CHAPTER 2

THE GEOMORPHOLOGY OF THE OFF-SHORE ISLANDS

The terms "high" and "low" islands were first used by Captain Cook to differentiate the islands composed of continental and volcanic rocks from those of coral material (Fairbridge, 1968, p. 568). Along the North Queensland coast between Double Point and Abbot Point the Great Barrier Reefs enclose several groups of high islands, each group continuing the structural trend of the mainland, generally in a north-north-west to south-south-east direction (fig. 2.1). Thus the Barnard Islands continue the trend of the Moresby Range near Innisfail, and Dunk Island, the Family Group and the Brooks Islands have a similar alignment to the Walter Hill Range. Further linear extensions of mainland structures are found in the Palm Islands and the isolated islands between the Palms and Townsville. South of Townsville, high islands are apparently less numerous but many isolated outcrops do occur, generally paralleling the hard rock escarpments behind the coastal plain. However, because of massive sedimentation from the Burdekin River and to a lesser extent from the Haughton and Elliot Rivers these have been incorporated within the coastal plain of the mainland. It is evident that the high islands are merely drowned extensions of mainland ranges, submerged during the late Pleistocene-early Holocene transgression.

The object of this chapter is to examine the geomorphological features of the high islands and to evaluate their contribution to the understanding of the evolution of the North Queensland coast. A basic contrast exists between the islands north of Hinchinbrooks and those to the south.
Fig. 2.1 North Queensland Islands with spit classification.
To the north, the wetter climate influences the nature of sedimentation around the islands. Contrasts in geology emphasize the climatic differences, as the northern islands consist almost entirely of metamorphic rocks whilst those of the south consist mainly of granite and of acid volcanic porphyries. The two largest islands, Hinchinbrook and Magnetic, have geomorphological features essentially the same as those of the adjacent mainland and will be considered in conjunction with the relevant area of mainland.

The islands rise fairly steeply from the shallow continental shelf which has an average depth of about 60 feet. In the wetter north, all but the steepest slopes have a thick covering of rainforest. Further south, the coastal cliffs are bare of vegetation but, except in the most exposed locations, shore platforms are not well developed and the slopes of the islands are the products of subaerial, rather than marine processes. What little steepening there is on the lower parts of the cliffs is more likely to be the result of removal by the Holocene transgression of the regolith which accumulated during the last low level stand of the sea. The cliffs can therefore be considered exhumed weathering fronts (Mabbutt, 1961).

By far the most interesting geomorphological features of the islands are those arising from deposition. Boulder foreshores extend around most islands, the boulders apparently being derived from the regolith removed by the sea. The majority of the high islands, however, have spits extending from their leeside northern or western shores and over the surrounding fringing coral reef. Great variation in morphology is displayed by these spits, but a cuspate shape is most characteristic. The smaller islands generally have the best developed features. Minor flats of unconsolidated deposits may be found elsewhere than on the north-western
side, but without the cuspatate shape. Examination of the spits and flats has comprised the greater part of research carried out on the islands.

The area covered by this chapter includes some 44 high islands. References to a number of these have appeared previously in geomorphological literature, but not in great detail (Andrews, 1902; Sussmilch, 1938). Short studies of single islands in the area were made in the early reports of the Great Barrier Reef Committee (Richards and Hedley, 1925; Marshall, Richards and Walkom, 1925; Hedley, 1925), with reference being made to raised coral, emerged platforms and abandoned sea caves. The only close studies made of the high islands, however, were those of Steers (1929, 1937) who discussed the origin of the island spits (1929, p.341) and concluded that, being on the leeside of the islands, the spits are the result of the refraction of the dominant south-easterly waves. These dominant waves undoubtedly play a very influential part in the moulding of the spits, but to regard these features as simple structures is misleading. This chapter illustrates the complexity of the spits and their importance in contributing to the understanding of the late Pleistocene and Holocene histories of the area.

The Materials of the Spits

The material making up the spits is a combination of terrigenous sediments derived from the high island, and biogenic material derived from the fringing reef and its marine organisms. The balance between the two sources of material is determined partly by climate, and partly by geology. The sharp climatic division in the area under study has a direct bearing on beach characteristics. The rapidity of weathering of the rocks of the wetter islands north of
Hinchinbrook, combined with the more rapid leaching of
calcareous biogenic material, means that terrigenous sand
deposits are generally more common on the spits of the
northern islands, than on those to the south. Thus the
proportion of sand of terrigenous and biogenic origins is
similar. In the drier zone terrigenous deposits are
generally of larger calibre and the breakdown of coral and
shell fragments is slower.

Variations within this general pattern occur as a
result of geology. In the wetter zone the metamorphic rock
(mica schists and gneisses) of islands such as Dunk and the
North Barnards, weather readily into fine grained quartzose
sediments, and fine sand makes up much of the spits of these
islands, often dominating over the biogenic material.
Granites on Fitzroy Island and the Brook Islands also weather
readily and the coarse sand and boulders resulting outweigh
the shell and coral debris. The present beaches of the
islands of the drier zone to the south are dominated by
biogenic materials irrespective of geology. Granites and
volcanic rocks make up most of the islands of this zone and
at present neither produces large amounts of fine grained
material, though boulders are common at the base of cliffs.

Where biogenic material is dominant it is usually in
the form of coral shingle beach ridges. The angular and
branching nature of the coarser coral fragments allows steep
angles of rest of up to 30° to be maintained. The coral
shingle of the older ridges readily acquires a black algal
coating. The loosely interlocking nature of the material
also allows for a certain amount of compaction and settling
after weathering and decomposition.

Because of the climatic and geological conditions, sand
beaches are relatively rare on the islands. Where they do
occur they tend to rise moderately steeply from the calcareous
mud which coats the reef flat, though the present beach and the older sand beach ridges are lower and more gently sloping than the ridges of coral shingle.

