleistocene shore platforms suggests that a tectonic factor may be
involved. The rate of tilting could well affect the Eemian deposits but it is not considered strong enough to affect the mid-Holocene shorelines. Tilting in an upwards direction seawards at a rate of 1 foot per six miles per 100,000 years (approx.) is indicated. The amount of vertical movement involved is not known, but again is not considered drastically to have affected the mid-Holocene shoreline.
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CHAPTER 8

DISCUSSION OF THE GEOMORPHOLOGICAL EVIDENCE FOR CLIMATIC CHANGE

The development of a morphogenetic approach to geomorphology (Peltier, 1950; Tanner, 1961; Büdel, 1963; Leopold, Wolman and Miller, 1964; Tricart and Cailleux, 1965; Wilson, 1968; Stoddart, 1969) has permitted the interpretation of past climates from the fossilised, non-active landforms of the present landscape. By far the greatest attention has been centred on Pleistocene climates and the pattern of cold, glacial climates with intervening warm interglacials of higher latitudes has been paralleled by an apparently synchronous pattern of pluvial and arid phases in tropical and sub-tropical latitudes. Variations in temperatures are also indicated in tropical areas during the Pleistocene with decreases during glacial periods of the order of 7°F (c.4°C.) compared to today's climate and increases during interglacials of about 3°F (c.2°C.) (Flohn, 1952; Emiliani, 1955; Fairbridge, 1961a). Little data is available from the Australian region to confirm the amplitude of these variations, though oxygen isotope palaeotemperatures determined by Dorman and Gill (1959a, b) suggest a late Pleistocene rise of temperature in southern Australia similar to that elsewhere.

These variations in temperature have possibly not been acknowledged sufficiently in previous climatic reconstructions in the Australian region (e.g. Whitehouse, 1940; Browne, 1945; Crocker, 1959) though more recently, Watkins (1967) did take into account the lower temperature factor in his
study of the relationship between climate and development of landforms in the Cainozoic of Queensland. It is suggested that the water balance approach is fundamental to climatic geomorphology. Evidence has been presented in Chapters 2 to 5 for both wetter and drier phases in the past climate of the research region. It is intended that these terms "wetter" and "drier" be used with caution and that they refer not simply to periods of higher or lower rainfall, but to times when the availability of water for geomorphic processes was either greater or less than it is at present. Such variations could result from simple fluctuations in annual rainfall totals, but they could be produced by alterations in the rainfall regime, with a greater or lesser proportion of the annual total falling in the cooler winter months when evaporation is less, or alternatively by lower or higher temperatures, with similar effects on precipitation effectiveness through evaporation.

In view of the evidence for temperature fluctuations during the Pleistocene, an analysis of the water balance of the Townsville area was considered an essential prerequisite for a discussion on climatic change. Figure 8.1 shows the water balance assessment based on Townsville figures for

a) the present, using mean monthly temperature and precipitation figures.

b) the Pleistocene glacial phases, assuming a similar precipitation pattern as today, but a depression of each month's mean temperature by 7°F.

c) the Pleistocene interglacial phases, assuming a similar precipitation pattern as today, but an increase in each month's mean temperature by 3°F.
Fig. 8.1 Potential evapo-transpiration water balance graphs for Townsville.

A. Present conditions  
B. Glacial conditions (7°F, cooler)  
C. Interglacial conditions (3°F, warmer)

\( R > \text{P-} \text{et} \)  
\( \text{P-} \text{et} > R' \)
Potential evapo-transpiration figures were computed using the Thornthwaite (1948) formulae based on temperature\(^1\). These formulae when applied to North Queensland, have a very close approximation to the considered figure based on evaporation measurements of 0.674 of the Australian Standard Evaporation Tank figure (Hounam, 1961).

At present the Townsville area receives an average of 42.7 inches of rain per annum. The total potential evapo-transpiration figure for the year is 49.68 inches, a deficit balance of 6.98 inches. Taking only the months when rainfall exceeds potential evapo-transpiration, it is calculated that there are 11.47 inches available for geomorphic processes (other than those which take place during the evaporation). There are 3 months when the rainfall figure is the greater. During the cooler Pleistocene phases it is estimated that the total potential evapo-transpiration figure would be 35.98 inches, an excess balance of 6.79 inches, and taking only the months when rainfall would have exceeded potential evapo-transpiration, which number 4, there is a total of 16.00 inches available for geomorphic processes. The calculations for a warmer interglacial phase show a total potential evapo-transpiration figure of 56.37 inches, a deficit of 13.67 inches, with rainfall being the greater.

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1. The formulae used are:

\[
P.E. \text{ (inches)} = \frac{T + 0.04T.(T-65) + T-m}{25.4}
\]

when \(T-m\) is positive

and \(P.E. \text{ (inches)} = \frac{T + 0.04T.(T-65) - 2(m-T)}{25.4}\)

when \(T-m\) is negative.

\(T\) = mean monthly temperature \(^o\text{F}\), and \(m\) = mean annual \(T^o\ \text{oF}\).
figure in only 2 months and producing only 9.78 inches for geomorphic process.

Although a number of assumptions are made in this analysis, including the assumption that the Pleistocene rainfall distribution was similar to that of present, and that the mean annual temperature variations calculated from elsewhere, were distributed evenly over the whole year, the results are considered valid. They indicate that a difference of over 20 inches existed in the water balance figures for glacial and interglacial phases, that the wet season was effectively twice as long and that the amount of water available after evapo-transpiration during the cooler periods was almost twice that for the interglacials. Although insufficient data are available to evaluate the effects on geomorphological processes, it is suggested that the temperature variations alone may have been sufficient to produce the observed fossil landforms in the research area. Moreover, the reductions and increases in temperature inferred though sufficient to produce effective changes in the water balance, but would not have greatly altered the general tropical nature of the environment.

**Climatic Conditions and Geomorphic Processes**

Under the present climatic regime, the hillslopes of the research area are shedding small angular debris which is apparently further broken down at the slope foot as the rivers generally carry a heavy load of sand size material. Alteration to clays is not taking place rapidly except in the most stable situations on flat or gently sloping terrain. Soil processes reflect the alternation of wet and dry seasons, but water table fluctuations are not great and accumulation of sesqui-oxides is limited the upper three feet (see
Chapter 4, p.202). The dessication of the environment is considered to result in an increase in the size and amount of slope debris as a result of a reduction in the vegetation cover and an increase in mechanical weathering processes (Langbein and Schumm, 1958), though Dury (1967) questions the increase in yield. Accumulation of fans would result at the foot of hillslopes and pedimentation would become the major process. Streams, which would flow on a seasonal basis to an even greater extent than they do now, would carry a heavier and coarser load. It is thought that the restricted mobility of sesqui-oxides which occurs in the soils today, would cease and carbonate accumulation would occur. Alternatively, if the environment were to become more humid, even on a seasonal basis only, there would be an increase in the water table fluctuations and an increase in sesqui-oxide accumulation over a greater depth of the unconsolidated deposits, and given sufficient time, lateritisation would become the major process. A denser vegetation cover would restrict weathering process and mobility of slope debris and help to increase the importance of chemical weathering. Sediment yield would trend towards finer materials and especially clays. Channelled flow would be found in the piedmont area with incision into any previous pediments.

