MARION BAY

SHORELINE MORPHOLOGY

Guus van de Geer, B.A.

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Department of Geography
The University of Tasmania

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ABSTRACT

At Marion Bay, a well marked line of high abandoned cliffs cut in basalt, sandstone and dolerite is found. In front of these cliffs is a wide sandy platform. A compact 'coffee rock' B horizon is a characteristic feature of the deposit. Elsewhere, a deposit of weathered basalt gravels occurs. The age of the deposits is thought to be Pleistocene but their origin is controversial.

A spit almost closes off a shallow lagoon behind which extensive development of salt marshes has taken place. The morphology of the spit is thought not to require a Postglacial fall in sea level.

Trend-surface mapping of sedimentary parameters of the beach sand reveals the pattern of spatial variation to be complex and temporal variation to be minimal. The pattern of variation appears to be predominantly caused by the carbonate fraction.

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I

INTRODUCTION

The general coastal outline of southeastern Tasmania resulted from the Postglacial submergence which flooded the lowlands and drowned the river valleys. The major part of the submergence took place between 12,000 and 6,000 years ago when sea level rose about 200 feet. For the last 6,000 years sea level has not varied to any great extent. During this period, marine processes have considerably modified the initial coastline by eroding headlands and closing re-entrants.

The Marion Bay area is located on the southeast coast of Tasmania, some 30 miles east of Hobart (Fig. 1). Here, a spit almost closes off Blackman Bay from the Tasman Sea. Behind the spit, to the west, the coastline is marked by a line of high abandoned cliffs cut in basalt, sandstone and dolerite. In front of these cliffs is a wide platform which terminates at its seaward end in low cliffs. Salt marshes have developed in front of these cliffs and behind the spit (Fig. 2).

Climate

Relevant climatic data for the study area are unavailable, so that recourse has had to be made to those from stations in the surrounding district (see Fig. 1).

Figure 1

Location of study area

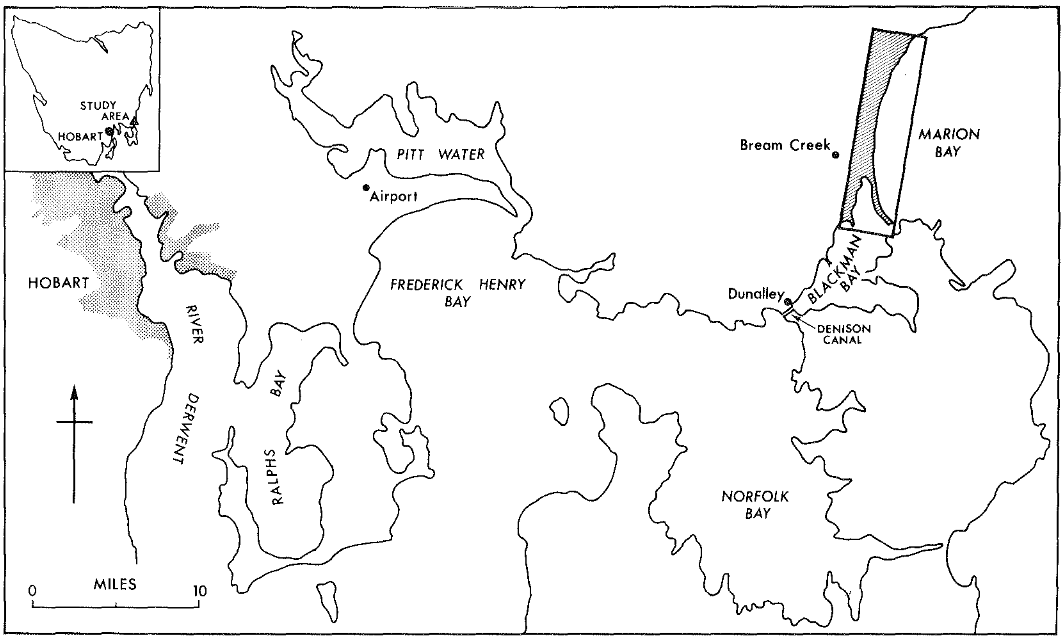
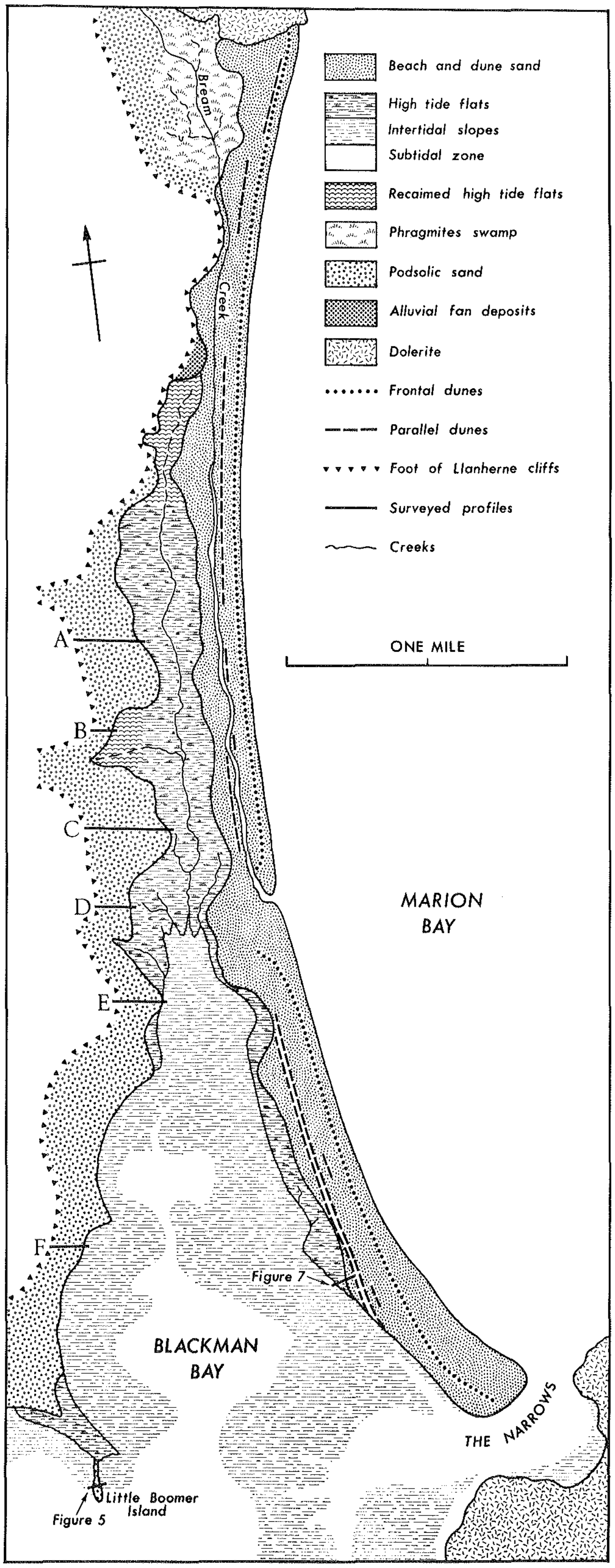

STUDY AREA
HOBART
PITT WATER
Airport
Bream Creek
MARION BAY
HOBART
FREDERICK HENRY BAY
RIVER
DERWENT
BAY
RALPHS
Dunalley
BLACKMAN BAY
DENISON CANAL
NORFOLK BAY
0
MILES
10

Figure 2

General geomorphology


Beach and dune sand
High tide flats
Intertidal slopes
Subtidal zone
Recaimed high tide flats
Phragmites swamp
Podsolic sand
Alluvial fan deposits
Dolerite
Frontal dunes
Parallel dunes
Foot of Llanherne cliffs
Surveyed profiles
Creeks
ONE MILE
Bream
Creek
A
B
C
D
E
F
MARION
BAY
Figure 7
BLACKMAN
BAY
THE NARROWS
Little Boomer
Island
Figure 5

The average yearly rainfall of the area in general ranges from 26-32 inches. It is fairly evenly distributed throughout the year (Table I).

Temperature, and evaporation rates are not recorded by the two stations in the district. The mean annual temperature is probably in the vicinity of 55°F (Langford, 1965).

Wind data for the Marion Bay area are unavailable. The nearest station is at Hobart Airport. Although data from this location cannot be regarded as being absolutely applicable to the study area, it is probably representative in general terms. Table II was originally compiled by Davies (1958) from Hobart Airport data and shows that at Marion Bay the frequency and velocity of offshore winds is considerably greater than onshore winds, and also that the shores of Blackman Bay lagoon are periodically subject to gale force winds.

Geology and soils

No comprehensive account of the geology of this part of southeastern Tasmania appears in the literature. The four major geological systems in the Marion Bay area are Triassic sedimentary rocks, Jurassic intrusions of dolerite, Tertiary extrusions of basalt, and Recent unconsolidated sediments.

The soils of the Marion Bay area have been described by Loveday (1957), who produced a reconnaissance map based on differences in lithology, on a scale of 1 inch to the mile. The various soil types are shown in Figure 3. Podsolic soils on dolerite and sandstone are

TABLE I

CLIMATIC DATA FOR DUNALLEY AND BREAM CREEK

Quantity and Place	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Average rainfall (in.) (1911 - 1968)													
Dunalley	1.71	1.91	2.13	2.52	2.52	2.39	1.68	1.78	1.84	2.98	2.43	2.51	26.40
Bream Creek	2.24	2.62	2.64	3.26	2.19	3.33	2.48	2.45	1.87	2.87	2.79	3.34	32.08

TABLE II

AVERAGE NUMBER OF OCCURRENCES PER ANNUM OF WINDS OF STATED DIRECTION AND SPEED, LASTING FOR $1\frac{1}{2}$ HOURS OR LONGER, OVER THE FIVE-YEARS PERIOD 1948-1952