The fringing reefs of the islands are important to the spits. Not only do they supply material to the spit in the form of broken fragments, but they also form the basement over which the spit has grown. Spring tide ranges around the islands are in excess of 9 feet and low water spring tides, a reef flat up to 200 yards wide may be exposed around even the smallest island. The widest part of the fringing reefs is found on the leeside of the islands, and the reef forms the foundations for spit growth. Vigorous coral growth is limited to the outer slope of the reef. Above low water mark the reef flats display zonation. From mean low water mark to approximately 3 feet above this the reef flat consists of dead coral in situ with living corals only in deeper pools. On the weather side of the islands, algal encrustations add to the reef material in this part of the reef. This zone is apparently the current source of coral shingle during storms. The death of the coral is in part the result of fresh water flushes resulting from cyclonic rainfall on the mainland (Hedley, 1925; Rainford, 1924-6). Recovery appears to be slow. From 3 to 6 feet above L.W.M. is a zone of dead coral in situ but very much destroyed and planed down to a near level surface. Calcareous sand and mud fill many of the cavities between individual corals. The upper part of the reef flat is entirely covered by this calcareous sand and mud, though in one example at least (Eclipse Island) the reef flat emerges into an in situ raised reef above high water mark.

In such a calcareous tropical environment, it is not surprising to find that cementation of all the types of shore deposits described is common. The resulting beach rocks and
beach conglomerates have given a permanence to the spits which, they would not have had as unconsolidated deposits. The cemented beach materials are found not only between tide levels on the present beach, but also off-shore to a depth of at least 25 feet below M.H.W.S. and inland on the higher parts of the spits to a height of 20 feet above M.H.W.S.

The origin of beach rock has been discussed most recently by Russell (1959, 1962, 1963, 1967) and this theme will be considered further in Chapter 6. However, it is generally agreed that cementation occurs at the water table as the result of precipitation of calcium carbonate from heavily charged ground water, the CaCO₃ initially being derived from the calcareous beach material itself. The maximum vertical thickness of cemented beach which can be attained is thus governed by the water table fluctuations. Within beaches and beach ridges close to the sea, especially those composed of coarse material, the fluctuations are governed by tidal changes and the thickness of beach rock reflects the tidal range. The upper level of cementation is therefore be a good indicator of high water mark at the time of formation. Cemented materials above or below the present cementation zone may indicate changes in the relative levels of land and sea. Removal of the overlying uncemented beach exposes an almost level surface which truncates the original depositional dip of the beach material. Some workers have attributed the level surface to marine abrasion, thus confusing the early interpretation of higher sea levels on the North Queensland continental islands and on nearby coral cays and low wooded islands of the Great Barrier Reefs (see for example Stanley, 1928, p.36).
Morphological Features of the Islands of the Drier Southern Area

The islands of the southern area are characterised by unvegetated coastal slopes, beaches of biogenic material, the widespread occurrence of beach rock and conglomerates, and the development of large and irregular leeside spits.

The Palm Islands (fig. 2.2)

North Palm Island, the northern end of Orpheus Island and Curacoa Island consist of volcanic porphyries probably of Upper Carboniferous age (de Keyser, Fardon and Cuttler, 1965). Tuff and breccias are reported on Orpheus Island. The remaining Palm Islands consist of granitic rocks, mostly biotite granite. Both the porphyries and the granites are intruded by swarms of dolerite dykes trending north-west to south-east.

i) North Palm Island (Pelorus)

North Palm Island is a small regularly shaped island rising to 924 feet. It has only a narrow fringing reef and spit development is limited to a small cuspate area of sand on the south-west corner.

ii) Orpheus Island

Orpheus Island consists of a long sinuous ridge about 450 feet high but reaching a maximum of 560 feet in the north. Both east and west coasts are indented and many of the small drainage lines on the east coast are graded to below present sea level, probably as tributaries to a proto-Herbert during the Pleistocene glacial low levels. Both Pioneer and Hazard Bays appear to have formed in this way, but the deepest inlet is found just north of Pioneer Bay. It is mangrove filled and partially closed by a coral shingle spit.
Fig. 2.2 The Palm Islands.
A narrow fringing reef occurs along the eastern side of Orpheus, widening in the bays. Bay heads of the more deeply indented bays are normally mangrove-filled; shallower bays normally have a series of sand or shingle ridges. The northern-most bay on the east coast is typical of these depositional areas (fig. 2.3). It consists of a steep coral shingle foreshore, partially cemented in the intertidal levels. The upper parts of this unvegetated ridge are made up of algae-blackened coral indicating a certain stability in the depositional environment. Behind this unvegetated ridge is a partially vegetated shingle ridge rising to 8.2 feet above M.H.W.S. and a further ridge rising to 12.7 feet which has a covering of rainforest. At the northern end of the bay this inner ridge encloses a lagoon of fresh water, the surface of which is approximately 5 feet above M.H.W.S. A rocky scree slope is found behind the lagoon. The present shingle beach rises to 4.2 feet and in view of the sheltered nature of this bay and the undoubted compaction of the shingle of the older ridges, the height of these older ridges may well indicate a higher sea level at time of deposition.

A more unique area of deposition is found on the southern end of the island (fig. 2.4). Three shallow bays exist here, each infilled with beach ridges. The southern-most beach is fairly simple, consisting of a sandy beach, with a double crested beach ridge rising to 8.0 feet. The next bay to the north has a foreshore of beach rock occurring between tide levels. Behind this is a ridge of coral sand and shingle rising to 8 feet. A small creek cuts through this ridge, exposing beach rock at its core. This does not extend above M.H.W.S., i.e. it occurs within the range of present cementation. Beach rock also floors the channel behind this ridge. A wide terrace of coral sand and shingle
Fig. 2.3 Section, coral shingle beach ridges north Orpheus Island.
Fig. 24. Southern end of Orpheus Island.
is found behind the channel and rises to 10.5 feet. This in turn is separated from the scree slope at the rear by a beach rock floored channel, the height here being at least 2 feet above the present range of cementation. This strongly suggests a higher sea level at the time of formation of the rearmost beach terrace. The northern bay also provides evidence for a higher sea level. It has a boulder spit trailing from its northern side and rising to over 18 feet. Boulders of up to 2 feet in diameter are found at the northern end, grading to about 6 inches to the south. The ridge encloses a lagoon. In front of the boulder spit is an area of cemented boulders of a similar calibre and it is evident that the boulder spit is the remnant of a much larger feature. The cemented boulder foreshore is undergoing erosion, the loosened boulders being redistributed in uncemented form at the southern end of the bay. Most of the cemented boulders have thus been truncated at or just above M.H.W.S., but occasional mesas of uneroded conglomerate remain, rising to at least 4 feet above M.H.W.S., apparently the original upper limit of cementation. This is 4 feet higher than the upper limit of current cementation.

iii) Fantome Island

Fantome Island formerly consisted of three separate rocky islands, now joined together by deposition. Sand beach ridges occur at the narrow 'waist' of the island, whilst the small rocky outcrop to the north appears to be joined to the rest of the island by a raised beach rock terrace similar to that on Brisk and Falcon Islands (see below). Unfortunately Fantome is the site of a leper colony and landing is prohibited. The raised beach rock could not therefore be confirmed, though Andrews (1902) refers to an "upper beach" 12 to 15 feet above M.H.W.S. on Fantome, with beach rock apparently in situ occurring at the same location.
iv) Curacoa Island (fig. 2.5)

Curacoa is a smaller but extremely interesting member of the Palm Group. It rises sharply to 971 feet and has two areas of deposition, a well formed cuspate spit to the north-west and a smaller area in the south-east.