The Pattern of Climatic Change in North Queensland

Assuming the changes outlined, it is possible to reconstruct the past water balance conditions in the North Queensland area. The earliest period examined is the last interglacial. The widespread occurrence of clay plains during this period may imply that an earlier phase existed which had moister conditions than the present. Moister
conditions producing deep weathering are indicated in the Cape Upstart area, where they produced large rounded corestones on the slopes of the small basic igneous outcrops found here. The large Pleistocene dune of this area is attached to and partly covers these outcrops thus giving a minimum age for this deep weathering episode, which may, however, date back to the previous glacial phase, possibly the Riss. However, by the end of the interglacial period, dessication had occurred accompanied by the regression of the sea from the interglacial high level. The early part of this sequence is possibly recorded by the dunes of late Pleistocene age, for the ones associated with a 4-foot sea level and interpreted as belonging to the regressive phase are the largest. Though the highest example is that to the south of Cape Upstart, the Inkerman beach ridge-dune provides the best contrast. The dune ridge at its northern end, where the calcarenite is found, rises to 45 feet but declines rapidly in height as a northern orientation is attained. In contrast, the dune at Green Hill, which has a similar orientation to the lower parts of the Inkerman ridge, is almost twice the height. Although this evidence is far from conclusive, the general increase in height of the Pleistocene ridges with the regressive phase is possible an indication of dessication.

That pedimentation and accumulation of angular fragments in the piedmont zone occurred at a lower sea level phase is best illustrated by Mount Douglas (Chapter 4, p.193). Here, the pediment on the seaward side of the outcrop and associated piedmont angular gravels slope beneath present sea level. The relationship of the late Pleistocene surface and the pediments of the Burdekin delta also suggest pedimentation during the early part of the last glacial low sea level. The pediments in the interior of the delta are
graded to this alluvial surface, apparently prior to its incision, but nearer the coast it is evident that the pediments also grade down to at least 25 feet below sea level. Again, it appears that the drier conditions were initiated in the interglacial and continued into the early part of the glacial phase.

Further deposits almost certainly belonging to the late Pleistocene arid conditions are found in the piedmont zone and on the coastal plain north of Townsville. Large angular fan gravels rest on pediment surfaces along almost the entire length of the foot of the coastal escarpment. Fan gravels are especially prevalent in the Frederick's Peak area where they are cemented, contain iron-stone nodules and occur beneath younger fan deposits. It would seem that the pediments of the research area are almost entirely fossil features belonging not to the most recent drier phase, but to that occurring in the late Pleistocene period. The streams deposits north of Townsville allocated to this period are extremely coarse in their lower sections, the younger, upper deposits grading into sands possibly indicating the change to moister conditions at a later date.

That moister conditions prevailed during the low sea level phase is certain. The most interesting evidence comes from the Mount Douglas sections again where the old pediment deposits become deeply weathered and lateritised, with the development of a sesqui-oxide accumulation horizon of about 1.5 feet overlying mottled and pallid zones. The whole sequence passes beneath present sea level. It is suggested that the piedmont area of Mount Douglas with its coarse gravels was a favourable location for moisture accumulation and water table fluctuations, which explains the more complete deep weathering which occurred here in comparison to the clay deposits of the coastal plain. Even here,
however, accumulation of ferro-manganese pisolites took place to a much greater depth than is occurring today. Similarly, the late Pleistocene fluvial deposits become weathered with accumulation of sesqui-oxides. In the scarp-foot zone, the coarser fan gravels suffered deep weathering to a similar extent as the Mount Douglas pediment deposits, probably for the same reasons. The moister phase is also marked by incision of the pediments and by the deposition of younger Pleistocene clays even in the piedmont area where they overlie the coarse gravels of the interglacial stage.

Possibly because the Burdekin delta region also contained alluvial deposits coarser than clays, which allowed water table fluctuations, explains why the interglacial deltaic surface became deeply weathered and oxidised here. Although this surface can be recognised over the whole delta, the borehole deposits which most closely resemble laterite, with a red cemented upper surface and underlying pallid zone, are those developed on coarser materials. Similarly, the red cemented deposits exposed at the surface in the Haughton River area were originally coarse gravels. Elsewhere in the delta, where clays appear to have been the predominant late Pleistocene surface deposits, accumulation of sesqui-oxides has been less general and limited to nodular or pisolitic forms. Although borehole evidence is less detailed in the Herbert River delta, a similar pattern seems to be found there.

The question as to whether the deep weathering which took place was the result of an altered water balance sequential upon the lowered temperatures, or whether it followed an increase in precipitation as well, is an interesting one. Certainly the weathering occurred over a wide area, and, considering the comparatively short time
span it appears to have been a rapid process. If lower temperatures alone were responsible for greater availability of moisture it might be expected that, with a similar rainfall regime as today, the effects would be felt along the entire length of what is the present dry sector of the north Queensland coast (from south of Ingham almost to Mackay). There are doubts concerning this for south of Cape Upstart, outside the research area, the landscape certainly changes. This may be a reflection of geological conditions, as massive granites become the only rock type found in the coastal zone, but pediments are more extensive, fresher in appearance and, apart from angular fan deposits, have no extensive colluvial cover as in the Townsville area. Research into the nature of the late Pleistocene alluvial surface of the Don River delta may determine the extent and nature of weathering, but certainly the general appearance of the landscape suggests that drier conditions existed here much more permanently than further north. Again, it may be significant that the only known occurrence of late Pleistocene raised beach rock is on Camp Island, at the southern limit of the research area. It has already been noted in Chapter 2 that on the wetter islands north of Hinchinbrook, raised beach rock of even mid-Holocene age does not survive. The wetter conditions of the last glacial may well be responsible for the erosion of raised beach rocks of interglacial age from the Palm Islands and the islands of Halifax Bay. The Camp Island raised beach rock may thus owe its survival to the absence of much wetter conditions during the latter part of the Pleistocene. It is interesting to note that two levels of raised beach rock, the upper one possibly of late Pleistocene age, are described on islands in the Bowen area, as for example, Middle Island (Stanley, 1928, p.36; Steers, 1929, p.346,
That conditions should alter so rapidly between the Burdekin delta and Bowen, a distance of 60 miles, is not surprising in view of the fact that today the average annual rainfall of Townsville is half that of Ingham, a similar distance to the north. The evidence thus suggests that the glacial phase climate was wetter as well as cooler than present.

The wetter conditions did not survive the end of the Pleistocene period. Dessication of the environment is indicated by the cessation of ferro-manganese accumulation in the soils of the coast plain and the initiation of a carbonate accumulation phase. Radio-carbon dating suggests that the drier conditions were effective by 15,000 years B.P. New fan accumulation in the piedmont zone and resumption of pedimentation are also allocated to this period. Massive waste deposits formed in the upper reaches of the streams. The present streams have incised themselves into these, leaving the arid phase deposits as stranded climatic terraces. It would seem that the drier phase extended at least until the mid-Holocene maximum sea level stage, as stream courses apparently graded to this higher level contain coarser deposits than those carried by streams at present. The widespread accumulation of levee deposits, which also appears to date from this period may also reflect the greater sediment yield produced under drier conditions.

The reversion to the moister climate of the present has stabilised the fans, caused incision of the streams into the coarse deposits of their headwaters, produced a sediment yield of smaller calibre and started a new though restricted accumulation of ferro-manganese nodules in the soils of the area. However, the variability of rainfall appears to produce an alternation between conditions favourable to fan accumulation and pedimentation, with those associated with
stabilization of fans and channelled flow in the piedmont zone, the latter conditions being the more common. It is suggested that the balance between the two is delicate.

Discussion

The pattern of climate indicated is one of conditions as dry as or drier than present existing during the warmer interglacial periods and wetter than present during the glacial period, though the dry climate appears to have extended into the early part of the low sea level stage of the glacial and to have resumed well in advance of the eustatic recovery of sea level. The climatic anticipation of the rise in sea level is understandable and parallels Fairbridge's (1961a) melt retardation hypothesis which suggests that climatic warming proceeds the melting of the temperate ice masses by at least 4,000 years and that the eustatic rise is at least 10,000 years behind the radiation oscillation which initiates the melting. Both Fairbridge (1961b) and Shepard (1961) agree that by 17,000 years B.P. the eustatic rise in sea level had started. In temperate latitudes the presence of massive areas of ice, even though in ablation, would tend to retard the recovery of temperature to a greater extent than in the tropics where there would be nothing to prevent an earlier recovery of temperature and reversion to the interglacial conditions. It is, therefore, not altogether surprising to find that the drier, supposedly interglacial conditions, existed by 15,000 years B.P. in north Queensland.