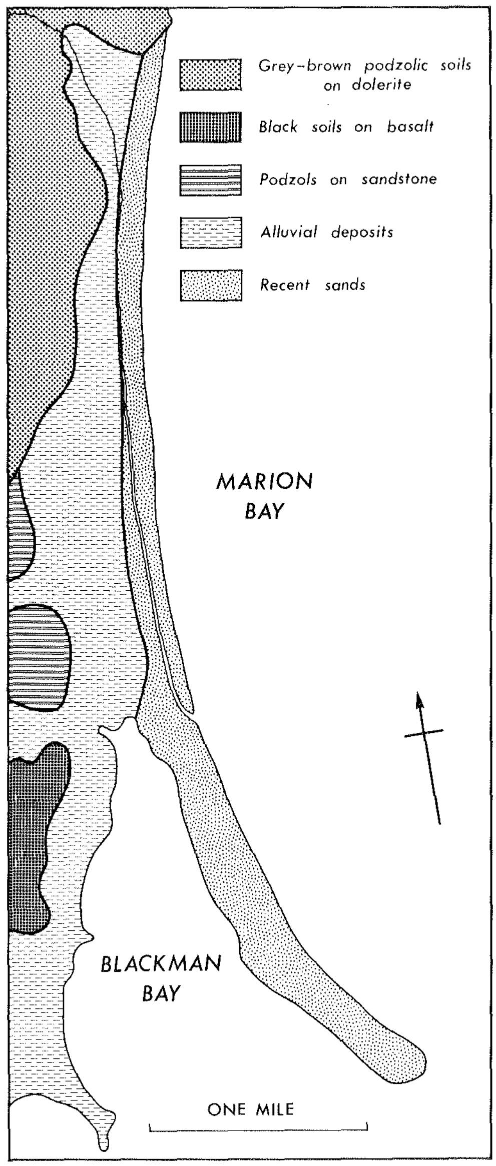
(after Davies, 1958)

	20-30 m.p.h.	30-40 m.p.h.	Over 40 m.p.h.
NE	2.2	0.0	0.0
E	0.0	0.0	0.0
SE	1.6	0.0	0.0
S	7.0	1.0	0.0
SW	3.6	0.2	0.0
W	13.4	1.4	0.0
NW	28.0	5.8	0.8
N	14.8	2.8	0.0
Total	70.6	10.2	0.8

clearly dominant in this area, but some black soils on basalt also occur. Soils of alluvial deposits and Recent sands cover most of the study area. Unfortunately, soils of alluvial deposits were not differentiated by Loveday (1957).

Figure 3

Soils (after Loveday, 1957)


Grey-brown podzolic soils on dolerite
Black soils on basalt
Podzols on sandstone
Alluvial deposits
Recent sands
MARION BAY
BLACKMAN BAY
ONE MILE

II

THE LLANHERNE SHORELINE

A reconnaissance study by Davies (1959) of the coast of southeastern Tasmania revealed widespread evidence of a higher sea level, lying between 12-15 feet above present sea level. Davies (1959) proposed to call this the Llanherne level and tentatively inferred that it dates from the last interglacial or interstadial of the Pleistocene.

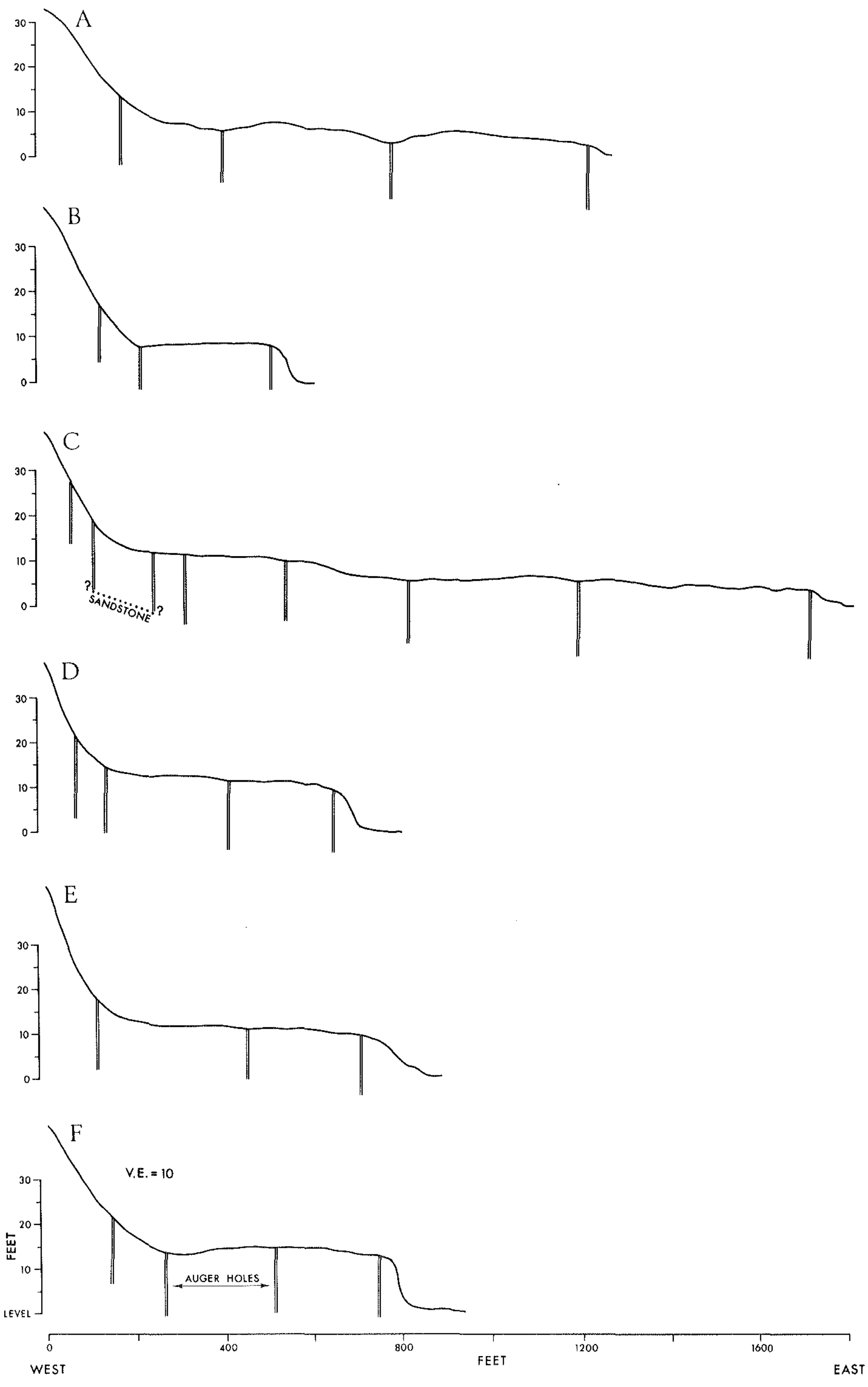
The Llanherne level at Marion Bay

At Marion Bay, the Llanherne level is a very prominent morphological feature (Plate 5). It is marked by strong cliffing in basalt, sandstone and dolerite, and a relatively wide platform (Fig. 2). Locally, the platform has been incised by small creeks, while elsewhere, Recent alluvial fans have partly obscured the shoreline and platform.

Profiles of the Llanherne platform (Fig. 4) were levelled with the aid of a Dumpy level. This was followed by augering along the lines of the profiles. Sediment samples were collected at augering sites. Samples were labelled, and stored for future sedimentary analysis. A small refraction seismograph was used in an attempt to determine the profile of the underlying bedrock but due to excessive interference caused by wind and/or breaking waves, no reliable results could be attained.

Figure 4

Llanherne profiles (for location, see Figure 2)



A
B
C
D
E
F
30
20
10
0
?
SANDSTONE
?
V.E. = 10
FEET
SEA LEVEL
AUGER HOLES
0
400
800
1200
1600
FEET
WEST
EAST

Davies (1959) stated that the Llanherne level at Marion Bay consists of a relatively wide platform, partly wave-cut, and that depositional features are limited. Contrary to this statement, the writer found no evidence of wave-cut platforms at this level. Augering revealed that the Llanherne platform consists of a mass of siliceous sand, at least 15 feet thick. A very compact 'coffee rock' B horizon, several feet thick, is a characteristic feature of the deposit. The digging of pits near the seaward edge of the levelled profiles indicated that the 'coffee rock' horizon extends for at least 6 feet below low water mark, thereby indicating that illuviation must have taken place during the Pleistocene phases of lowered sea level.

As will be noted from the levelled profiles, the height of the proposed shoreline varies quite significantly, the heights ranging from about 8 to 15 feet above high water mark. There is no ready explanation for this variation. It may be partly due to post-depositional modification by wind. There is some evidence to support this suggestion. Locally, the platforms show evidence of deflation in the form of shallow, irregular depressions, which have been invaded by Phragmites communis (see profile A, Figure 4).

It is tempting to suggest here that the Llanherne level in this area is perhaps not a marine feature, but represents an accumulation of wind-blown sand that was derived from the emerged sea floor during Pleistocene phases of glacio-eustatically lowered sea level (Bird, 1968, pp.136-138). Alternatively, the sand may have been derived by deflation of the sandy A horizon of podsolic soils formed on friable Triassic sandstone. This is thought to have taken place in a number of areas in eastern Tasmania (Davies, 1967).

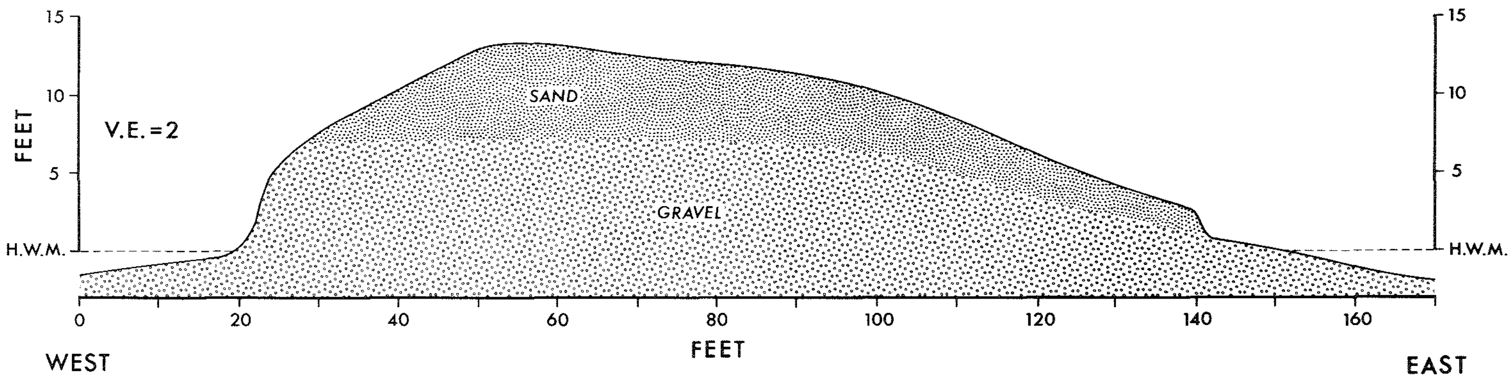
Little Boomer Island (see Fig. 2) forms part of a tombolo, consisting largely of weathered basalt gravel. The lower part of the deposit has been cemented into a solid mass by limonitic sand that fills the spaces between individual particles. A layer of fine, siliceous podsolic sand overlies the gravels (Plate 7). The cross-sectional shape of Little Boomer Island (Fig. 5), suggests that the gravel deposit may represent a remnant of a spit, dating back from the Pleistocene when Blackman Bay was facing the open ocean and active quarrying of the nearby basalt cliffs took place, providing materials for the construction of depositional forms. The sand overlying the gravel is probably of the same age and origin as the Llanherne platform.