A short description of the Curacoa Island spit has recently been published (Hopley, 1968). The relative simplicity of the structure serves as a guide to the origin of more complex morphology of other islands. Essentially it consists of a boulder embankment on its north-western side with younger coral shingle beach ridges orientated towards the south. The boulder embankment is a simple spit, anchored to the main part of the island and displaying two lateral arms trailing to the south. The crest of the main ridge maintains a height of between 16 and 17 feet for the whole of its length. The boulders range from a mean diameter of approximately 2 feet at the anchor point to between 0.6 and 0.75 feet at the western end. The embankment today trends north-east to south-west but by tracing the main crest it is clear that, at the time of formation, the main axis was closer to east-north-east to west-south-west. Much of the original spit has been truncated. Basal portions of the boulder spit now outcrop along the present northern beach and show that the whole of the lower part of the boulder material is firmly cemented. A smaller area of cemented boulder conglomerate is also found on the beach along the extended line of the outer lateral ridge. Truncation may also have occurred here. Between the present shoreline and the boulder spit are several coral shingle ridges. Beneath these, the level of cementation of the boulders rises to at least 6 feet above M.H.W.S. Along the shore the conglomerate forms a platform just above H.W.M. which appears to be a wave-cut feature. On its seaward
Fig. 2.5 Curacao Island spit.
edge it drops away sharply and though it is encrusted with living coral cementation was observed to 25 feet below M.H.W.S. The coarseness of the material involved and the proximity of the present cemented deposits to the original shoreline suggest that the water table involved in the cementing process would have approximated very closely to sea level. The Curacoa exposures thus suggest a simultaneous construction of the boulder spit and cementation in the intertidal zone in response to a rising sea level, a rise which extended to at least 6 feet above M.H.W.S.

The area between the boulder spit and the main part of the island is infilled with coral shingle beach ridges. The crests of these range in height from 10 to 14.5 feet above M.H.W.S. in an irregular fashion. Compaction and settling of the coral shingle may have affected the older inner ridges. The coral shingle ridges on the outer edge of the boulder spit rise in height from 6 to 14 feet, the lower ones on the exposed platform at the level of cementation.

Radiometric dating was carried out for three samples from Curacoa, giving the following results:

i) GaK-1545 Coral from cemented base of boulder spit 2 feet below H.W.M. - 5070 years ± 110 B.P.

ii) GaK-1546 Coral from uncemented crest of boulder spit - 5250 years ± 100 B.P.

iii) GaK-1547 Shell from inner coral shingle ridge - 2620 years ± 90 B.P.

The evidence suggests that the boulder spit was built by the rising Holocene sea level during which a level of approximately 6 feet above present was attained 5,000 to 6,000 years ago. Infilling with coral shingle beach ridges has occurred as sea level retreated from this mid-Holocene maximum.
I Mangrove lined ria, Orpheus Island.

II Curacao Island spit.
The smaller depositional area on the south-east coast is less illuminating as far as the geomorphological history of the islands is concerned. It occupies two shallow indentations on the coast. The western beach has beach rock along the foreshore and a single beach ridge rising to 13.4 feet. The eastern beach has two beach ridges which have been cut through by a small stream thus exposing good sections. The outer ridge, rising to 9.7 feet, consists of coral sand overlying a cemented conglomerate rising to at least 3 feet above M.H.W.S. The outer ridge, rising to 15.9 feet, also has a core of cemented material consisting of beach rock in the upper parts and of conglomerate lower down. Cementation was observed to a height of 2 feet above H.W.M. A depositional sequence similar to that on the spit has occurred here with coarser boulder beach being deposited first, followed by later additions of biogenic beach materials (coral sand). It would appear from the observed levels of cementation that sea level was higher during or after the period of boulder beach deposition.

v) Great Palm Island

The main island of the Palm Group is triangular in shape, extending about 6 miles in a north-south direction and 8 miles east-west. Great Palm is a mountainous island, rising to 1,500 feet and much of the eastern part comprises large exfoliation sheets, which in part form the coastal cliffs of the southern and eastern coasts. It is very exposed to the south and east and a number of shore platforms can be observed from the sea, some of them beyond the reach of modern formation. However, the open aspect also made it difficult to land and surveys of the platforms were possible only around Wallaby Point and along the south coast. A wide reef is found in Coolgaree Bay and along parts of the southern coast. Elsewhere the reef occurs in patches.
Small streams entering into Coolgaree Bay and Bullumbooroo Bay have maintained narrow channels across the reef during upgrowth of the coral.

In his paper of 1902, Andrews noted the occurrence of "an interesting flat" at Challenger Bay joining two quite separate parts of the island. Young sand beach ridges occur at each end of this flat, which today is the location of the air strip for the Palms, but the plain consists essentially of sandy clay and coarse sand without shells or calcareous material. The height of this plain, 15 feet above H.W.M., and the weathered nature of the deposits, are comparable to those of the adjacent mainland which appear to be late Pleistocene in age (see Chapter 4).

Other alluvial areas on Great Palm appear to be younger. The area of the aboriginal settlement is essentially a deltaic fan with the addition of coral sand beaches. Beach rock is found along the shore. The alluvial area to the north is a partially filled lagoon dammed behind a large sand spit. Just south of Wallaby Point occurs a small cuspatate sandflat, rising to 14.4 feet above M.H.W.S. and composed of fine sand, the upper parts of which may be windblown. The flat is being eroded, exposing not only current beach rock in the intertidal zone but also a much more ancient cemented deposit consisting of poorly sorted boulders up to 1.5 feet in diameter. The conglomerate extends onto Wallaby Point where it appears to be the remnants of a boulder spit extending around Wallaby Point and cemented at levels above H.W.M. It appears to be similar to those on Orpheus and Curacoa, and it seems reasonable to allocate a mid-Holocene date to this feature. This would mean that the 1.4-foot platform and the higher platforms at 3.1 and 10.7 feet into which it is cut are older, though the possibility does exist that the lower platform is contemporary to the spit. The sandflat
at 14.4 feet is younger for it rests upon the eroded remnants of the boulder spit.