Why the interglacial conditions should prevail during the eustatic lowering of sea level of the last interglacial, is more difficult to understand if it is accepted that temperate and tropical climatic changes were in phase during
the Pleistocene. It may well be that whilst the conditions which trigger off a melting of the ice sheets will automatically produce climatic changes in tropical latitudes, the conditions which produce the start of a glaciation have less effect and tropical glacial stage conditions are more dependent upon the changes in circulation produced by the ice sheets themselves. This could explain the retardation of climatic change in north Queensland at the end of the last interglacial.

The present wet season, and the great variability of rainfall in the research area are a reflection of the not completely reliable extension of the Inter-tropical Convergence (I.T.C.) this far south during the summer months. It may be assumed that the wetter phase saw not only an improved water balance position as a result of lowered temperatures, but also a more reliable wet season, conditions possibly regularly resembling those of the wetter wet seasons now experienced only occasionally. Townsville for example over the last 100 years, has experienced a "wet" year of over 60 inches rainfall a total of 18 times, and over 50 inches a total of 38 times. These wet years generally indicate the seasons when the I.T.C. clearly extends south of Townsville. The great variability of Townsville's rainfall also indicates its dependence on the progress southwards of the I.T.C. Ingham's rainfall is much less variable because the passage of the T.T.C. is more dependable. Years when Townsville has less than 35 inches of rainfall see no great departure from the mean at Ingham. It is thus suggested that the glacial period saw the mean summer position of the I.T.C. over the coast of north Queensland 60 miles further south than it is today. The Bowen area could therefore be still in the zone of unpredictable summer rains, with a restriction in the deep
weathering processes. In a recent paper, Bird and Hopley (1969) suggest a migration of expansion and contraction of the climatic zones during the Pleistocene, with wetter conditions extending north of the present Af climatic area, as well as to the south of it. This too may be associated with the migration of the I.T.C. further south and its delayed return northwards out of the Australian region. Disturbances associated with the I.T.C. would thus be experienced in northern Australia for a longer period, producing wetter conditions, though probably still seasonal.

These conclusions are not altogether in accord with the changes postulated for the tropics in the literature. Fairbridge (1961a, 1968) considers that the glacial periods were ones of reduced rainfall as a result of less evaporation. He has illustrated his ideas in North Africa (1964) where he relates the pluvial phases of the Sahara with the period of post-glacial climatic optimum (10,000 to 4,000 years B.P.). In a figure reproduced in each of the papers to which reference has been made, Fairbridge does, however, indicate an expansion of the warm equatorial zone during the glacial, though stressing that the equatorial latitudes as a whole were drier.

Fairbridge's views are opposed to those of Büdel (1951) who shows a migration polewards of 3° for the humid savanna and tropical rainforest zone during the Wurm glacial. This would be quite sufficient to give the Townsville area the higher rainfall postulated for the late Pleistocene.

In Australia the only detailed studies of climatic change during the Quaternary have been carried out in the south-eastern portion of the continent where they have been related to glacial and periglacial activity (e.g. Galloway, 1965; Derbyshire, 1969). Galloway, in particular, from
evidence of cold, dry, windy conditions in south-eastern Australia, postulates that there was an extension of the high pressure arid belt during the glaciation, explaining certain "pluvial" features in terms of reduced evaporation. His findings are, however, opposed by Dury (1967).

A number of early studies of Australian climatic changes (e.g. Whitehouse, 1940; Crocker, 1959) also indicated that, contrary to Galloway's conclusions, the Pleistocene glacial periods were periods of higher rainfall, and interglacial periods of desert expansion. Gentilli (1961) claims that the narrowing and intensification of the climatic zones during the Pleistocene glacial periods would increase the rainfall along the equatorial convergence, between intensified tropical easterlies. He also extends the humid glacial climate to at least 7,000 years B.P. his "Great Aridity" occurring only at the mid-Holocene stage. The conclusions reached in north Queensland may confirm his views on the activity along the I.T.C. but it would appear that in coastal tropical Queensland, at least, the arid period may have to be extended further back.

Extending the conclusions of Gentilli, Coaldrake (1968) has more recently assumed generally moister conditions over the whole of north-east Australia during the Würm. He also considers that the interglacial climate, though drier in the interior with an expansion of the central arid zone, would not be altered to any great extent along the coast. This may be an overgeneralization.

Walker (1966), indicates that botanical data is as yet insufficient to use reliably to reconstruct climatic change, at least over the last 8,000 years. However, in a very comprehensive survey of phytogeographical elements in the Australian region, Burbidge (1960) makes a number of comments which are relevant to the evidence for climatic variations
in north Queensland. Although primarily recognising only a general Pleistocene pluvial period in Australia and a more recent "Great Aridity" along the lines of Crocker and Wood (1947) she does allow for several climatic oscillations during the Pleistocene. North-east Queensland is seen as an important entry and exit point for plants, which linked Australia with New Guinea, New Caledonia and New Zealand. Burbidge concludes that migration of Indo-Malaysian elements into Australia during the Pleistocene could only have occurred during the low sea level phases, and that for migration of rainforest species to have taken place, the climate must have been wet. This relates closely to the findings presented in this chapter, for in the years when the I.T.C. migrates further south than Townsville the areas to the north normally have higher than average rains as the return northwards of the I.T.C. is delayed, and convectional instability in the moist air behind the I.T.C. is experienced over a longer period. Thus, not only do higher rainfalls occur, but the wet season becomes prolonged and there is a contraction in the length of the dry season, which has a greater influence on the distribution of rainforest than rainfall totals alone. These conditions are envisaged consistently for the last glacial low sea level and, with the improved water balance resulting from lowered temperatures, there would be no climatic barrier to the migration of Indo-Malaysian flora at least as far south as Townsville. Burbidge indicates that a number of apparently recent floristic arrivals have not dispersed out of north Queensland. Although a time factor may be involved here, the indication of a dry zone south of the Burdekin delta may also have prevented dispersal further south.

A further point made by Burbidge, is that migration of *Eucalyptus* sp. from Australia to New Guinea must also have
taken place during a Pleistocene low sea level and that the presence of Australian elements in dry monsoon climates of Malaysia may similarly be explained. She provides three possible explanations for the apparently anomalous position of high rainfall Indo-Malaysian species moving south across a land bridge at the same time as low rainfall Australian species were moving north:

i) that the climate was not consistently pluvial during the Pleistocene low sea levels

ii) that there was a gradation east to west of climates across the land bridge

iii) that the migration took place earlier than the Pleistocene when a land bridge existed at the time of an arid climate.

Although Burbidge favours the latter explanation, especially for the presence of Australian elements in Malaysia, problems still remain. The evidence presented in this chapter may at least give more weight to the first alternative to explain the migration of eucalypts into New Guinea. It has been indicated that the dry conditions of the last interglacial extended into the low sea level phase, possibly long enough for these to coincide with the formation of the Australian-New Guinea land bridge.

Conclusions

The conclusions reached on climatic change in north Queensland based on geomorphological evidence are summarised below. They are far from being in complete agreement with hypotheses concerning climatic changes for the whole of Australia which have been published. However, this is not altogether surprising considering the size of the Australian continent and the fact that Pleistocene climatic changes in
the tropics have generally been interpolated from evidence in the southern or interior portions of the continent.