This description of the Llanherne level, and speculation concerning its origin clearly points to a need for detailed studies at Marion Bay and other Llanherne sites. Future investigations should include analysis of the sediments. Size and shape analysis may indicate the type of environment in which the sediments were deposited, and from this basis the processes causing the deposition may be clarified (see for example Friedman, 1961; Nossin, 1959).

Figure 5

Cross-section of Little Boomer Island

(for location, see Figure 2)


15
10
5
FEET
H.W.M.
V.E. = 2
SAND
GRAVEL
0
20
40
60
80
100
120
140
160
FEET
WEST
EAST
15
10
5
H.W.M.

III

MARION SPIT

The beach

Marion Beach is a gently curving sand beach which for its whole length is backed by dunes. The outline of the beach is clearly determined by wave action. On calm days, a constructive ocean swell is refracted by contact with the sea floor in such a way that it anticipates the coastal outline and on arrival fits it perfectly (Davies, 1959), the waves breaking simultaneously on long sections of the beach. Due to the lack of a suitable hydrographic chart of this section of coastline, no refraction diagram could be constructed. Crude measurements from aerial photographs indicated that southeasterly swell waves, having an average wave length of approximately 700 feet, equivalent to a wave period of 12 seconds, fit the beach perfectly. According to Davies (1964) southeasterly swell is dominant on the east coast of Tasmania and evidently originates in the wave trains that radiate from storm centres in the Southern Ocean.

Waves that approach the shoreline obliquely, arriving at an angle, set up a deflected nearshore water circulation, and the combined action of transverse swash on the beach (beach drifting) and resultant currents in the nearshore zone (longshore drifting) produces a movement of sand along the shore (Bird, 1968). No attempt was made by the writer to study longshore drift, however, the frequent occurrence of beach cusps suggests that Marion Beach is predominantly swash aligned and only periodically drift aligned. As northeasterly winds occur more frequently than southeasterly winds (Table II), it is likely that predominant drifting is southwards.

At the Narrows the pattern of refracted swell is somewhat complicated when ocean swell encounters a low offshore threshold bar outside the entrance to Blackman Bay lagoon (Plate 4). The wave crests are retarded as they cross the bar. Once over the bar, the refracted waves are diffracted by a deeper lateral channel close inshore until they fit the outline of the beach. The outline of the beach at this section of the spit is therefore determined by a local pattern of refracted swell.

The beach profile varies in response to wave action: in calm weather low swell waves form 'spilling' breakers with a constructive swash which moves sand onto the beach to build up a low convex berm along the length of the beach (Fig. 6), but during storms, higher and steeper waves from 'plunging' breakers, with collapsing crests which produce less swash, and a more destructive backwash which scours sand from the beach, removing the berm, lowering the profile, and frequently cutting back the outer margin of the foredunes (Plate 8).

The cycle of 'cut' and 'fill' (Davies, 1957) was studied by the writer at the centre of the beach (Fig. 8), and evidently involves the transfer of sand from the beach to a low offshore bar during periods of storm wave activity, and from the bar to a beach berm during conditions of calm weather when constructive swell waves are dominant. In general the offshore profile, beyond the foreshore zone, is a smooth and gentle slope, but less than a quarter of a mile off the beach sandstone reefs outcrop at a depth of 30 to 40 feet, marking the outer edge of the spit.

The beach sediments consist of quartz sand and generally less than 5 percent carbonate material. The beach sand characteristics of 5 samples taken at Bascom's reference point at the sites shown in Figure 6, are summarized in Table III.

TABLE III

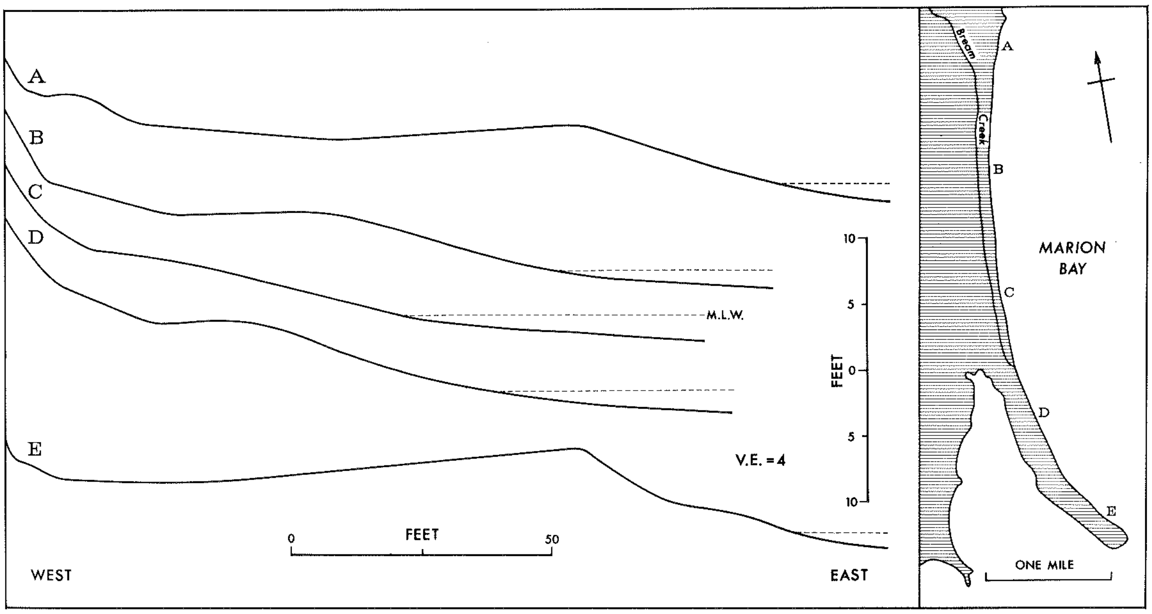
SIZE PARAMETERS (FOLK AND WARD, 1957)
AND COMPOSITION OF BEACH SEDIMENTS
AT BASCOM'S REFERENCE POINT

Beach Profile	Mean	Sorting	Skewness	Kurtosis	Percentage Carbonate
A	2.3066	0.3707	-0.9264	1.0260	1.96
B	2.4578	0.4090	-0.0238	0.9665	1.44
C	2.3829	0.4093	-0.0044	0.9940	1.19
D	2.3049	0.3888	-0.0268	1.0240	1.79
E	2.0606	0.3621	0.0936	0.9139	4.02

As will be noted, the beach sand is predominantly fine and moderately well sorted, and contains little carbonate material.

Figure 6

Beach profiles


A
B
C
D
E
M.L.W.
10
5
0
5
10
FEET
V.E. = 4
0
FEET
50
WEST
EAST
Bream
Creek
A
B
C
D
E
MARION
BAY
ONE MILE

There appears to be no significant variation in grainsize along the beach. The slight increase in percentage carbonate material along the southernmost sector of the beach is probably due to carbonate-rich sediments being flushed out by ebb currents through the inlet connecting Blackman Bay lagoon with the open ocean. A detailed account of spatial and temporal variation of the beach sand characteristics will be presented in Chapter IV.

Beach cusps are frequently present along the beach (Plates 1-4). There is as yet no general agreement on how they form and why they should be the shapes and sizes they are, however, it is generally considered that conditions are best for cusp formation if the waves approach exactly parallel to the shore, and that the spacing of the cusps is related to the wave height (Bascom, 1964).

It was noted on several occasions that cusps were present along the whole length of the beach at times when constructive swell waves were dominant, and also that the largest cusps were located along the northern half of the beach and gradually decreased in size away from this point, thereby indicating decreasing wave energy due to increasing wave refraction in a southward direction.

Whereas the inlet to Blackman Bay lagoon is located at the southern end of the beach where the dominant southeasterly swell is intensely refracted and wave action therefore weakened (Bascom, 1954), the location of the outlet of Bream Creek appears to contradict Bascom's Law. It may of course be argued that Bream Creek is still in the process of migrating in a southward direction, however, the mouth is marked by large blow-out dunes of varying ages indicating a fair degree of permanence. This suggests that if the outlet is migrating, it is doing so at a very slow rate.

The outlet of Bream Creek oscillates within approximately 500 yards along the shore. Commonly the outlet is sealed off by a high beach berm (Plate 2), particularly during the summer months when constructive swell conditions are dominant, while after periods of heavy rainfall in the catchment area and/or when the beach profile has been lowered by storm wave activity, a wide and shallow channel meanders across the beach.

Dunes

The beach berm built up by the ocean swell may become the foundation of a foredune, built when colonizing grasses initiate the accretion of wind-blown sand derived from the foreshore, and becoming higher and wider as accretion continues (Davies, 1957). Marion Beach, however, shows evidence of general recession rather than progradation. Beach berms and incipient foredunes are periodically built, but they rarely survive for more than a few months, being swept away during storms, frequently resulting in severe erosion of the older foredunes. It appears that 'cut' has exceeded 'fill' on Marion Beach during recent years. A comparison of aerial photographs taken in 1946 and 1966 showed that the shoreline had either receded slightly, particularly along the centre of the beach, or was in more or less the same position. A number of workers have noted similar evidence for beach recession elsewhere (see for example, Davies, 1957: Bird, 1965: Thom, 1968; Russell, 1967), and have speculated on the merits of such factors as an increase in storminess, a rise in sea level, and a diminished sand supply in the offshore area. Stormier conditions would prevent the deposition of stable beach and dune forms, and deepening of the offshore water by sea level rise would allow larger, more erosive waves to attack the shore: either of these changes would interrupt the progradation of the beach by shoreward-drifting sand. A diminished sand supply would also result in shoreline erosion (Thom, 1968). Clearly this, is a complex problem and much field research remains to be done before the role of the various factors in the erosion process can be objectively evaluated.