One further area of interest occurs on the eastern side of Great Palm. This is in the Pencil Bay area. The head of the bay has sand ridges rising to 10 feet and beach rock exposed along the foreshore. However, the area of interest is around the point at the southern side of the bay where a platform with conglomerate is found at about the high tide level, cut into a higher platform at 5.7 feet above M.H.W.S. upon which rests a storm beach of boulders and coral shingle. A little further around the point the lower platform disappears beneath a raised fringing reef exposed from 5.5 feet below to 1.5 feet above M.H.W.S. This is considered to be mid-Holocene like the nearby raised reef on Eclipse Island (see below).

The south coast has a wide fringing reef and a number of open bays orientated towards the south-west. Possibly because of this orientation the beach ridges at the heads of these bays are extremely wide, up to 100 yards across, though only about 10 feet high. The intervening headlands are in the form of granite exfoliation domes though a small amount of platform development occurs, probably again due to the open exposure. An abney level survey was carried out at a number of localities giving the following mean heights for the platforms:

i) Butler Bay - 0 feet, 3.25 feet
ii) Mundy Bay (west) - 0.25 feet, 4.6 feet
iii) Mundy Bay (east) - 2.7 feet, 7.7 feet, 11.0 feet

Well developed platforms were observed around South East Cape but survey was not possible.

vi) Eclipse Island (fig. 2.6)

Eclipse Island is one of four small islands at the
Fig. 2.6 Eclipse, Falcon, Brisk and Esk Island spits.
southern end of the Palm Group. The high, rocky section of the island is only lightly vegetated. It is cliffed, with a boulder beach at the base of the cliffs. A detailed survey was made of the spit which extends from the northwestern side of the island. It is extremely irregular in shape and complex in its morphology. The spit has two separate parts, the older part consisting of a weathered beach rock platform, and a younger cuspate area of coral shingle ridges to the east. The platform consists of a cemented coral sand and shingle deposit including small amounts of shell and small stones. The maximum height of cementation observed is 9.5 feet, but the whole feature rises to a maximum of 11.5 feet above M.H.W.S., the higher areas surfaced by a dark, sandy soil containing abundant coral fragments. The whole feature is bounded by a sharp cliff, especially to the north where a marine abrasion platform of the same material extends towards the reef flat. The strike of the beach rock suggests that the original spit had a more northerly orientation. Modern beach rock outcrops along the southern shores of the platform area. A small extension, of recent origin, and composed of coral shingle surmounted by calcareous sand, is found on the tip of the spit.

The younger area of coral shingle ridges is separated from the beach rock platform by a low mangrove-filled depression. On the eastern side of this depression, and extending beneath the ridges, is an exposure of emerged reef including corals (mostly Porites sp.) in position of growth. The height of this raised reef is close to present M.H.W.S., approximately 8 feet above the height at which coral is growing at present. The raised reef apparently slopes down to the modern reef flat without any sharp break of slope. The shingle ridges resting on this reef rise to 9.5 feet.
and behind them is a small platform of cemented coral at 10.0 feet which appears to be part of the main beach rock platform. A low boulder beach is found seawards of the coral shingle ridges. This is in an active stage of accumulation from cliff erosion on the south-eastern side of the island. Radio-carbon assay of two samples from the island gave the following results:

GaK-1543 coral and shell from raised beach rock - 4,100 years ± 90 B.P.

GaK-1544 coral from raised reef - 590 years ± 70 B.P.

The origin of the raised beach rock is considered to have been a simple spit of coral shingle cemented at its base and suffering later erosion. The age is apparently mid-Holocene. The age of the coral from the reef is anomalous and points to contamination of the sample. It is suspected that the age of the raised reef is also mid-Holocene.

iv) Esk, Falcon and Brisk Islands (fig. 2.6)

These three granitic islands each have well-developed spits on their north-western sides, and smaller areas of reef flat deposits occur elsewhere. The islands are otherwise featureless.

The Esk Island spit consists of three single coral shingle ridges rising to 6.5, 10.5 and 11.5 feet above M.H.W.S. respectively. Modern beach rock outcrops on the beach. Ridges of coral sand also infill a small bay on the south-eastern side of the island. Since they are more exposed than the coral shingle ridges these ridges rise to 20 feet. Raised beach rock rises to at least 5 feet in the outer ridge, as shown on the banks of a small stream. Slabs of beach rock which may or may not be in situ, are found at 15 feet above M.H.W.S. between two of the ridges.

The base of the Falcon Island spit is formed from the
cemented remnants of an older spit. The outer ramparts of this spit enclose a central depression. The orientation of the beach rock around the spit, which appears to have been planed down by the waves, indicates that the original orientation was in a more northerly direction. A modern addition of coral sand and shingle is found on the end of the feature.

The Brisk Island spit incorporates a former small island. Again the major part of the formation is the trimmed remnant of an older feature of which the core is a boulder embankment. Surrounding this, and partly enclosing a central depression, is the cemented base of a former beach system rising to 15 feet. The level of cementation is somewhat below this. The point of this original spit, as indicated by a beach rock exposure, was to the north-west. The modern extension, however, is further to the east and is in the form of a sinuous coral shingle spit which joins Brisk to Falcon Island at low water.

An isolated granite rock, Dido Rock, is found just west of Esk Island. It has a small fringing reef and a spit of modern coral shingle. The rock itself has prominent notching at 0.3 feet below M.H.W.S. (possibly the active notch), and a further notch with an extensive platform at 13.2 feet. The summit of Dido Rock may be a further platform at 20.5 feet.

The Islands of Halifax Bay

Four islands, each with a well-developed spit as their most prominent feature, are found in Halifax Bay between the Palms and Magnetic Island. In addition, there are three unvegetated rocks, only one of which, Fly Island, is noteworthy. The rock type of Fly, Havannah and Acheron Islands is again pink biotite granite. Rattlesnake and Herald are made up of massive acid porphyry. All islands are cut by dolerite dykes.
III Eclipse Island.

IV Eclipse Island spit, Falcon and Esk Islands in background.
V Falcon Island spit. Note the trend of an older spit indicated by beach rock.