The changes envisaged are not great and can generally be explained in terms of the more common occurrence in the past of what are now exceptional climatic years. The relatively small changes which are considered to have taken place in the atmospheric circulation in north Queensland during the late Quaternary have probably been magnified by variations in water balance conditions resulting from temperature fluctuations. The changes which have occurred are:

1. At some period prior to the regression phase of the last interglacial period, a wetter climate existed. This may have been contemporaneous with the penultimate glacial period.
2. The latter part of the last interglacial experienced a climate drier than present. The conditions could have been produced simply by higher temperatures, rather than decreased rainfall. The dry conditions continued into the low sea level phase.
3. During the last glacial period, a wetter climate existed which was produced not only by improved water balance conditions with lowered temperatures, but also by an extension of the mean position of the Inter-tropical Convergence 60 miles further south than its present mean position during the summer months.
4. Dry conditions again prevailed from the latter part of the Pleistocene (at least 15,000 years B.P.), to the mid-Holocene period 4,000 to 5,000 years B.P. The higher temperatures of this period may again have been influential.
5. The present climatic pattern is intermediate between the two extremes, though more closely allied to the drier phases. A slight lowering of temperature may have occurred since mid-Holocene times.
References


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CHAPTER 9

MORPHOGENIC FEATURES OF A TROPICAL WET AND DRY COAST

The conclusions from the previous chapter indicate that though the research area may have experienced a wetter climate during the Pleistocene, the seasonality of the rainfall persisted. The consistency of the climate during the period when the coastal landforms of the North Queensland area were evolving results in many of the present features of the coast being attributable directly or indirectly to the one morphogenic system. Whilst a climatic approach is commonly adopted in general geomorphological studies (see references in Chapter 8), its application to coastal studies has been restricted, though Davies (1964) has proposed a morphogenetic approach which acknowledges the existence of "climatic factors of morphogenetic significance affecting such things as beach regimes and materials, cliff and platform weathering, and the regional formation of coral reefs, salt marshes and coastal dunes". Modes of coastal evolution in contrasted climates have been discussed by Tricart and Cailleux (1965a), with emphasis on the features of humid tropical zone coasts, notably in Brazil and West Africa. More recently Bird and Hopley (1969) have considered how far the coastal features in the humid tropical sector of north-east Queensland conform with those described elsewhere in similar climates.

However, the treatment of the tropical wet and dry area as a separate coastal morphogenic zone has not apparently
occurred previously, though Tricart and Cailleux (1965a) indicate that some of the features they describe are more common in the wet and dry tropics, than the continuously wet zone. It may be argued that the wet and dry tropics constitute only a transitional zone between the tropical wet and the desert climates. Alternatively, in view of the greater temperature extremes experienced by the wet and dry tropics, they may be transitional between the tropical wet system and temperate areas. However, a savanna morphogenetic region is recognised in the systems of both Peltier (1950) and Tricart and Cailleux (1965b). It is argued in this chapter that such a morphogenetic region may be recognised in the coastal zone.

The wet and dry tropical zone into which the research region fits is basically the Aw type in the Köppen classification. Such climates are limited by the precipitation of the driest month falling below 2.4 inches, and the temperature of the coolest month not falling below 64.4°F. A large proportion of the Australian coast lies within this system. The Australian tropical coasts are climatically related to those of parts of India, East Africa, parts of West Africa and north-east Brazil.

The nature of landforms on any coast is dependent on the processes operating in three interrelated zones. First, the processes working in the coastal hinterland, i.e. in the basins of the rivers flowing to the coast, have an important influence on the type of sediment being supplied to the littoral zone. Secondly, there are processes operating within the littoral zone itself, where the interplay between sub-aerial and marine activities may be less directly dependent upon climate, but where, nevertheless, indirect influences are morphologically important. Finally, there is the off-shore zone, where another source of beach
Sediments may be found in the form of either fluviually deposited or sub-aerially weathered material belonging to low sea level phases of the Pleistocene or material of biogenic origin. Water temperatures and wave and swell characteristics are also important off-shore influences on the littoral zone which may be dependent upon climate. The contribution of these three zones in the research area is examined below.

Sediment Supply from the Hinterland

The geology and physiography of the hinterland of the research area is favourable to a rapid supply of sediment to the coastal zone. The presence of a deeply weathered fossil regolith in the upper reaches of the major catchments and the occurrence of large areas of granite, the rapid granular decomposition of which appears to produce a steady supply of sand size material, are factors which mean that coastal streams invariably carry a large load to the coast. The process of sediment supply is undoubtedly helped by the sub-humid climate of the catchments. As has been mentioned earlier, following the conclusions of Langbein and Schumm (1958) and Leopold, Wolman and Miller (1964), the rainfall of the basins of the rivers of the research area is close to that which will result in the maximum sediment yield. However, these conclusions are questioned by Dury (1967) and evidence from North Queensland presented by Douglas (1965) tends to support Fournier's (1960) conclusions that in general, erosion is a function of the amount of rainfall and the intensity with which it falls. In his study of four catchment areas on the Atherton Tableland, Douglas indicates the maximum sediment yield to come from the river which drains the highest rainfall area (Behana Creek) but that the figure for the lowest rainfall area (based on observations of the
Wild River) is not significantly lower. Certainly per unit volume of water, the lower rainfall area, with a mean annual precipitation of 40 inches, has the greater potential for sediment yield. Douglas noted that when rain does fall in this area, it falls with great intensity and too rapidly to infiltrate and make up the soil moisture deficit. Surface run-off, picking up loose soil particles, quickly reaches the stream channels. The discontinuous vegetation cover does little to interfere with the rapid run-off.

The question of rainfall intensity is an important one. Jennings (1967) mapped rainfall intensities in Australia and indicates the highest crude intensities to be in the tropics. The Aw climate areas, with the exception of a narrow corridor in the Ord River area of Western Australia, all have rainfall intensities greater than 50 points of rain per rain day. The highest intensities occur within the research area with intensities greater than 65 points per rain day over the whole area, and the highest intensity in the whole of Australia occurring at Reid River, 34 miles south of Townsville with 98.9 points per rain day. It is not the purpose of this chapter to enter into the discussion on the relationship of precipitation and sediment yield (for a discussion of results, see Stoddart, 1969). It is sufficient to note that, even if absolute yields of sediment in rivers in Aw climates do not exceed those of rivers of the wetter Af and Am climates, their yield per unit volume of run-off is likely to be high. Moreover, with intense chemical decomposition restricted to a short wet season, it seems reasonable to assume that the sediment yield will include a lower proportion of clays and soluble minerals and an increase in sand size and larger calibre materials. This is important to coastal processes, for whilst finer material delivered to the coast may be carried far from the
littoral zone, to be eventually deposited on the continental shelf and beyond, the larger material is unloaded in the near shore zone, where given suitable wave conditions, it may be transported onshore at a later date. It may be significant that Maxwell (1968), even though suggesting that the supply of fluvial sediments to the continental shelf behind the Great Barrier Reefs is low, indicates that mud facies are dominant in the inshore zone of the high rainfall area near Innisfail (fig. 144B). His figure 138B shows that sediments are highly terrigenous (less than 20% carbonates) in the area between Cape Upstart and the Black River. His figures 138A-D indicate that terrigenous materials in the near shore zone of the continental shelf, may be correlated not only with major river mouths, but also with lower rainfall areas.

No figures are available to indicate the size of river loads in the research area. All streams are choked with sand and fine gravel and flow is restricted to a few months of the year for all except the major Burdekin and Herbert Rivers. In a recent mining company report, Sutherland (1970) indicates that the 100 year flood discharge of the Burdekin River at Ayr is 1.3 million cusecs, of which 0.915 cusecs would flow in the main channel. He suggests that during particularly heavy flooding there is potentially a 30 to 40 feet depth of mobile sand in the river bed. The general indication is, therefore, that fluvial sediment supply is particularly heavy along the coast of the research area, and that the bulk of this material is sand.