As was pointed out by Davies (1957), the height and spacing of parallel dunes is a function of the rate of sand supply to the shore, the history of cut and fill, and the effectiveness of vegetation in stabilizing the sand and building the dunes. Where sand supply is rapid on a prograding shore, a large number of low, closely spaced parallel beach ridges are formed, but where sand supply is slow due to a small sediment budget and/or periods of 'fill' separated by very long periods of 'cut', high, widely separated parallel dunes will form.

As will be noted on Plates 1-4, no beach ridges are present in the study area. The primary dunes are of the higher parallel type, and are partly obliterated by secondary, or parabolic dunes. There is no means whereby the history of 'cut' and 'fill' can be evaluated, however, as was noted previously, the offshore area covered by sand is generally less than a quarter of a mile wide, and there are no streams replenishing the sediment supply. This seems to suggest that the offshore sediment budget has probably never been a very large one and that therefore the rate of berm formation has been relatively slow, resulting in the development of widely spaced parallel dunes instead of low, closely spaced ridges. The parallel dunes show no marked variation in height and spacing.

Stages in the evolution of the spit may be traced with reference to the pattern of the parallel dunes, for these mark the alignment of former shorelines; the spit having been widened by progradation on the seaward side until the shoreline attained its present alignment. Progradation appears to have been greatest along the southern sector of the spit. Here also some re-alignment of the shoreline appears to have taken place (Fig. 2).

The dunes consist of fine quartz sand with less than one percent shell material. Augering revealed a characteristic succession of soil profiles across the parallel dunes indicating their increasing age away from the shore. The leaching of carbonates from the upper layer by percolating rainwater is followed by the eluviation of the iron oxides. Organic matter derived from dune vegetation and some of the iron oxides are washed down through the sand to accumulate as an illuvial "B" horizon of very lightly cemented sand rock generally close to the level of seasonal fluctuations of the water table. The depth of leaching increases from dune crest to dune crest on transects across the spit from the youngest dunes on the seaward side to the oldest on the landward side, where the leached layer extends to depths of up to 5 feet and is underlain by sand stained reddish-brown, but without the coherence of true coffee rock.

Parabolic dunes interrupt the pattern of parallel dunes and have generally developed by partial rearrangement and displacement of a pre-existing parallel dune pattern. This is clearly seen in the blowouts which have formed in the foredunes, where the wind has excavated elongated hollows in the seaward margin of dunes, particularly where the seaward margin consists of a crumbling cliff as a result of wave erosion.

Blowouts and parabolic dunes may be initiated in various ways, where the vegetation cover which held parallel dunes in place is damaged or completely destroyed. Locally, repreated burning and other forms of direct or indirect human interference may have led to the development of blowouts and parabolic dunes. Also an exceptionally large mobile parabolic dune has resulted from the oscillation of the outlet of Bream Creek (Plate 2). However, the writer believes that most of the parallel dunes have been modified by blowout development following the accentuated marine erosion of the beach in recent decades (see also Thom, 1965; Bird, 1965). As these develop they are obliterating the parallel dune pattern. The height of parabolic dunes increases in a southward direction along the shore, indicating increasing exposure to onshore winds. Some of the blowouts have developed into fairly large parabolic dunes, but these have since been stabilized by vegetation so that at the present time most of the parabolic dunes in the area are more or less fixed in position.

A characteristic succession of vegetation across the dunes is an outstanding feature. The annual shore plant Cakile edentula is usually the first plant to colonize and stabilize the embryo dunes in this area. It is commonly succeeded by the introduced marram grass, Ammophila arenaria which traps wind-blown sand to build foredunes at the back of the prograding beach. Growing foredunes remain grassy but once a newer foredune develops, thereby cutting off the supply of wind-blown sand from the beach, growth ceases and the marram grass is replaced by dune scrub communities, dominated by Acacia sophorae. On older dunes the scrub gives place to woodland with an undergrowth of bracken. Considerable clearing of the dune woodland has taken place in this area.

The evolution of the spit

The initiation of the spit is not easily explained. It stands in front of a tidal lagoon behind which lies the Llanherne level. The Llanherne level is largely undamaged by marine erosion. The spit must therefore have come into existence in such a way that ocean waves never returned to the Llanherne level.

The quantity of sand contained in the 5 miles long spit is enormous. There is no evidence to justify the idea that a major source of sand has existed north or south of the study area, nor are there any rivers entering the sea which could have supplied substantial quantities of arenaceous sediment. It seems equally unlikely that erosion of the dolerite cliffs would have yielded much sediment. As was noted previously, waves generated by onshore winds in coastal waters may arrive at an angle to the shoreline, and produce longshore drifting. On this east facing beach there is little evidence of longshore drift because the beach is backed by dunes parallel to the shoreline, indicating progradation on the same (swash) alignment. The writer therefore believes that the bulk of the sand has been eroded from the sea floor and carried shoreward by southeasterly swell waves during the Recent marine transgression. A number of workers have invoked a similar sequence of events to explain the development of extensive barrier formations elsewhere (see for example Bird, 1965, 1968; Zenkovich, 1967; Shepard, 1960; Russell, 1958). It is also possible that the long, low ocean southeasterly swell continued to bring shoreward some sea floor sand even after the Postglacial marine transgression came to an end (van Straaten 1959, 1961). The low feldspar content of the beach and dune sand (Davies, personal communication) is consistent with the idea of selective abrasion, favouring the persistence of the more resistant quartz grains, in sand which has been repeatedly reworked over a long period of time by wave action.

Investigations of the sediments on the continental shelf of New South Wales (Shirley, 1964) has indicated that quartz sand of the kind found along beaches and dunes is restricted in the nearshore zone. Offshore, there is a zone of terrigenous mud across which sand could not be transported, and beyond that a zone of coarse shell sand derived from deep-sea fauna, too deep for shoreward drifting by wave action. The absence of large masses of sand awaiting shoreward transportation from the sea floor off the coast of New South Wales suggests that shoreward drifting took place mainly during the Recent marine transgression, and that the coastal sand deposits are largely a legacy of this phase. Little is known about the distribution of continental shelf sediments off the east coast of Tasmania; however, it seems reasonable to assume that the general sediment distribution pattern is probably very similar to that found in New South Wales.

The view that the sea attained a higher level 6000 years ago and then dropped back to its present stand has been widely accepted by Australian coastal geomorphologists (Fairbridge, 1950, 1961; Gill, 1961; Davies, 1958, 1959, 1961), but evidence for eustatic oscillations should be world-wide, except of course where tectonic movements have obliterated it, and it appears that this is not the case (Russell, 1963, 1964).

According to Davies (1957, 1958, 1961) Recent beach ridge systems in Tasmania show an overall decrease in height seaward which may be correlated with a fall in sea level occurring when they were formed. This fall from the Milford shoreline was in the order of 2 or 3 feet in southeastern Tasmania, but up to 5 or 6 feet along the north coast (Davies, 1961). The Milford shoreline is considered to represent the limit of Postglacial submergence in Tasmania which by world-wide analogy, would date from about 6000 years before the present (Davies, 1959).

The Mildford shoreline at Marion Bay

The Milford shoreline at Marion Bay has been described by Davies (1959). This writer believes that the spit was initiated at the Milford level and grew southward from a dolerite headland, situated just south from the point where Bream Creek originally reached the coast. This spit extended the full length of the present spit and salt marshes are thought to have developed behind it at its northern end. Later, as the sea level fell, a raised sand beach and shell ridges widened the spit to the west, and the spit prograded seaward, adding foredunes which in part rest on a second spit which emanated from the dolerite headland north of Bream Creek. This has caused the creek to be sandwiched between the inner and outer spit.

A section of the emerged inner spit is visible along the southwestern sector. Here, the spit has been eroded by storm waves, generated in Blackman Bay lagoon, exposing a bed of semi-concretionary sand and shell, representative of the spit at Milford level (Plates 9 and 10).

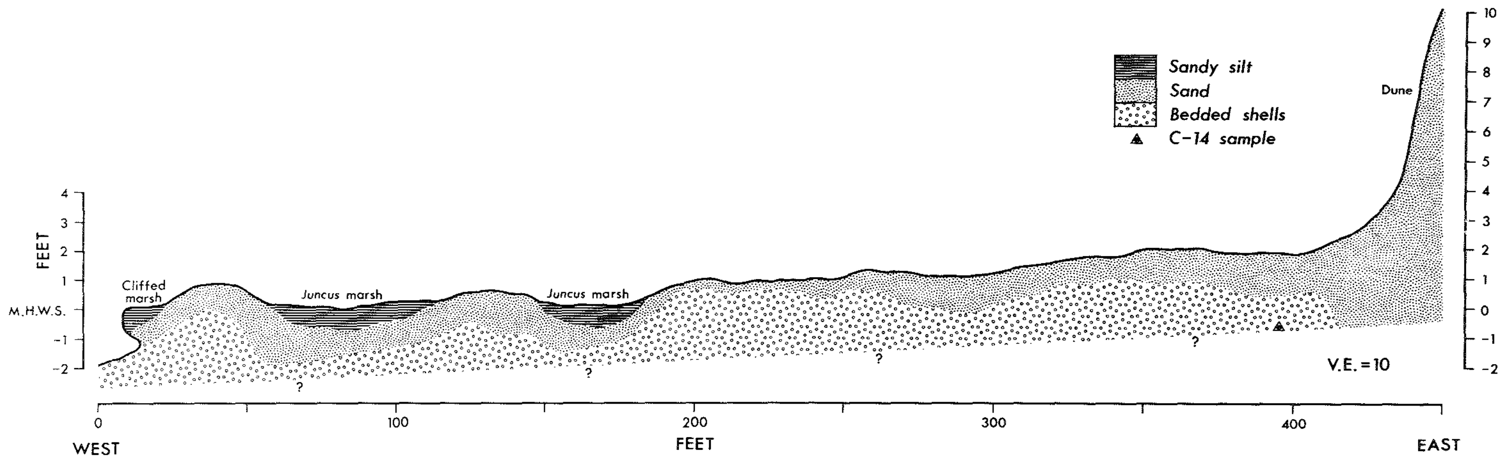
A section of the Milford beach was levelled and augered at the location shown in Figure 2. The section shown in Figure 7, strongly suggests that a fall in sea level has taken place, as postulated by Davies (1959), however, the writer believes that the sequence shown in the section can be explained without invoking sea level change.