VI Brisk Island spit.
i) Havannah and Fly Islands (fig. 2.7)

The two granitic islands of Havannah and Fly have prominent spits on their north-western sides. The larger island, Havannah, has a complex spit of which the oldest part is a remnant of a conglomerate platform rising to 3.7 feet on the northern side. Large boulders up to 2 feet in diameter are found in this conglomerate and there is a general grading to a smaller size towards the west. The conglomerate appears to be the remains of a small boulder spit from which the uncemented material has been removed. Post-dating, and resting upon the conglomerate, is a beach rock plateau in which the level of cementation rises to 9.2 feet, though a low curving ridge of uncemented and weathered coral debris rests upon this platform and rises to 15 feet. This feature has a well developed black soil, though including many recognisable coral fragments. A small cuspate area of fresh coral shingle completes the apex of the spit. Modern beach rock is found between tide levels on both northern and south-western shores. To the south of the spit, and extending around much of the higher portion of the island, is a boulder beach parts of which are cemented. This beach partly lies above high water mark and is now completely stable. It apparently passes beneath the major part of the spit and may be contemporaneous with the conglomerate platform.

The Fly Island spit is similar. It consists of a boulder conglomerate platform trimmed by the waves. This again appears to be the remnant of a former boulder spit. Maximum height of the conglomerate is 7.3 feet above M.H.W at the base of the spit, where it rests upon a wave-cut platform at 4.4 feet. Coral shingle forms a modern spit lying on the conglomerate platform.
VII Fly Island and Havannah Island.

VIII Havannah Island spit.
Fig. 2.7 Havannah and Fly Islands.
ii) Acheron Island (fig. 2.8)

Acheron has a small spit on its western end extending out over a wide reef flat. The feature consists of two parts, an active spit of coral shingle partially overriding an older boulder spit with a trend slightly more towards the south-west. The lower parts of the boulder spit are firmly cemented to at least 1.5 feet above H.W.M. whilst the uncemented boulders appear to have been removed from the tip of the spit. Near the island the remnants of the anchor end remain, rising to 9.0 feet. The material consists of boulders up to 3 feet in diameter together with smaller shingle and coral fragments. In places the conglomerate may be seen resting on a platform at or just above H.W.M.

iii) Rattlesnake Island (fig. 2.9)

The high parts of Rattlesnake Island and neighbouring Herald Island are composed of late Palaeozoic porphyry. Spits extend from the eastern sides of each island. The core of the Rattlesnake spit is a tombolo, mainly of boulders, joining a small rocky outcrop to the main part of the island.

Infilling of the embayments on either side of the tombolo by beach ridges of coral sand and shingle has followed. The beach ridges have been built out beyond the shelter of the embayment and erosion of the unanchored north-western ends of the ridges has occurred. The inner ridges have been cemented and beach rock is found to a height of 11.7 feet above M.H.W.S. Most of the uncemented surface material from these ridges has been removed and the inner part of the spit is a simple beach rock plateau with no surface relief apart from the incised course of a small intermittent stream. The original pattern of ridges is still discernable from the air. The deposits of the innermost ridge contain a high percentage of porphyry boulders. The resulting conglomerate
Fig. 2.8 Acheron Island.

- Coral shingle
- Boulder beach
- Conglomerate
- Bedrock
- Edge of reef
Fig. 2.9 Rattlesnake and Herald Islands.
is cemented to a rock platform with a mean height slightly above H.W.M. The outcrop of the raised beach rock on the beach nearer the point of the spit (Section G-H, fig. 2.10) is interesting. The beach rock rises to 10.7 feet in the section and the dip, towards the south-west, is consistent with the trend of the beach ridge within which it was formed. However, a lower ledge of beach rock occurs at 1.2 feet, with a dip towards the north-west. This is apparently the basal deposit of a beach which formed after the major erosional phase, but before the sea had attained its present level in relation to the land. The outer ridges of the spit are more in their original form and their surface is undulating and composed of fine coral sand. A small outcrop of beach rock nearer the apex of the spit outcrops between tide levels.

The evidence from Rattlesnake indicates the building of a spit from a beach ridge series during a fall of sea level relative to the land. A sample from the 10.7 feet section of raised beach rock gave the following radiocarbon assay:

GaK-2016 beach rock from Rattlesnake Island-3240 years ± 100 B.P.

The age is younger than that given for the mid-Holocene transgression by the Curacoa and Eclipse Island samples, and the sample may have been slightly contaminated by material from the lower beach which has left the 1.2-foot beach rock, or by later cementation.

vi) Herald Island (fig. 2.9)

The spit on Herald Island is similar to that of Rattlesnake in that the original feature must have been much larger than the present remnant. The strike of the beach rock remaining from the early history of this spit suggests the original morphology to have been a cuspate
foreland made up from a complex series of beach ridges. Like Rattlesnake, Herald has suffered greatest erosion on the north-western side and all that remains of the oldest ridges is a narrow platform of beach rock rising to 16 feet above M.H.W.S., though detached blocks of the material rise to 21 feet. The beach rock presents a steep cliff face to the sea. The material is again mostly coral sand, but containing boulders, shell (including Tridachna sp.) and coral blocks. Results of radio-carbon dating of samples from this deposit are:

GaK-2014  shell (Trochus sp.) from near top of outcrop - 4280 years ± 100 B.P.
GaK-2015  beach rock (coral debris) from base of outcrop - 3540 years ± 90 B.P.

The height to which cementation was found suggested that the deposit may been older than the lower beach rock plateau described so far. However, the morphology of the deposit suggests that the higher beach rock was originally at the rear of a wide beach ridge sequence. The water table at which the cementation took place may thus have been higher than actual sea level at that time. It would seem that proximity of the shore zone at all stages of cementation (as for example in the Curacoa boulder spit) is necessary if the cemented level is to have exact value as an indicator of past sea levels.

Further south along the spit, another outcrop of beach rock rises to 4.2 feet above M.H.W.S. This level is fairly widespread in the southern part of the spit and its southern margin is marked by a sharp break of slope. Against this is banked a sand beach ridge of recent origin. An erosional phase is indicated between the deposition of this ridge and the 4.2-foot beach rock. The sand ridge is, in turn, being eroded and is cliffed on its seaward side.
Fig. 2.16 Sections, across island spits.
An exposure of beach rock 30 yards wide and outcropping between tide levels, is found on the beach.