The Littoral Zone - Clifled Coasts

Actively receding cliffs are very limited in the research area. Solid rock outcrops on the mainland are rare and even where rock does occur both here and on the
islands, it is doubtful whether much erosion is taking place. It has already been noted that the cliffs of the off-shore islands and of Mount Douglas are essentially little modified exhumed weathering fronts. Wave attack is generally less vigorous than further south on the Australian coast, partly because of the exclusion of the high energy ocean swells by the Great Barrier Reefs, but also because of the comparative rarity of strong winds in the tropics (Jennings, 1965). The absence of rock types such as sandstone, mudstone or limestone which might have more readily yielded cliff forms, and the ubiquity of resistant granites and volcanic rocks has been a further factor in the absence or slow rate of cliff recession. Shore platforms are also poorly developed, the foreshore topography generally being rugged and irregular similar to that of the wetter zone to the north (Bird and Hopley, 1969). However, possibly owing to the presence of more easily eroded metamorphic rocks in the wetter zone, a high tide notch is much better developed than in the drier south. Certainly lithology is an influencing factor here. However, the present writer has noted that in New Guinea (Louisiade Archipelago) the formation of wide shore platforms also in metamorphic rocks (schists and phyllites) and behind a barrier reef, is aided by subaerial chemical decomposition of the rock down to the intertidal level (Hopley, in press). A similar process has been suggested for the platforms of the Barnard Islands (see Chapter 2). Such a process could not be a significant factor in the research area, whatever the lithology. Although deep weathering appears to have produced a regolith during the late Pleistocene, providing core stones for the construction of Holocene boulder spits, there is clearly little weathering preparation of the foreshore occurring today. Minor weathering forms, such as spray pitting and tafoni, occur where
lithologies are suitable but these appear to be similar to those of both the wetter coast to the north and the cooler coast to the south (see Bird and Hopley, 1969; Bird and Dent, 1966).

A major difference between the rocky shores of the wetter coastal zone to the north and the research area, is the presence of a vegetation cover almost down to high tide level in the wetter area. Cliff slopes may thus retain their weathering mantle and differ little from the wholly subaerial slopes of the hinterland. Such slopes are typical of the off-shore islands as far south as Hinchinbrook and the transition to still convex, but bare rock forms in the Palm Islands is sharp. A similar transition occurs on the mainland.

Headlands both in the wetter and drier coastal areas provide suitable environments for molluscan fauna and adjacent beaches consistently have a higher than normal carbonate content. Sediment yield direct from the rock outcrops is not great. In the wetter zone the material delivered to the beach is generally of clay size in all but the most sheltered environments, is transported away from the littoral zone. The yield from outcrops in the drier research area is mostly in the form of grits or coarse sands which combine with shell fragments to form the coarser fraction of the local beaches. The lithological contrast of micaschists, phyllites and gneisses with some basalt in the wetter zone and granites and volcanic rocks further south contributes to this contrast in beach materials.

The Littoral Zone - Depositional Coasts

The large sediment load of predominantly sand size material which is brought down to the coast by the rivers and the low yield from cliff erosion and, on the mainland
away from headlands, from biogenic sources, results in depositional features being dominated by sands of fluvial origin. Indeed, so massive is the sediment yield that depositional landforms are the typical morphological features of the coast in question. Broad barrier systems of parallel beach ridges are typical of all exposed coasts and are replaced by mangrove and salt marsh only at the southern ends of embayments sheltered by the dominant south-easterly waves by prominent headlands as in Cleveland, Bowling Green and Upstart Bays. This indicates that a sand supply is available to a high proportion of the coast, partly the result of the close spacing of coastal streams and of the fact that even the smallest carry an abundant sand load, and partly the result of the nature of the material supplied by the rivers. Since it is largely sand size it is quickly deposited by the rivers as they enter the sea. However, a large proportion of the load appears to lie within the range 2.0 to 2.5 φ which has been shown to be that most easily transported by waves onshore and along shore (Fuller, 1962). Thus the material is of sufficient size to prevent it being carried far onto the continental shelf, but not large enough to prevent it being carried onshore again.

With the larger rivers, sediment supply is more rapid than sediment movement and rapid progradation is taking place close to the river mouths. However, the rapid growth of off-shore barriers and spits (as in the Burdekin region) and the width of the near level marine and littoral plain, allow for rapid changes in river courses within the zone close to the coast. Thus an area of rapid progradation and formation of deltaic cuspate forelands, may suddenly lose its sediment supply with resulting erosion as coastal straightening takes place. Although the nature of dunes on the North Queensland coast is discussed below, it may be indicated that coastal
erosion is characteristically accompanied by dune formation
where an open orientation between east and south is avail-
able. As alternations between progradation and erosion
appear to be ultimately related to the rapid fluvial sediment
supply, it seems reasonable to regard them as morphogenic
features.

The construction of multiple beach ridges may also be
considered as related to climatic influences for their
formation has been shown to be correlated with coasts where
beach face angles appropriate to the beach material and most
significant wave type are steeper than the overall shore
profile (Savage, 1959). As beach faces are steeper with
coarser material and lower waves, ridge building is favoured
by either of these conditions (Davies, 1968). Continual
shallowing of the off-shore profile, usually because of
abundant sediment supply, according to Johnson (1919), will
result in multiple beach ridges. All these characteristics
are found in the coast between Cape Upstart and the Herbert
River delta. The rapid supply of coarser material and the
general low wave height (owing both to generally low wind
velocities and to exclusion of ocean swells by the Great
Barrier Reefs) may be considered as being indirectly
dependent upon climatic factors.

In spite of a long dry season, stabilization of beach
ridges by vegetation is rapid. The dune creepers Ipomoea
pes-caprae and Canavalia rosea are particularly rapid
colonisers. Weathering and soil formation on the ridges
and dunes is closely dependent upon climate. Holocene
ridges have rapidly acquired a profile stained in its upper
few feet by humic material. However, the severe leaching
which is evident on even the Holocene ridges of the wetter
coast further north, is lacking in the ridges of the
Townsville area. The formation of beach rock by the
accumulation of calcium carbonate at the water table within the ridges, is a feature of beach ridge weathering restricted to the drier zone (see below). Contrasts also exist between the weathering of Pleistocene ridges on the wet and on the seasonally wet and dry tropical coasts. In the research area, weathering of the older deposits is not severe, a certain amount of breakdown to clay occurring in some ridges, but with oxidation of sands, producing a typically red colour, being the usual form of weathering. In contrast, podsolisation of the sands appears characteristic of wetter areas both to north and south. Bird and Hopley (1969), describe alluvial ferruginous sand rock near Kurrimine (Innisfail area) and this is overlain by severely leached, white, quartzose sands. Similar materials are also described from southern Queensland and northern New South Wales (Coadrake, 1955; McGarity, 1956). These, too, appear to be Pleistocene in age (Langford-Smith and Thom, in press). The survival of beach rock and even dune calcarenite of Pleistocene age, is also an indication of the less severe nature of leaching of coastal deposits in the drier tropics.