It seems reasonable to assume that the sandy threshold bar (see Fig. 2) has not always been as extensive as it is at present. The would have enabled the effect of waves, generated by southerly and southwesterly winds, to impinge closer inshore and to construct a storm beach, consisting of detrital shell material, slightly above the level of mean high tides at springs, while elsewhere weak cliffing in unconsolidated materials at the foot of the Llanherne platform took place. The development of the threshold bar resulted in a gradual decrease in wave energy, thereby decreasing the rate of deposition of detrital shell material. Periodic storm wave activity resulted in the formation of low shell ridges, the swales of which were later invaded by salt marsh vegetation. Further shallowing of the lagoon resulted in tidal action becoming more important than wave action which led to the development of salt marshes.

Although this hypothetical sequence of events goes some way towards explaining the situation along the shores of Blackman Bay lagoon, it does not of course explain the presence of the slightly podsolized sandy layer overlying the shell bed. Possibly the sand

Figure 7

Cross-section of Milford beach (for location, see Figure 2)



Sandy silt
Sand
Bedded shells
C-14 sample
Dune
Cliffed marsh
Juncus marsh
Juncus marsh
M.H.W.S.
FEET
V.E. = 10
WEST
FEET
EAST

is of aeolian origin, derived from the threshold bar during periods of low water, and/or was blown off the dunes.

It may of course be argued that the hypothetical sequence of events suggested here need not have been exclusive of sea level change. Indeed, a slight emergence would in fact have accentuated and perhaps speeded the development of the shell bed and shell ridges; however, a C-14 date of 1890 ± 90 B.P. was obtained from a sample of the shell bed which is considerably younger than one would expect from a site that is considered to represent the limit of Postglacial sea level. Contrary to Davies' (1959) suggestion, the writer failed to find evidence of 'raised' salt marsh deposits at the northern end of the lagoon. Also, the development of the outer spit, which resulted in the curious position of Bream Creek, could have taken place without a fall in sea level. The digging of pits in the dunes at either side of the creek failed to show a difference in the degree of podsolization of the sand, thereby indicating that the succession of events was essentially continuous. This was also noted by Davies (1959).

Although the writer's findings cannot be said to contradict the suggestions put forward by Davies (1959), they do, however, indicate a need for wider investigation into this controversial problem at other Milford sites.

IV

BEACH STUDY

Aim of the study

Whereas temporal variation of beach profiles is very well documented in the literature (see for example King, 1959; Bascom, 1964), temporal variation of beach sediment characteristics appears to have received considerably less attention. The only field studies known to the writer are those by Trask and Johnson (1955), and Ingle (1966).

The present study is an attempt to investigate the magnitude of spatial and temporal variation of beach sediment characteristics, and to determine the extent to which such changes are related to the variation in beach profile.

Field techniques

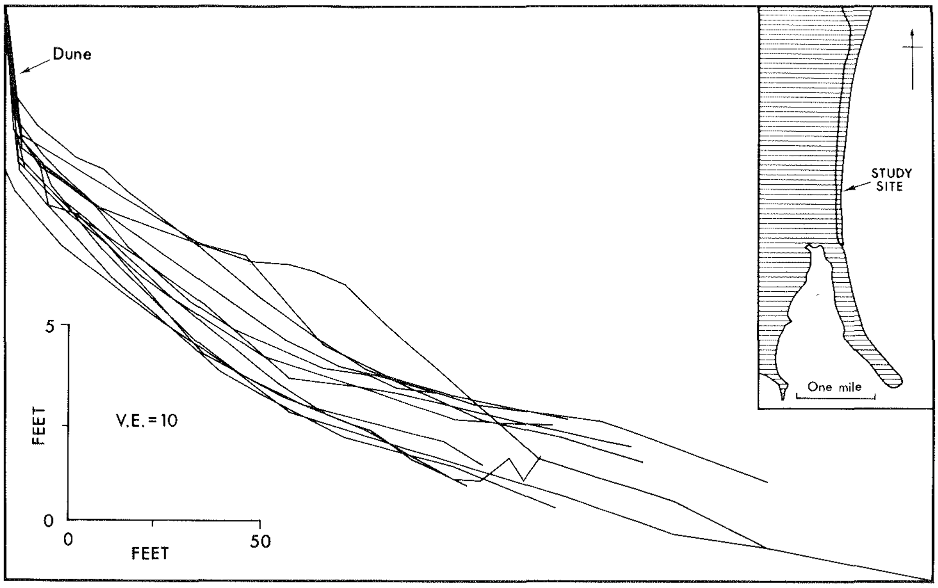
Twelve beach profiles were surveyed at monthly intervals with the aid of a Dumpy level, at a site situated approximately at the centre of Marion Beach (Fig. 8). Because of the occasional presence of cusps at the site, it was sometimes found necessary to adjust the established survey line so that it always passed through the centre of the bay of a cusp, thereby ensuring consistency. In order to avoid bias from entering into the sampling programme a systematic procedure was adopted. Sampling always commenced at the upper limit

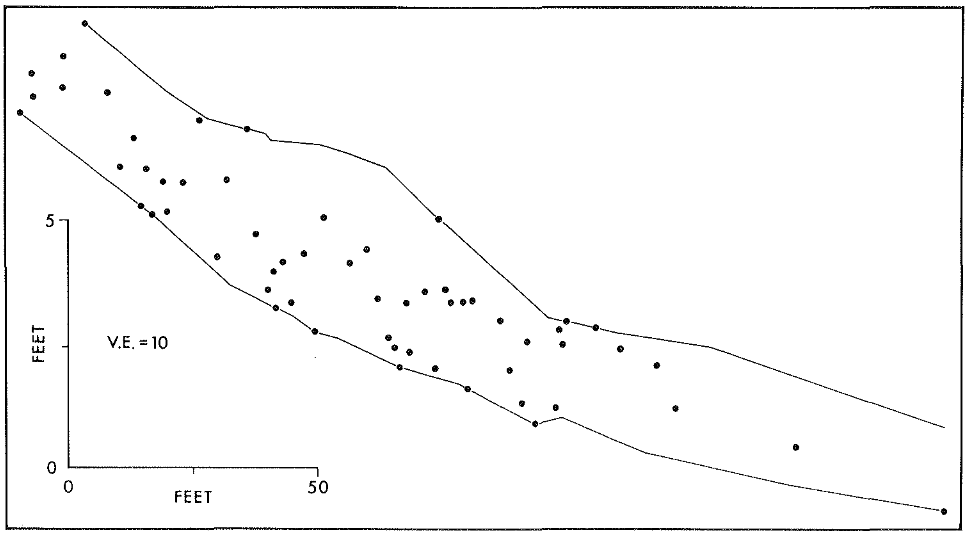
Figure 8

Superimposed beach profiles

Figure 9

Sweep zone profile and distribution of sample points


Dune
STUDY SITE
One mile
5
FEET
V.E. = 10
0
0
FEET
50


5
FEET
V.E. = 10
0
0
FEET
50

of the swash zone and continued across the swash slope and foreshore at 25 foot intervals for a total distance of 100 feet. Samples were obtained during the beach profile survey with the aid of a 3 inch diameter metal cylinder by pushing it 3 inches into the sand, thereby recovering a constant volume. Early attempts to extend the survey and sampling programme into the breaker zone failed because of unfavourable physical conditions.

Laboratory methods

Samples were dried in an oven at approximately 100°C. The samples were split with the aid of a mechanical sample splitter and a subsample ranging from 50-60 grams was subjected to mechanical analysis for 15 minutes in a vibrating nest of sieves of mesh sizes -2.5ϕ to 4ϕ and a mesh size interval of 0.5ϕ. Fractions where weighed on an air-damped Mettler balance, accurate to 0.0001 g. Another subsample of approximately 10 grams was digested in 10 percent HCl and the percentage of carbonate material determined.

Sediment parameters

Parameters were calculated by means of the University's Elliott 503 computer, using a programme that was written by Chick (1969). The parameters used in this study are the coarsest percentile, median percentile, and the moment measures.

Trend-surface analysis

Conventional interpolation of isopleths between the sample points would provide a relatively objective expression of spatial and temporal variation of the beach sand characteristics, but isopleths are drawn only between sample points and their immediate surrounding neighbours, with no information being contributed to areas beyond the polygon of nearest points. Trend-surface analysis provides the added sophistication of drawing isopleths of three dimensional regressions, with each sample point contributing information to the whole area being mapped (Krumbein and Graybill, 1965, pp.319-355). Computed isopleths therefore provide a useful means of depicting the trend component inherent in the data but possibly masked by local or random variability.

A hierarchy of mathematical surfaces may be fitted to the data, and the 'explained' portion of the observed variability, expressed as the percentage of reduction of the total sum of squares, may then increase with surfaces of successively higher degree. When the variability has been generalized by a best-fit mathematical surface, valuable information may be obtained by mapping the deviations of individual observations from the computed surface.

A computer programme written in ALGOL was especially modified by Mr. N.K. Chick, to meet the requirements of the investigation. The size parameters, the percentage of carbonate material, and the UV locational rectangular grid co-ordinates of the 60 samples provided the basic data for the calculation and mapping of trend-surfaces.

The sweep zone profile (Fig. 9), and the computer print-out was the basis for Figures 10-15, which contain the percentage variability accounted for by each surface (S), and maps of the highest surfaces obtained. Also indicated for each of the trend-surfaces is the significance of the trend (F), derived by an informal analysis of variance based on the method of Anderson and Bancroft (1952, p.214), as discussed by Krumbein and Graybill (1965, pp.336-337). Because of the pilot nature of the study, no attempt was made to map and interpret the deviations from the trends.

Results

Median grainsize. Variation in median grainsize is shown in Figure 10. Only the linear and quadratic surface could be obtained from the data. The computer print-out indicated that tight clustering of some of the data points had caused the cubic surface to 'blow up' (for discussion see Krumbein and Graybill, 1965, pp.345-346).

Whereas beaches consisting of coarse particles generally show marked variation of grain size with the seasons or with changing wave conditions (Trask and Johnson, 1955; Ingle, 1966), this is apparently not true for beaches consiting of fine sand, such as Marion Beach.

In considering variation of median grainsize for the sweep zone profile as a whole, the trend shown generally supports the findings of workers elsewhere (King, 1959; Ingle, 1966). Finer sand is generally found on the foreshore and towards the backshore. The coarser sand is found on the swash slope and upper part of the foreshore, due to the winnowing out of fine sand by the swash and backwash. It is more difficult to explain the coarser fraction on the berm crest which is reached by swash only during periods of very high water. It may be partly due to the effect of wind winnowing out the finer sand.

Sorting. The cubic trend-surface for sorting is shown in Figure 11. The better sorted sand tends to be concentrated on the swash slope and backshore. Sorting tends to deteriorate slightly across the foreshore in response to increasing energy of shore processes.