**Camp Island, Abbot Bay (fig. 2.11)**

Camp Island consists of basic plutonic rocks, mainly gabbro. It is about half a mile long and, because of wave refraction around Abbot Point, its spit extends from the south-western side. The exposed eastern side displays a series of well developed shore platforms.

A major part of the spit is made up of a plateau of beach rock consisting of extremely weathered coral fragments in a calcareous sandy matrix. The surface is flat, apart from a few low mounds of uncemented coral shingle, and averages 15.2 feet above M.H.W.S. Two boulder spits are embanked against the beach rock. The one to the south rises to 23 feet above M.H.W.S., with the lower 6.7 feet cemented. Boulders are large, ranging up to 3 feet in diameter, and are poorly sorted. The northern boulder spit is similar where it is banked against the beach rock plateau. However, several coral shingle ridges are banked against the spit and conceal any evidence of basal cementation. Beyond the plateau the spit has been extended, in a sinuous fashion across the reef flat. This appears to be a later addition, and the indications are that it has resulted from reworking of the older feature. Part of this addition has been buried beneath small irregular dunes 10 feet high, the parabolas of which are orientated to the south-east. Coral shingle embankments fill in the embayment between the end of the southern boulder spit and the beach rock plateau. Mangroves are found in the small bay to the south.

The Camp Island spit has similarities to that on Curacoa. The levels of cementation are almost identical and the evidence suggests that the Camp Island boulder spits are
Approx 200yds

Solid Coral shingle Sand Raised beach rock Boulders Boulder conglomerate

Degraded cliff with rock platform

Dunes Boulder spit extending below L.W.M.

GaK-1548

N

Approx 200yds

Fig. 2.11 Camp Island.
also of mid-Holocene age. Infilling of the embayment with coral shingle, extension of the boulder spits by resorting and building of the dunes are of a later date. The main difference between Curacoa and Camp Islands is the presence of an older element on Camp Island, namely the beach rock plateau. Again, a sample was taken for radiometric dating:

GaK-1548 coral fragments from near top of beach rock plateau - 20,200 years ± 600 B.P.

Contamination from the present calcareous environment is probable and the date can be regarded as minimal only. The beach rock plateau appears to be the remnant of a spit developed during a late Pleistocene interglacial or interstadial phase.

The shore platforms on the eastern side of Camp Island are better developed than on any other island examined in the southern part of the research area. These platforms were surveyed along a 150-yard section using a "Quickset" level and staff. Two levels were clearly identifiable at corrected heights of -0.3 feet (range +0.6 to -1.2 feet) and +7.4 feet (range 7.1 to 7.7 feet). An intermediate level at about 3.7 feet may also be present. The -0.3-foot level is definitely above the present zone of abrasion. It also has resting upon it the remnants of a conglomerate which may be correlated with the major boulder spit. If this is so then the lower platform is most likely of mid-Holocene age. The much more fragmentary higher level may thus be equated with the late Pleistocene beach rock. A degraded cliff is found behind the platforms. Current abrasive activity is largely limited to a level only a little above low water mark (6.5 feet below M.H.W.S. approx.).
IX Rattlesnake Island. Magnetic Island in distance.

X Camp Island.
Morphological Features of the Islands of the Wetter Northern Zone

The islands of the wetter zone north of Hinchinbrook are generally small and display contrasting features to the islands further south. These include the nature of beach material discussed earlier in this chapter and the covering with rainforest of coastal slopes right down to the foreshore which will be discussed in Chapter 9.

Again, many of the islands have leeside spits, their most interesting geomorphological feature. However, the spits of the northern islands contrast with those to the south. The most noticeable feature of these islands is the much more regular shape of the spits. Though still found predominantly on the north-western sides of the islands, the spits are outlined by long smooth beach curves in contrast to the irregular shapes of the spits on the more southerly islands such as Eclipse, Herald or Camp. The main reason for this is the lack of a core of solid raised beach rock which can maintain former orientations of the spits. Beach rock occurs on the northern islands, but only rarely above M.H.W.S. It has already been noted that, on the wetter mainland coast north of Ingham, the calcareous content of the beach sand has to be much higher to produce beach rock than it need be on the coast to the south owing to the rapidity of leaching (Bird and Hopley, 1969). On the islands, the beach deposits are sufficiently calcareous to produce beach rock, but the weathering of raised beach rock above the carbonate accumulation zone is so severe that the calcareous cement is leached to lower levels. The result is that the majority of spits in the wetter zone are composed of fine, coral sand with more recent additions of coral shingle. The refracted south-easterly waves can
more easily shift this unconsolidated material to form the simpler spit morphology. Older elements on these spits are difficult to define though areas of deep soil profiles can be identified on the spits of islands such as Dunk.

Further contrasts are seen in the larger number of islands completely lacking spits and in the nature of the terrigenous deposits. In the drier zone the only islands without spits are small and rise steeply from the sea floor. Fringing reefs invariably are not present. In the wetter zone reefs may be present, but the only indication of spit development is a slight widening of the beach at the appropriate point. Another contributing factor is the rapid leaching of biogenic material and the finer nature of the terrigenous deposits as discussed above, which allows for their more immediate removal from the reef flat and into deeper water. Apart from massive blocks released by undercutting, coarser material is completely lacking and boulder spits are not known in the wetter zone. This again means that a more permanent element is missing, and is a contributory factor to the uniformity of the spits of the islands north of Hinchinbrook.

i) The North Barnard Islands (fig. 2.12)

The North Barnard Islands are a simple continuation of the Moresby Range and consist similarly of Barnard Metamorphics, highly altered schists and gneiss of probable Middle Palaeozoic age (Jones and Jones, 1956; de Keyser, 1964). They are steeply cliffed, and a wide and continuous platform exists at the cliff base, best developed on the eastern sides of Lindquist and Jesse Islands and around the whole of Kent Island. The platform, which has a width of 15 yards, has been described by Hedley (1925) and by Steers (1929, p.345). It rises to about 7 feet above M.H.W.S.
Fig. 2.12 Barnard Islands.
Small spits, consisting largely of coral shingle and sand, are found on the northern end of each island. They are simple features, without cementation and without evidence for higher sea levels.

ii) The South Barnard Islands (fig. 2.12)

Stephens and Sisters Islands consist of Cainozoic basalt and agglomerate. Both have wide platforms developed around the base of the cliffs. Again, the platform has been described by Steers (1929, p.345) who remarked on its fresh appearance and on the steepness of the cliffs behind. This bench is lower than that on the North Barnards, occurring at or slightly above the high tide level. However, it appears to be beyond the range of current bench-forming processes. Both islands have spits on their western sides, that on Stephens Island being larger and very typical of the wetter north. It is symmetrical, composed of sand (mostly biogenic) and well vegetated, but displays no signs of older portions belonging to sea levels different from the present.

iii) Dunk Island (fig. 2.13)

Dunk Island is about 3 miles long, rises to 789 feet and has the largest spit of the islands in the area surveyed, attached to its western side. The western part of the island is made up of Barron River Metamorphics (Palaeozoic slate and phyllites) whilst the eastern part is granitic. However, the whole of the higher part of the island is clothed in rainforest which descends to the shore level. No distinct platforms are observable.