In the review on beach rock formation in Chapter 6, it was noted that conditions for cementation of beach deposits may well be at their optimum in the tropical wet and dry morphogenic region. However, the restricted occurrence of beach rock on the mainland coast is an anomalous feature which may be explained only by reference to the nature of beach materials as fluvially derived sands of extremely low carbonate content. Even under ideal conditions it is suggested that a minimum carbonate content of at least 30% is necessary for cementation. Such conditions are met on the mainland only around headlands, and so rapid is coastal progradation that these appear to be quickly engulfed within beach ridge systems thus limiting the calcareous material to a comparatively
small number of ridges. On the islands, however, the high biogenic content of beach materials combines with the climatic factors to allow rapid cementation of a wide range of beach materials on almost every beach. It is the importance of beach rock as a stabilizing agency, its rapidity of formation and its slow rate of erosion in the tropical wet and dry climate which makes the irregular island spits of the research region features of morphogenic significance. To the north, beach rock forms less readily, and apparently, when it does form and becomes emerged, is quickly consumed by weathering. Thus island spits to the north are nearly all of Holocene age and more regular in shape (see Chapter 2). Further south, outside the tropics, both the lack of fringing coral reefs as a basement for spit development and the slower rates of formation or even complete absence of beach rock, are factors which prevent significant spit development.

Although Russell and McIntire (1965) report beach rock on the Queensland coast only as far south as Sarina near Mackay, there are reports of it further south around Shoalwater Bay (Jardine, 1928) and it occurs commonly on the coral cays of the southern limits of the Great Barrier Reefs (extensively, for example, on Heron Island). The present author has also observed cemented beach deposits of beach rock type exposed during coastal recession at Byron Bay in New South Wales. However, it is evident that towards the southern Queensland coast, even given highly calcareous beach materials, cementation occurs much less readily.

The absence or poor development of dunes in areas of tropical wet climates has been discussed at length in numerous papers (Nossin, 1961; Jennings, 1964, 1965; Bird, 1965; Bird and Hopley, 1969). It appears that beach sands become windborne far less readily than on coasts in cooler and drier environments. In a discussion of the factors
involved Bird and Hopley (1969) dismiss the suggestion of Morton (1957) who described the inhibition of beach sand deflation on the Gold Coast (West Africa) in terms of protective surface coasts of salt-cemented sands by evaporation of beach moisture in dry weather, as such a process has not been generally observed in the tropics. The idea that dune development is impeded by rapid invasion and stabilization of backshore sands by luxuriant vegetation is not tenable as the presence of such vegetation would aid rather than prevent dune building if sand were being blown from the beach. The suggestion that beach sands are generally too wet to be removed by wind action is not entirely satisfactory, for strong winds can deflate wet sands, but the comparative rarity of strong winds in the humid tropics and the fact that when they do occur, they are often accompanied by heavy soaking rains (Jennings, 1965; Tricart and Cailleux, 1965) seems to go far towards explaining the poverty of coastal dune development in this environment.

Although these remarks are directed toward dune development in wet tropical climates, the comparative rarity of dunes in the research area would seem to suggest that similar restrictions are operating here. However, the restriction in orientation is by no means as strict as it is on the wetter coast further north (Bird and Hopley, 1969). The rarity of dunes is surprising in view of the large amounts of sand delivered to the coastal zone. Certainly, salt-cemented crusts have not been observed and whilst colonisation of beach ridges is relatively rapid, it appears that this is not a significant influence. The conclusion that strong winds are generally rare in the tropics is a characteristic which is shared by both wet and seasonally wet and dry tropical climates. The contention that when strong winds do occur, they are accompanied by heavy rains is not altogether
appropriate however, as with the exception of weather associated with tropical cyclones (discussed below), the strongest winds occur during the winter months when rainfall of any kind is rare. The dunes are invariably limited to locations open to the prevailing south-easterly winds, which is normally towards the northern ends of major embayments. However, the general trends of the coast line in the research area tend to restrict the proportion of coast with an aspect suitable for dune development. The implication of the distribution of dunes is that wind action has been strong enough only to move sand from the beach to the backshore on the most exposed sectors of the coast. This is readily understood when wind roses for wind speeds greater than Beaufort Scale 3 are studied (i.e. at velocities sufficient for deflation). Figure 9.1 indicates wind roses of this type for Cairns, Townsville and Mackay. The importance of a south-easterly orientation in the wet zone at Cairns, where 88.2% of sand moving winds come from the south-east is obvious. Further south at Townsville and Mackay, the importance of a single direction is not as great, though more than 75% of sand moving winds still blow from a single quadrant. At Mackay this is again the south-eastern quadrant but at Townsville is the north-easterly direction. The apparently anomalous situation at Townsville may be explained in terms of turbulent distortion of the regional wind pattern by the location of the wind gauge in the lee of Castle Hill. The slightly wider area of dune forming winds in the area south of the wet tropics, may be a factor in the small increase in dune occurrence.

Although coarse deposits predominate, the southern ends of many of the major bays are sheltered from the larger waves approaching from a south-easterly, easterly or north-easterly direction. The lower wave energy in these environ-
Fig. 9.1 Wind roses for wind speed Beaufort Force 3 and above.
ments allows only finer sediments to be delivered. Further north in the high rainfall areas, similar environments are almost exclusively colonised by mangroves. In temperate areas salt marsh would fill this ecological niche. In the research area, and possibly in other similar climatic regions, these areas appear to be intermediate between the tropical wet and temperate forms. Mangroves are extensive but by no means the only type of environment found. In comparison to the wetter areas they are much more restricted to the immediate vicinity of creeks and to sheltered seaward margins where inundation occurs frequently. In the slightly higher areas, where tides may wash less than 117 times a year (Macnai, 1967) there is an abrupt transition to bare, unvegetated mud flats with salt encrustations. It would appear that in areas without a good circulation water, the combination of high evaporation and seasonal rainfall causes salinity rates too high for the successful establishment of mangrove or any other vegetation.

Bare unvegetated mud flats are extensive in the Townsville area and in parts of Cleveland, Bowling Green and Upstart Bays form the dominant morphological unit. High salinity causes not only a general lack of vegetation, but an intensity of chemical weathering which is matched by few other environments (Coleman et al, 1966). Plants which can tolerate pure sea water are not able to develop adaptations to the augmented salt concentration brought about by evaporation over much longer periods than daily or half daily fluctuations. Fosberg (1961) has noted the occurrence of such flats along the Queensland coast and elsewhere in the tropics where a long dry season exists, though his observation that such areas also have large tidal ranges does not apply to the Townsville region. In the wetter tropics, high salt accumulations are prevented by fresh water flushing.
during intense downpours which can occur throughout the year. Further south on the eastern Australian coast (probably south of Gladstone), not only is the rainfall distribution more even, but lower temperatures, at least during the winter months, restrict the amount of evaporation. Mangroves, however, do not colonise such areas. Instead, a cover of salt tolerant grasses, in particular *Sporobolus virginicus*, is characteristic of such areas.

Salt marsh vegetation does exist in the tropical wet and dry climate of the research area. However, it does not fill the same ecological position as it does further south. In general its distribution is limited to low clay plains of apparently marine origin which are rarely, if ever, inundated by even the highest spring tides. In the research region, such areas appear to have evolved from former mangrove and mud flat environments elevated above the tidal limits by the late Holocene regression. The salt marsh of the research area appears to have as much in common with the salt pans of interior Australia as with the coastal marshes further south. Evaporation brings the salt of the clay deposits to the surface only slowly, and though conditions are saline enough to maintain a halophytic vegetation cover (including *Arthrocnemum leiospathyum*, *A. halecnemoides*, *Salicornia australis* and *Suaeda australis*), the summer wet season allows the flushing of surface accumulations before they reach toxic levels. In more humid tropical areas, removal of the salt from similar deposits appears to be accomplished quickly and rainforest appears to have accomplished a rapid colonisation.