Coarsest percentile. The trend-surface for the coarsest percentile (Fig. 12), is interesting in that it suggests a relationship with sorting. It appears that, as grainsize of the coarsest percentile increases, that is, the values decrease in the ø notation, the sorting index increases. From this one could conclude that the coarser the grainsize of the coarsest percentile, the poorer the sorting. The significance of this statistical relationship will be examined later (see Correlations).

Skewness. The skewness trend (Fig. 13) shows that the sediments become more negatively skewed as distance from the shore increases due to the increasing energy of shore processes in selectively removing the finer particles from the lower foreshore and the tendency for the coarser particles to be deposited on the upper foreshore and swash slope.

Kurtosis. The kurtosis trend (Fig. 14) shows a transition from mesokurtic to leptokurtic sediment distribution curves with increasing distance from the shore.

Percentage Carbonate. The percentage carbonate values (Fig. 15) show that the percentage of shell material becomes greater with increasing distance from the shore. The map also shows that the swash slopes of fill profiles tend to contain a slightly higher percentage of carbonate material than the swash slopes of cut profiles. This may be partly due to the fact that the mass per surface area of shell material is smaller than of quartz grains, and that therefore the carbonate fractions are readily winnowed out from the swash slope by backwash during periods of storm wave activity. The superimposed beach profiles (Fig. 8), suggest another possible cause, namely, that during periods of severe beach erosion some dune sand, containing very little carbonate material (see *Dunes*, Chapter IV), is redistributed by the backwash, thereby diluting the carbonate content of the beach sand.

Correlations

Correlation analysis was used to determine the relationship between grainsize parameters, composition, and location of the 60 samples. The results are shown in Table IV. With $n = 58$, the correlation is highly significant if r modulus is greater than 0.408 and significant if r modulus exceeds 0.246. Sixteen coefficients in the table are shown to be highly significant while another three are significant.

Figures 10-15

Trend-surface maps

Isopleth intervals = 0.5 standard deviation

<u>Median grainsize</u>

Linear surface; S = 16,36%, F > 99%

Linear plus quadratic surface; S = 27.72%, F = > 99.9%

Figure 10

Quadratic trend-surface

Isopleth interval = 0.132 ϕ

<u>Sorting</u>

Linear surface; S = 35.08%, F > 99.9%

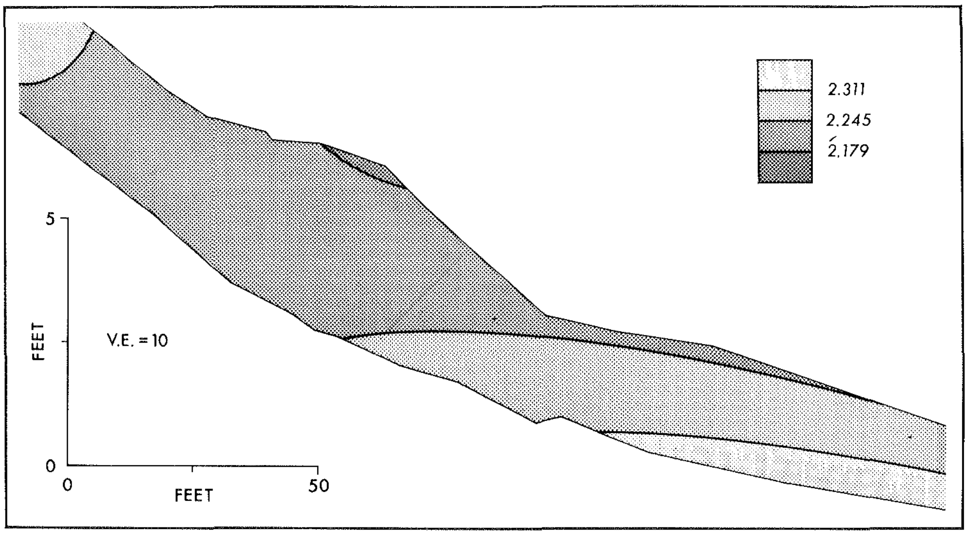
Linear plus quadratic surface; S = 48.91%, F > = 99.9%

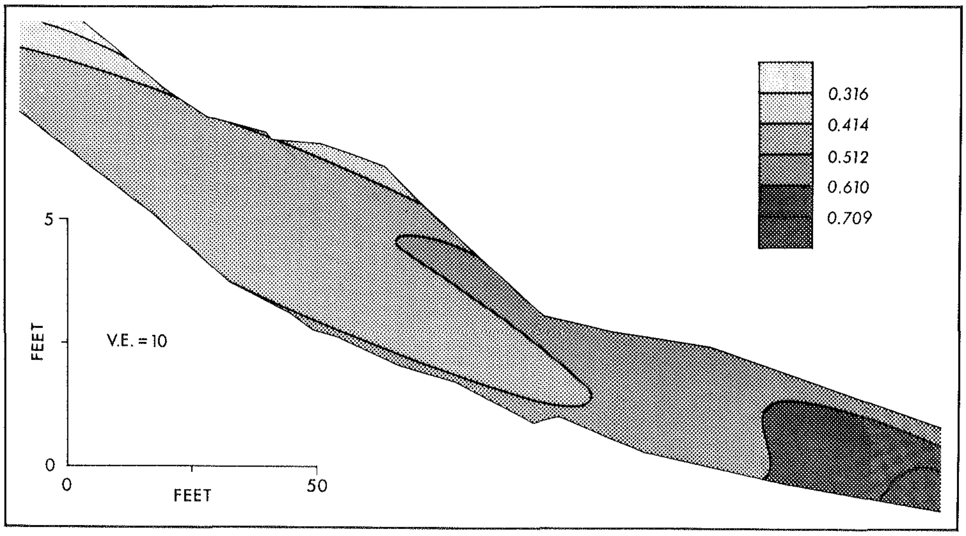
Linear plus quadratic plus cubic surface; S = 54.60%, F > 99.9%

Figure 11

Cubic trend-surface

Isopleth interval = 0.197 ϕ


2.311
2.245
2.179
5
FEET
V.E. = 10
0
0
FEET
50


0.316
0.414
0.512
0.610
0.709
5
FEET
V.E. = 10
0
0
FEET
50

<u>Coarsest percentile</u>

Linear surface; $S = 33.58\%$, $F > 99.9\%$

Linear plus quadratic surface; $S = 44.02\%$, $F > 99.9\%$

Linear plus quadratic plus cubic surface; $S = 49.60\%$, $F > 99.9\%$

Figure 12

Cubic trend-surface

Isopleth interval = 1.113 ϕ

<u>Skewness</u>

Linear surface; $S = 46.88\%$, $F > 99.9\%$

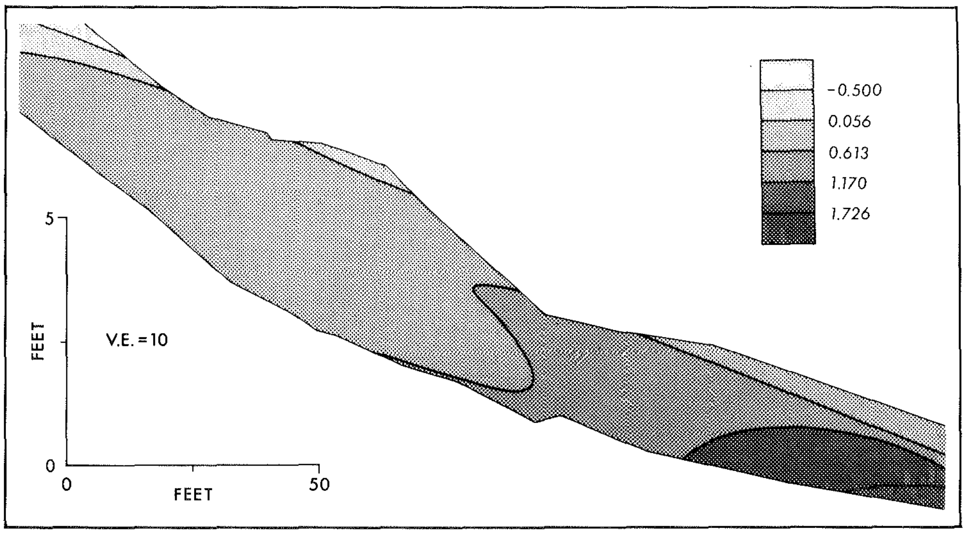
Linear plus quadratic surface; $S = 50.3\%$, $F > 99.9\%$

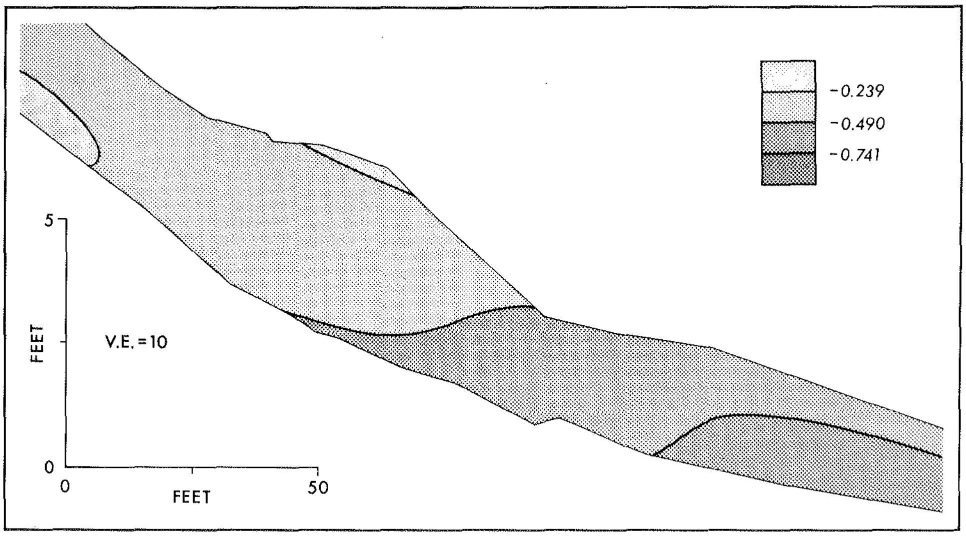
Linear plus quadratic plus cubic surface; $S = 50.68\%$, $F > 99.9\%$