The spit is a remarkable feature, very symmetrical, almost a mile long and obviously shaped in its latest episode by the refracted swells coming around the main part of the island. It has appeared in the literature earlier
Fig. 2.13 Dunk Island.
(Andrews, 1902; Steers, 1929). Andrews examined a section close to the high part of the island and observing angular fragments and a clayey matrix, concluded that the whole spit was similar and "doubtless due to redistribution by long-shore action of matter lost to the island by marine erosion". Steers (p. 342) attributed the feature to wave and current action. Neither author had opportunity to analyse the spit in detail and the present writer has examined it only on three brief visits to the island. However, it is evident that the feature is complex, for whilst the western end is made up of fresh unleached sand of biogenic and terrigenous origin in the form of lightly vegetated (mainly *Casuarina sp.*) beach ridges, the central part of the spit, rising to over 20 feet, is quite different. It consists of white leached quartz sand and lithic grains apparently overlying a humic hardpan of coffee rock and covered in rainforest. On the adjacent mainland, identical deposits have already been attributed to the late Pleistocene (Bird and Hopley, 1969) (see Chapter 8). Regolith from the slopes of the high island has slumped on top of the basal portion of the spit.

If the core of the spit is late Pleistocene, and the outer edges at the western end and northern side are Holocene, the question arises of the occurrence of deposits belonging to the mid-Holocene higher sea level as found on other islands further south. There are, however, no deposits which can be attributed to this episode. It may exist in the older Holocene ridges, but from their fresh appearance this seems unlikely. It appears that the spit is constantly being eroded and rebuilt. The southern side at present is undergoing retreat, into the Pleistocene deposits. Without the stabilising influence of beach rock, and the beach sands have far too low a carbonate content
to allow this in the wet climate, the spit is open to rapid remodelling and it is likely that any mid-Holocene deposits have been removed. The original Pleistocene spit appears to have been extremely large and possibly orientated farther south than the present one. Certainly the large size of the feature today owes much to the unusual preservation of a large part of the older spit.

iv) The Family Islands (fig. 2.14)

The Family Islands are a small group of granitic knolls rising sharply out of the sea. Cliffting and benching has not occurred. All the islands display small sand spits of recent origin on their north-western sides.

v) Gould and Garden Islands (fig. 2.14)

These two islands are also granitic, though Gould has a small area of a more basic intrusive rock on its south-western side. Both have spits on their western sides, the one on Gould being about 200 yards long. It is wooded and though no exposures are visible, it is suspected that this spit may have an older core similar to that on Dunk. Intertidal beach rock occurs around the apex of the spit.

vi) Brook Islands (fig. 2.14)

The Brook Islands appear to be drowned granitic tors. The larger islands of the group have exfoliation domes, whilst all display block disintegration along the joints. Boulder beaches are found around most of the islands, but are especially well developed around South Island. Middle Island comprises two granitic domes, joined together by a sand spit. Each of the islands has a small spit or widening of the beach on its northern end, the one on North Island being the largest. It is also the only one with beach rock.
Fig. 2.14 Islands of Rockingham Bay.
XI Camp Island. Elliot River estuary on mainland.

XII Gould Island spit.
XIII Garden Island spit. Hinchinbrook Island to rear.

XIV Brook Islands. Family Islands and Dunk in distance.
Discussion and Conclusions

Evidence from the high islands sheds strong light on the late Pleistocene and Holocene evolution of the North Queensland coastline. Although the significance of these findings at both the regional and larger levels will be discussed in later chapters it is appropriate here to discuss the evidence at the local level and to summarize the conclusions.

There is much evidence that many of the island spits were at least initiated at a time when the sea stood higher in relation to the land than it does at present. Much of the evidence comes from the raised beach rock and the question arises as to the legitimacy of using water table cementation horizons as indicators of past sea levels. Russell (1967, p.137) has pointed out the dangers of relating beach rock elevation to past sea levels in areas of rapid shoreline retreat, and there are many indications of changes of spit orientation combined with erosion. Thus there are cases where the level of the beach rock surface is a doubtful indicator of the sea level at the time of formation. Herald Island is an excellent example. The high beach rock cliff has resulted from extensive erosion and the beach rock surface slopes gently down from the 16-foot level. The large size of the original spit possibly allowed a gradient to develop in the water table. Generally, however, the spits have been sufficiently small and of sufficiently coarse material to allow cementation to take place only very close to the high tide level. Beach rock provides good evidence of former sea levels where it outcrops at a constant level, and where the original morphology of the spit can be reconstructed so that it can be seen that at no stage was the beach rock sufficiently far from the sea.
to permit the building up of a significant water table gradient. The majority of outcrops on the spits described conform to these conditions.

The beach rock therefore indicates relatively higher sea levels. The evidence from Camp Island strongly indicates a late Pleistocene interglacial of interstadial level of approximately 15 feet. Other islands possibly contain remnants of Pleistocene spits, but the core areas of most are overgrown, often with rainforest, and the Pleistocene level is not sufficiently distinct from the maximum level of the mid-Holocene transgression to make it easily distinguishable. Steers (1929, p.346; 1937, p.21) describes and discusses two levels of beach rock cementation on Middle Island near Bowen. The higher of these corresponds well with the Camp Island example.

The mid-Holocene level is better documented. Levels of raised beach rock vary, but the more reliable examples are all within the range 6 to 11 feet. The lower levels around 6 feet come from the boulder spits and cementation is suspected slightly higher than this in the centre of these features. The evidence suggests that the mid-Holocene level in North Queensland was around 10 feet above the present. The absolute age for the attainment of this height would appear to be about 4,000 to 5,000 years B.P. The radiometric dates are considered minimal only, owing to the high risk of contamination from younger carbon in the highly calcareous environment. The evidence from Curacoa, where conglomerate is found down to at least 25 feet below M.H.W.S., indicates the rising sea level of the early Holocene.