Thus climatic conditions apparently determine that acceleration of normal intertidal deposition in quiet water conditions by the aid of vegetation, either in the form of mangroves, as in the wetter north, or by salt marsh, as in
the cooler and wetter south, is not a widespread feature of the coast of the Townsville area. Indeed, the fine grained coastal deposits suffer erosion and planation to a level not far above M.H.W.S. by the extension of low salting cliffs. Thus in spite of only a moderate tidal range, large areas of the salt flats may be inundated by the highest tides.

The Off-shore Zone

There is, in the tropics, a considerable uniformity in physical and chemical conditions of tropical waters (Orr, 1933). Theoretically, therefore it may be expected that off-shore conditions will be similar in all tropical morphogenic systems. However, the off-shore zone itself is affected by morphogenic characteristics of the land itself and thus, indirectly the influence of this zone may have morphogenic significance.

During low Pleistocene sea levels much of this continental shelf was exposed and, whilst climatic conditions may not have been identical to those of present, the geomorphic processes were essentially subaerial and dependent upon climatic conditions. The evidence put forward in Chapter 8 suggests that though wetter, the latest low sea level climatic phase was still essentially one with a significant dry season. Processes may be assumed to have been similar to those operating today. Reference has already been made to Maxwell's (1968) work which indicates predominantly sandy deposits of terrigenous origin along the coast under discussion. Accumulation of these may be attributed to fluvial activity similar to that on todays coasts, during the period of low sea level.

The most important feature of the off-shore zone is the growth of coral reefs. In general terms coral formations
are a morphogenic feature of all tropical areas and the variations in form of the outer barrier (Fairbridge, 1950, 1967) are related to non-climatic features. However, there do appear to be certain features in the distribution of coral reefs which are related to the seasonal rainfall pattern of the research area. Fairbridge (1967) has noted that suspended sediment in turbid waters may be tolerated by the corals but that they are intolerant of salinity changes. The concentration of precipitation to a comparatively few days of the year means that, in the near shore zone at least, and especially in the vicinity of major rivers, salinity fluctuations are sufficient to prevent the growth of fringing and near shore reefs. These are restricted to headlands such as Cape Upstart, which are remote from major rivers and which in many ways are similar to the off-shore islands which have wide fringing reefs. The poor development of mainland reefs compared with, for example, the coast of Papua-New Guinea may be related to the high incidence of torrential downpours and greater intensity of rainfall even on the North Queensland wet coast. Douglas (1967a, b, 1969) concluded that the nature of rainfall in North Queensland was sufficiently different (more intense) compared to that of Malaysia, to be responsible for significant differences in channel forms. It may well be that these same characteristics prevent a greater development of fringing reefs on any part of the mainland coast of the research area.

The Effects of Tropical Cyclones

The geomorphic implications of the seasonality of rainfall outlined above are even further emphasised by the effects of tropical cyclones. Intense rainfall, with 24-hour totals in excess of 20 inches, high winds and heavy seas even in relatively sheltered waters, and the temporary
raising of sea level all have far reaching geomorphic effects.

Coral reefs in particular are susceptible to the passage of a cyclone. At Stone Island near Bowen a flourishing fringing reef (Saville-Kent, 1893) was largely destroyed by the coincidence of a low spring tide and heavy rainfall from the 1918 cyclone in which 19 inches fell in 3 days (Hedley, 1925; Steers, 1937). Flourishing coral reefs around the Palm Islands photographed by Saville-Kent (1893) also appear to have been destroyed by the same agency. As tropical cyclone genesis occurs in the tropics more than 5° away from the equator, their effects in general are experienced in Af climates only at their poleward extremities and it is the Aw and Am climates in which the cyclones cause greatest changes. The fact that the Innisfail is at the southern limit of Af climates and may experience tropical cyclonic activity, with rainfall intensity sufficient to reduce salinity at least in the near-shore zone may well be an influence in the paucity of mainland fringing reefs here, compared to the New Guinea coast, which, though an area of cyclone formation, does not normally experience the full force of activity.

There are no figures to indicate the amount of geomorphological work carried out by cyclones. Douglas's (1965) work in the tropical wet area of the Atherton Tableland suggests that even in years without cyclonic activity 50% of the sediment load is carried by flows occurring less than 37% of the time, and for the Wild River which has a regime approaching that of the streams of the study area, 50% of the load was carried by flows occurring only 1.4% of the time. In the drier climate of the research area, the occasional passage of a cyclone may result in more geomorphological work being carried out within 24 hours than is accomplished under normal conditions over several years.
Rainfall of cyclonic intensity is required to cause flooding in the Burdekin Delta, and thus to set in motion the full depth of transitory bed sediments. Evidence from the delta mouth suggests periods of extremely rapid build up correlated with high rainfall periods, the most intense of which are cyclonic in origin. Similarly, reports from local inhabitants of the Don River Delta near Bowen indicate that changes in the course of the Lower Don occur during the passage of each cyclone, which in this area has a mean periodicity of about once every 10 years. It is suggested that some of the major changes in course which have taken place in the Burdekin Delta may have been related to periods of cyclonic rainfall.

The abnormally high amounts of energy available for geomorphic work is not limited only to the effects of heavy rainfall. The high wind speeds associated with the passage of a cyclone may bring about both constructional and erosional activity. Preliminary reports from the Proserpine area indicate that the passage of cyclone Ada (January, 1970) produced a great deal of coastal erosion on the mainland, but on the islands the major process was one of construction, with the formation of new coral shingle beach ridges. There is here, the implication of a truncation of the fringing reefs by the heavy seas. On many of the islands described in Chapter 2, coral shingle beach ridges rising to 8 or more feet above M.H.W.S. immediately behind the beach occur in what must be considered sheltered environments during normal conditions. The fact that the winds accompanying a cyclone may come from any point of the compass is considered an important factor in producing high energy constructional features in areas normally not subjected to such activity i.e. in areas not open to the east or south-east. On the mainland, the formation of cheniers in the sheltered southern
and eastern corners of embayments may also be associated with abnormal conditions. On the Gulf coast of Louisiana, Russell (1967) considers that cheniers are constructed during periods of coastal retreat when waves transport the coarsest sediments available to them landward to form beaches. Intervening clay and mud deposits form during periods of coastal advance, the alternation between advance and retreat being associated with Mississippi River migrations. In the research area, the cheniers of eastern Upstart Bay, Bowling Green Bay, Cleveland Bay and the Bohle estuary show no evidence of being associated with periodic advance and retreat of the coast, and with the exception of those at the mouth of the Bohle River, do not appear to be in a location which could be affected by changes in river mouths. They apparently indicate progradation of the coast, possibly aided by a falling sea level, but in normally quiet water environments with occasional incursions of higher energy when coarser material is swept in from the adjacent sea floor. The high wave energy produced by a tropical cyclone is suggested as the major factor in chenier construction in sheltered environments.

A Comparison of the Coastal Landforms of the Research Area with those of Coasts with Similar Climates

The features of the coast of the Townsville area which appear to have morphogenic significance have been outlined. Fundamentally, the coast is a depositional one with rapid supply of sand size material and formation of multiple beach ridges. Dune development, however, is limited. Climatic conditions for cementation of beach deposits are ideal, but normally the carbonate content in the beach is insufficient. Mangroves are not as extensive as in wetter climates except in areas of good water circulations. Large areas of bare
intertidal mud and salt flats appear to be typical of this coast. Wave energy is generally low, a result of both the normally low wind speeds and the protection given by offshore reefs. However, along the mainland coast, fringing reefs are limited. Clifed coasts are rare and normally consist of bare rock slopes which may be exhumed weathering fronts rather than true sea cliffs. Short and intensive periods of geomorphic activity may take place at widely separated and irregular intervals associated with the passage of tropical cyclones.