Figure 13

Cubic trend-surface

Isopleth interval = 0.501 ϕ


-0.500
0.056
0.613
1.170
1.726
5
FEET
V.E. = 10
0
0
FEET
50


-0.239
-0.490
-0.741
5
FEET
V.E. = 10
0
0
FEET
50

Kurtosis

Linear surface; S = 34.96%, F > 99.9%

Linear plus quadratic surface; S = 36.01%, F > 99.9%

Linear plus quadratic plus cubic surface; S = 36.68%, F > 99.9%

Figure 14

Cubic trend-surface

Isopleth interval = 0.923 ϕ

Carbonate

Linear surface; S = 51.90%, F > 99.9%

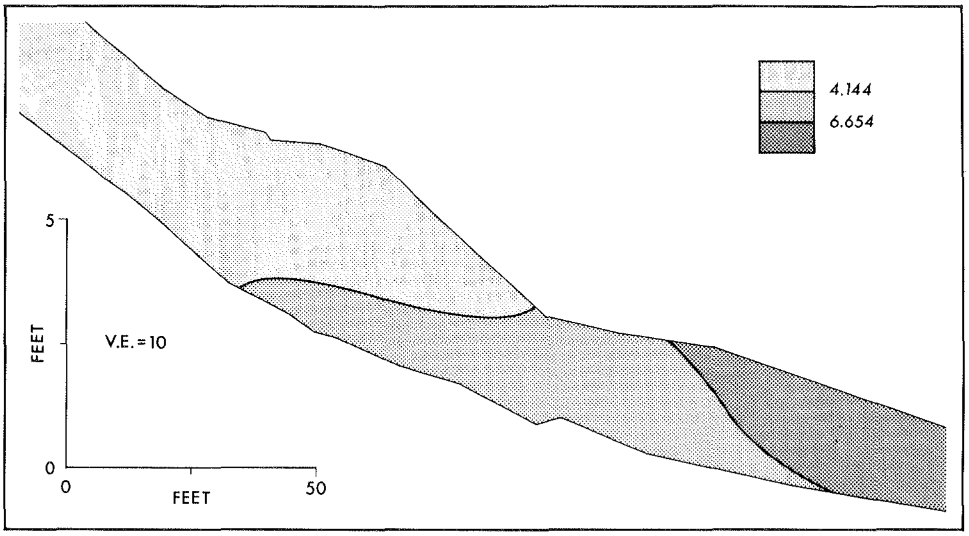
Linear plus quadratic surface; S = 63.80%, F > 99.9%

Linear plus qudratic plus cubic surface; S = 65.13%, F > 99.9%

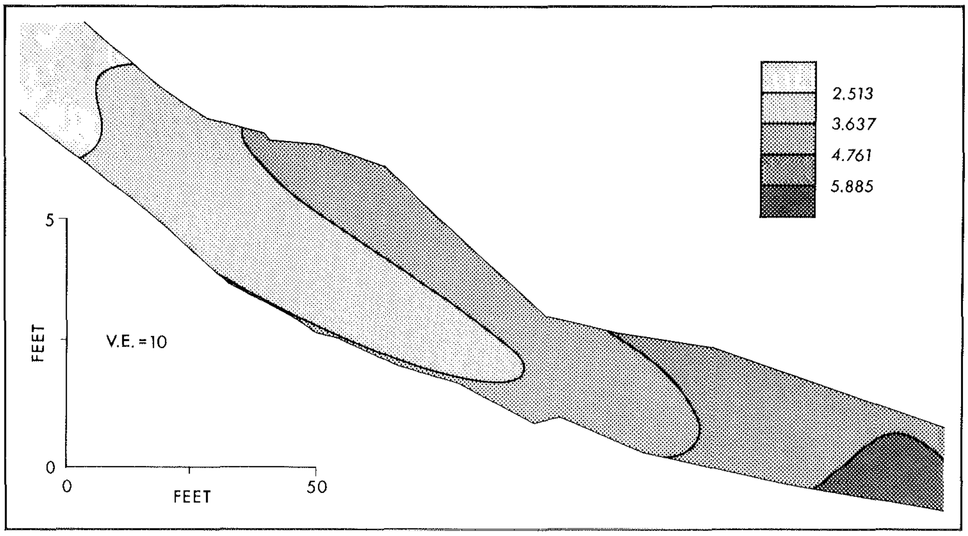
Figure 15

Cubic trend-surface

Isopleth interval = 2.248%



4.144
6.654
5
0
FEET
V.E. = 10
0
FEET
50



2.513
3.637
4.761
5.885
5
0
FEET
V.E. = 10
0
FEET
50

TABLE IV

INTERPARAMETER CORRELATION COEFFICIENTS

	Coarsest Percentile	Median	Mean	Sorting	Skewness	Kurtosis	Percentage Carbonate	Distance from shore
Coarsest Percentile	-	-0.1790	0.3220	-0.9518	0.8237	-0.5864	-0.8719	-0.5010
Median	-0.1790	-	0.7979	0.2260	-0.3883	0.3472	0.2407	0.3873
Mean	0.3220	0.7979	-	-0.3103	-0.0227	0.1556	-0.2302	0.1598
Sorting	-0.9518	0.2260	-0.3103	-	-0.7483	0.4920	0.8907	0.5068
Skewness	0.8237	-0.3883	-0.0227	-0.7483	-	-0.9226	-0.7510	-0.6257
Kurtosis	-0.5864	0.3472	0.1556	0.4920	-0.9226	-	0.4888	0.5370
Percentage Carbonate	-0.8719	0.2407	-0.2302	0.8907	-0.7510	0.4888	-	0.6726
Distance from shore	-0.5010	0.3873	0.1598	0.5068	-0.6257	0.5370	0.6726	-

Significance: For $P = 0.1$, $r = 0.208$; $P = 0.05$, $r = 0.246$; $P = 0.01$, $r = 0.326$; $P = 0.001$, $r = 0.408$.

Several of the highly significant coefficients are very interesting indeed and support the interparameter relationships suggested by the trend-surface maps. The coarsest percentile shows a highly significant correlation with sorting, skewness, kurtosis, percentage carbonate, and distance from the shore. From these correlations one can conclude that the coarsest percentile of the samples consists mainly of carbonate material, and also, that as the grainsize of the coarsest percentile and percentage carbonate increase with increasing distance from the shore, the sediments become less well sorted and the sediment distribution curves tend to become more negatively skewed and leptokurtic. It is also noticeable that when median grainsize increases, skewness increases in a positive direction and the sediment distribution curves become mesokurtic. No significant statistical relationship between mean grainsize and sorting appears to exist.

Factor Analysis

In order to provide a better understanding of the basic causes responsible for the variation of the beach sand characteristics, R mode factor analysis was applied to 6 variables. It was found that the variation of the 60 samples could be very largely summarized by the information contained in the first three factors which together account for 96.92% of the total variance of the original data. The separate contribution of each varimax factor is listed in Table V, and the varimax factor loading matrix is shown in Table VI.

Note that factor I is closely related to the parameters of sorting, percentage carbonate and coarsest percentile and therefore may be identified as the carbonate factor, explaining 49.13% of the total variance. Factor II, on the other hand, has a high factor loading only for the median grainsize of the sand and is therefore the grainsize factor, explaining only 17.52% of the variation. Factor III is clearly related to the skewness and kurtosis of the samples and represents the size distribution factor, which explains a further 30.27% of the variation.

The results of the factor analysis thus show that the spatial and possible temporal variation in beach sand characteristics at Marion Bay appears to be predominantly caused by the carbonate fraction. Bearing in mind that the size range of the non-carbonate beach material is very small, this conclusion is hardly surprising.

Perhaps a better understanding of the nature and the spatial distribution of the three factors would have been gained by mapping the factor scores, or better still, subjecting them to trend-surface analysis, thereby obtaining maps showing factor trends. Unfortunately, pressure of time did not permit this method of analysis to be included in the present study.

TABLE V

VARIANCE FROM VARIMAX FACTORS

	FACTOR I	FACTOR II	FACTOR III
% variance	49.13	17.52	30.27
Cumultative % variance	49.13	66.65	96.92

TABLE VI

VARIMAX MATRIX

	FACTOR I	FACTOR II	FACTOR III
Coarsest Percentile	0.901156	-0.02422	0.379189
Sorting	-0.944206	0.095576	-0.243361
Skewness	0.578039	-0.201317	0.786454
Kurtosis	-0.254612	0.160476	-0.951109
Percentage Carbonate	-0.914754	0.123474	-0.243679
Median Grainsize	-0.092371	0.979697	-0.175687

V

BLACKMAN BAY LAGOON

Blackman Bay consists of three distinct environments: high tide flats, above the level of mean high tide, the intertidal slopes, between the levels of mean high and mean low tides, and a subtidal zone below the low tide level (Fig. 2). The terminology followed is that suggested by Davies (1972, in press). The spring tide range at The Narrows is approximately 4 feet, but seldom exceeds 2½ feet in the lagoon.

The high tide flats

An extensive, densely vegetated high tide flat has developed at the northern end of the lagoon. Elsewhere, high tide flat development has been restricted to narrow fringes, and small areas that have developed behind low ridges composed of sand and detrital shell, deposited during periods of relatively strong wave action.