Other evidence of higher Holocene sea levels is available. Raised reefs occur at or just above M.H.W.S. on a number of the islands under discussion (fig. 2.1).
The height relationship to the postulated mid-Holocene sea level is similar to that of living corals to present H.W.M.

Shore platforms are generally not well developed. There are a number of reasons for this, some of which have already been outlined (Driscoll and Hopley, 1968). They include:

i) the limiting of the local fetch by the Great Barrier Reefs, which largely exclude the long Pacific swells and limit wave action to the wind waves generated within the lagoon;

ii) the lithology of the rocks of the islands, and of the mainland, is not, in general, favourable to any of the processes operating to form shore platforms. The granites and volcanic rocks are especially resistant;

iii) the presence of a protective ramp of boulders around the shores of many islands. These boulder beaches appear stable at present.

For the most part, the platforms are fragmentary, poorly developed and limited to exposed headlands. However, the islands of the wetter zone in general have wider and more extensive platforms. This may be due in part to more susceptible rock types, but the presence of a bench completely around some of the Barnard Islands even in the most sheltered locations suggests that preparation of the rock by subaerial weathering prior to littoral processes may be very effective.

The presence of two clearly defined bench levels on the islands, the one at or just above M.H.W.S., the other at about 7 feet higher, agrees well with the earlier findings of Steers along the whole of the Queensland coast, (Steers, 1929, p.343-50; p.16-25). The upper platform is clearly elevated beyond the range of modern processes. The lower
platform does, however, become submerged by extreme high tides, and Steers felt it necessary to prove the authenticity of the feature as evidence for emergence. (Steers, 1937, p.20-21). His evidence included an argument for the zone of maximum cutting being below mean water-level, the weathering of the inner edge of the platform and presence of a stable vegetated cliff behind it and the colonisation of the platform in some places by mangroves, which is hardly likely to happen if erosion were active.

The evidence presented in this chapter is also strongly suggestive that the lower platform just above M.H.W.S. is an emerged feature. In a number of localities conglomerate rests upon the platform and it will be argued that the majority of conglomerates are mid-Holocene in age. Thus at Wallaby Point on Great Palm Island, on Fly Island and on Acheron Island the base of the conglomerate, where it is cemented to the platform, is above the maximum level at which cementation is taking place today. This would appear to be conclusive evidence of the antiquity of the platform. It is at least mid-Holocene (approximately 4,000 years B.P.) in age. Cementation can take place rapidly (see Chapter 6) and there is nothing to prevent cementation of deposits to an erosional platform during possibly a period of fewer storms when the abrasive tools of the platform could become sufficiently stabilised.

Closely associated with the fluctuating Holocene sea levels is the varying nature of beach material on the spits. This will be discussed at greater length in Chapter 6, but the main details may be put forward here. The older beach deposits of mid-Holocene age contain much more terrigenous material than the present beaches. The Curacoa spit is an excellent example. The maximum of the transgression is marked by a boulder spit, whilst the regression from this
level has resulted in a complete change in beach material, the later ridges consisting almost exclusively of coral shingle. Similarly, the oldest section of the Havannah Island spit is a boulder conglomerate, whilst the boulder spits are the oldest Holocene deposits on Camp Island and the core of the Brisk Island spit is a boulder embankment. Even where the older raised beach rocks are predominantly of biogenic material, as on Eclipse Island, it is generally true to say that they contain more terrigenous material than their modern counterparts. The tropical environment allowed a deeply weathered slope mantle to develop during the late Pleistocene low sea level. The rising Holocene sea has been able to rework these deposits and incorporate them in the spits, exposing the underlying weathering front which today forms the island cliffs unaltered in all but the most exposed positions. The boulder spits are the reworked core-stones from the regolith. The boulder ramparts around the islands though uncemented are apparently of the same origin. The best evidence for this comes from Havannah Island (fig. 2.7) where the boulder rampart passes beneath the bulk of the spit. On the northern islands of the wetter zone, where weathering was more complete and coupled with a different geology, the production of core-stones and thus of boulder ramparts, has been less common.

The regression phase from the higher Holocene sea level has exposed the fringing reefs. These have presumably been truncated by the sea not only to form the higher parts of the modern reef flats, but also to provide material for the rapid formation of beach ridges built predominantly of coral shingle or sand.

The features of the spits possibly indicate former climatic conditions. The older beach rocks preserve the original orientation which in many cases differs from that of present day growth. These changes are not consistent
for all spits and, because of the changing nature of the beach materials, and of the great refraction of the waves which form the spits, it is difficult to determine accurately the exact changes involved. However, the pattern of extension of the fringing reefs during the Holocene and the effects this could have had on wave refraction, may be a factor influencing spit orientations. What is more certain is that wave activity was stronger at the time of formation of the boulder spits. These rise up to 15 feet above the postulated M.H.W.S. at time of formation. The modern equivalents, largely reworked material from the mid-Holocene boulder beaches and of smaller calibre, rarely rise above modern high water mark. Whether this is the result of greater wind strength generally, to greater cyclone activity in the summer season, or even to greater exposure to Pacific Ocean swells as the result of less protection from the Great Barrier Reefs, cannot be determined.

Summary

1. There is a strong contrast between the islands of the wetter north and those of the southern part of the study area. This is a result of both climatic and lithological contrasts.

2. The complex spits, resulting from leeside deposition on fringing reef flats, indicate significant phases in the evolution of the islands. Modern growth of these spits is continuing but the earlier portions are of mid-Holocene or even late Pleistocene age.

3. Cementation of the beach deposits has been essential in the preservation of the older elements, and indicates higher water tables and thus higher sea levels at the time of formation of portions of the spits.
4. Less favourable conditions for the formation and preservation of cemented beach deposits in the more humid sector of the North Queensland coast, combined with different lithology, has resulted in northern spits being more uniform in morphology and materials.

5. Emerged shore platforms are associated with the higher sea levels shown by cemented beach deposits.

6. Other late Quaternary environmental changes are indicated by features of weathering and coastal morphology, notably in climate and the nature of beach materials.
References


Fig. 3.1 The Burdekin delta, geomorphology.