A large proportion of the Australian coast belongs to the same climatic region. C.S.I.R.O. Land Research Series reports allow a comparison to be made between the research area and a large part of the tropical coast (Christian and Stewart, 1952; Christian et al, 1952; Speck et al, 1960; Speck et al, 1964; Perry et al, 1964; Twidale, 1966; Speck et al, 1968; Story et al, 1969). The areas covered by these reports include parts of the Gulf of Carpentaria, the Northern Territory and northern Western Australia. A remarkable similarity exists between these coasts and that of the research area. Locally beach ridges may be widely spaced and the supply of sand to the beach may not be as great but this is considered a reflection of the nature of the hinterland which is generally low, and composed of non-arenaceous rocks. In such conditions, the salt flats tend to increase in area. Bare unvegetated flats appear the most ubiquitous and characteristic feature of the coasts of the Aw climatic zone in Australia with mangroves limited to estuaries and lower intertidal areas. Dunes are generally low, no major dune sequence being described in any of the reports. The large dune fields which occur on the eastern coast of Cape York Peninsula are evidently related more to the availability of a sand supply derived from Pleistocene sands and Jurassic
sandstones combined with locally easterly or south-easterly coastal orientations, than to any contrast in the morphogenic processes.

The question of beach rock as a morphogenic feature in Australia is debatable, largely because of the lack of data on its exact distributional limits. The observations made by Russell and McIntyre (1965) indicate that lithification of beach materials does extend outside the limits of the Aw climatic zone, recurving as far south as Rottnest Island near Perth in Western Australia. It may be significant, however, that these authors note that south of Onslow, beach rock outcrops are poor. The west coast of Cape York Peninsula described by Valentin (1959, 1961) appears to be morphologically similar to that of the research area. Beaches with shelly facies are limited however, to the area between Karumba and Aurukun Mission. Elsewhere the carbonate content of beaches is low (R.F. Isbell, pers. comm.). Within this shelly zone beach rock occurs widely, but whereas the exposures are firmly cemented in the south, they became much more friable further north, in spite of an almost pure shell-grit content. It is interesting to note that within this region rainfall increases from about 38 inches in the south, to 64 inches near Aurukun, which is high for an Aw station.

It is unfortunate that detailed descriptions of coastal landforms in many parts of the tropics are not available. Tricart and Cailleux (1965a), in a 38-page section of their book, examine features of tropical coasts, taking examples from Brazil and West Africa. Though concentrating their attention on the wet tropics they do note that fluvio-marine deposition is a characteristic feature of all the tropics. Significantly, they observe that the Senegal River is depositing in its delta an enormous load of sand with a
median diameter of about 2.0 μ. The hinterland is similar to that of the Burdekin and the sediment yield appears to have the same characteristics. The change from argillaceous to arenaceous sedimentation from the tropical wet to sub-humid tropical climates is also noted by Stoddart (1969) who quotes figures for the proportion of sand making up known bottom sediments on the inner continental shelf in rainy tropical climates (31.4%), sub-humid tropical (38.4%) and warm semi-arid climates (59.5%). The figures for mud distribution show a corresponding decrease (48.5%, 37.0% and 24.0% respectively). It is not surprising therefore to find that sand beach ridges are the characteristic coastal morphology of coasts within the Aw climatic zone, as shown, for example, by Fairbridge (1967b), and Fairbridge and Richards (1969) in Brazil, Battistini (1969) in Madagascar and Curray and Moore (1963) in Mexico. It is evident that the climate of the hinterland is an important factor. Coastal zones with Af or Am climates, if drained by rivers which have flowed through areas with a sub-humid tropical climate, may be dominated by a massive sand sediment yield, providing that the lithology favours a sand yield, as for example the Niger in West Africa (Allen, 1963). Alternatively if the rivers in an Aw climatic zone are draining a wetter catchment, then swamps and mangroves may dominate over the sand ridges. The point is well illustrated by the drier sector of the Papuan coast near Port Moresby, which though fringed by beach ridges, has a much higher proportion of swamp land then appears typical of Aw coasts. However, even here, the drier climate tends to increase salinity rates in the higher intertidal areas and bare tidal flats are a feature of the coastal zone (Mabbutt et al, 1965).

Mangroves are common to all tropical coasts (Scholl, 1968) and it is clear from the comments of Macnae (1966, 1967) that
the reduction in distribution noted in the Townsville area compared to the wetter coast further north is a feature common to all the sub-humid tropical coasts. He notes that along desert coasts only one or two of the most hardy mangroves survive. With the decrease in mangroves, the increase of bare areas appears to be a common factor. Fosberg (1961) in particular notes their occurrence in southern Ecuador and north-west Nicaragua, both areas with Aw climates.

Certain characteristics of the distribution of beach rock have been noted in Chapter 6. From an overall appreciation of the references given in that chapter it is clear that though beach rock may extend out of the tropics, its greatest development occurs within the tropical zone. It is also evident that the incidence of beach rock decreases with increasing rainfall. Tricart and Cailleux (1965a) note that beach rock is essentially a feature of the drier climates.

The literature in general indicates that most rapid cementation apparently takes place in Aw climates (see for example Russell's 1959 comments on the Caribbean area). However, it is also evident that beach rock may have greater exposure in even drier tropical climates, for whilst its formation may be slower, the availability of beach materials with an originally high calcareous content may be the dominant factor. However, if sands of the Aw zone do have a high calcareous content, perhaps as the result of the onshore movement of biogenic material from the inshore continental shelf, then beach rock may be found in abundance. Branner (1904), for example, describes beach rock outcropping intermittently for 1,000 miles along the north-east Brazilian coast.

Reference to the geomorphic effects of tropical cyclones is limited. In Mauritius, McIntire and Walker (1964) found that cliff abrasion, the cutting of platforms above calm
weather sea level, and the modification of beach profiles and beach ridge topography all took place in brief episodes of storm wave activity during tropical cyclones. In British Honduras, Stoddart (1962, 1965) describes the effects of a hurricane noting the disappearance of up to 90% of reef corals in some areas, the destruction of vegetation, marginal beach erosion, local construction of fresh coral shingle and rubble ridges and the disappearance of seven cays. Resurvey of the area four years later indicated only slow recovery of the reefs. Stoddart's conclusions, that geomorphic changes at and above sea level appear to be permanent at least until modified by later hurricane action, agree with the observations made on the North Queensland coast on the importance of the abnormal conditions to local geomorphology.

The indications are that the North Queensland coast around Townsville has many morphogenic counterparts. Many of the major features may be attributed directly or indirectly to the tropical wet and dry climate. Whether these features may be allocated to a quite separate morphogenic system or not is perhaps debatable. If transitional, then Aw coasts would appear to lie between tropical wet (Af) and desert (BS, BW) coasts rather than the tropical and temperate systems. From the evidence of continental shelf sediments (Stoddart, 1969), there is an increase in the importance of sand away from the wet tropics towards both the drier and cooler climates but the supply of sand to the coast is intermittent and more closely resembles the sediment yield characteristics of the drier climates. Moreover, the changes noted in mangrove ecology tend to be changes which continue steadily towards the drier tropical climates, rather than towards the temperate area, where mangroves tend to be replaced by salt marsh. The occurrence of unvegetated salt
pans is another feature which indicates a progression towards the drier, rather than cooler climates. Tropical cyclone activity in the area is an important morphogenic feature, but even this may extend beyond the limits of the Aw climatic area to affect drier regions (for example, Western Australia) or cooler regions (such as the Gulf coast of the U.S.A.). However, though it may be convenient to regard the research area as being transitional between other tropical and sub-tropical morphogenic systems, the combination of landforms present appear to be found elsewhere in similar climatic areas. Transitional though the area may be, the geomorphic processes and resulting landforms in the coastal zone are sufficiently distinct to allow the recognition of a separate morphogenic system in seasonally wet tropical climates.
References


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