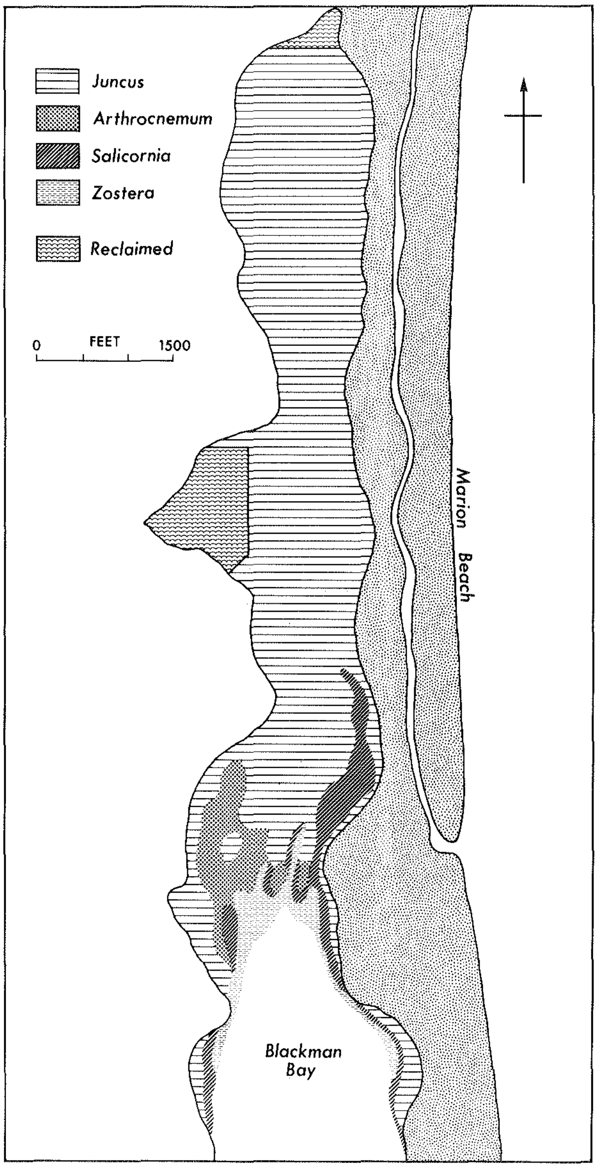
The high tide flat sediments are predominantly sandy silts. Blackman Bay is such a low energy environment, that the sediments are generally very fine grained when they reach the high tide flats. Anaerobic conditions prevail just below the surface as is indicated by the blue-black colour of the soil and a strong odour of hydrogen sulphide emitted whenever it is disturbed. The water table lies either at or slightly below the surface. Tidal channels do not continue out onto the intertidal slopes from the high tide flats. This is because the sediments of the intertidal slopes are generally not cohesive enough to maintain a clearly defined channel without the aid of vegetation. The digging of drainage ditches, and the construction of a causeway to provide public access to Marion Beach, have resulted in considerable modification of the natural drainage systems (Plates 1 and 2). Because of this, no attempt was made to study the hydraulic geometry and morphometry of the tidal channels.

A short botanical account of the salt marsh vegetation of the area was given by Curtis and Somerville (1947). There are three major vegetation zones (Fig. 16). Salicornia is the pioneer plant and dominates the low lying areas subject to frequent inundation by the tide. Locally, it advances onto the soft mud of the uppermost margins of the intertidal slopes. At a slightly higher level, the Salicornia association is invaded by Arthrocnemum. Commonly, occasional tussocks of Juncus are scattered throughout the Arthrocnemum zone, but the greater number of these plants occurs on the higher parts of the high tide flats, where periods of inundation occur only during high spring tides. There is little morphological expression of floristic changes other than a very gradual rising of the high tide flat surface.

Locally, cattle and sheep have almost completely destroyed the salt marsh vegetation, which has led to the development of a number of poorly drained areas. During spring tides, and for some time thereafter, such areas will often retain water, while in summer, when evaporation is intense, the water becomes highly saline, so the

Figure 16

Generalised zonation of salt marsh vegetation


Juncus
Arthrocnemum
Salicornia
Zostera
Reclaimed
0 FEET 1500
Marion Beach
Blackman Bay

conditions are adverse for plant growth.

A steeply sloping or undercut cliff commonly marks the boundary between the high tide flats and the intertidal slopes (Plate 12). Such cliffs are particularly well developed along the more exposed eastern shoreline. Curtis and Somerville (1947), suggested that the erosion of the seaward margins of the high tide flats may be due to complex tides that have resulted from the cutting of Denison Canal in 1930. High tide flat recession is not unique to the study area (Bird, 1968; Guilcher, 1954). Continued erosion of the seaward edge of high tide flats can be due to several factors. One of the most common causes is current scour alongside a lateral migrating tidal channel; however, this does not appear to be the case in the study area. Localized recession of high tide flats may also be the result of changes in lagoon configuration caused by wave and current action around its shores, particularly at high tide, when sectors more exposed to strong wind and wave action tend to be eroded, and the material deposited on other parts of the shoreline, or in the subtidal zone, in the manner described by Bird and Ranwell (1964). A eustatic rise of sea level, considered to be at a rate of 1 mm per year, or about 4 inches during the past century (Bird, 1968), would upset the high tide flat equilibrium established for any particular sea level. In areas exposed to periodic wave activity, an increase in storminess (Davies, 1957) would lead to a steepening of the intertidal slope profile and result in undercutting of the high tide flat margins, particularly during high tides. Changes in sediment supply must also be considered. If at present there is less sand available for barrier construction compared with the period when the recent barriers were initiated in their present subaereal position, as has been suggested by Thom (1968), then such reduction would also make its effects felt in tidal lagoons. Of course, this line of reasoning can incorporate the effects of sea level rise and increased storminess. Unfortunately, lack of observations does not enable one to design a process-response model of the shoreline area making it difficult to evaluate these hypotheses.

The intertidal slopes and subtidal zone

The intertidal slopes and subtidal zone occupy the main part of Blackman Bay lagoon. The western half of the lagoon is very shallow and relatively featureless. The sediments consist of silt with a high proportion of fine sand and shell material. Near the seaward end of the lagoon there is a relatively sharp change in subtidal zone morphology, the featureless floor of the lagoon attaining a depth of approximately 15 feet in front of a steep and irregular bank of sand facing up the lagoon. This slope represents the inner margin of a broad sandy threshold, the surface of which is relatively flat, submerged at high tide but largely exposed at low tide when a single channel up to 20 feet deep winds through it to the sea.

The threshold sediment is very similar in appearance to the sand found on Marion Beach except that it contains a higher proportion of whole and detrital shell material and is locally muddy, with an admixture of silt, clay, and organic matter, not encountered in beach sand. Muddy sediments are particularly evident in very sheltered areas and are generally found along the upper margins of the intertidal slopes bordering the high tide flats. Such areas are commonly vegetated by a dense growth of Zostera.

The sandy threshold is essentially a part of the barrier system which has not been built up above high tide level. It was formed by sand being washed into the lagoon from Marion Bay and blown in from the dunes by local winds. During periods of flood tide, waves and currents move sand into the lagoon; during ebb tide, some of this is carried back out to sea, however, sand that spills over the inner slope of the threshold cannot be returned in this way, so that the tendency is towards a widening of the threshold as infilling of the lagoon proceeds (Bird, 1967).

In some areas, lagoon thresholds commonly consist of a complex of shoals, ebb and flood channels (see for example van Veen, 1950; Robinson, 1960; Armstrong Price, 1963). In the study area such features are not very well developed. This clearly reflects the small tidal range, the volumes of water entering and leaving the lagoon being small, and the ebb and flood currents consequently weak. Similar lagoon threshold morphology has also been noted by Bird (1967), along microtidal sectors of the south coast of New South Wales.

Changes in lagoon configuration

Interpretation of aerial photographs taken in 1946 and 1966 failed to show marked morphological changes. Shoreline recession, generally less than 10 feet, appears to have taken place along the southernmost sector of the eastern shoreline which is exposed to periodic wave activity, generated by strong southerly and southwesterly winds.

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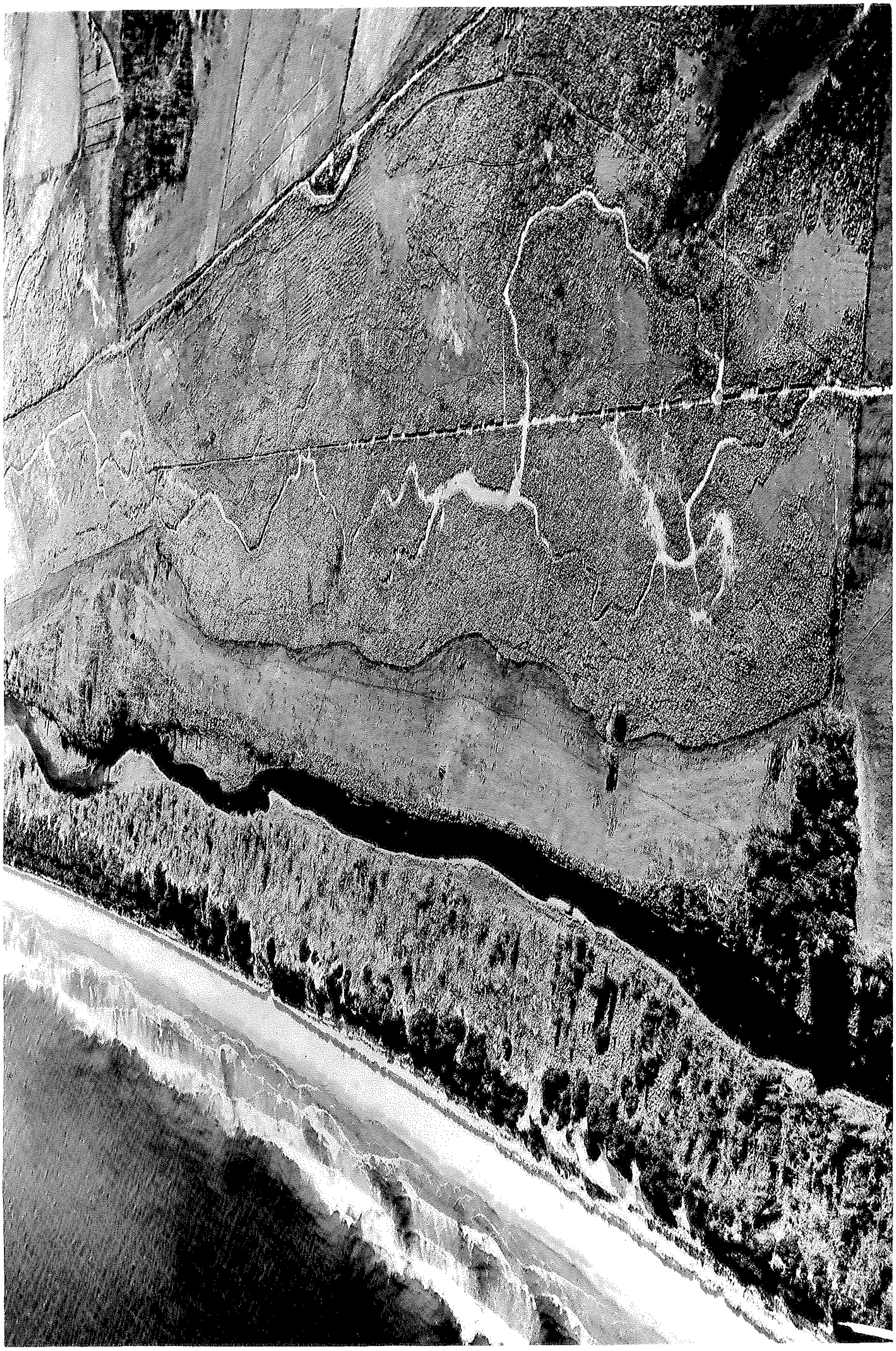
PLATES

Plates 1 - 4

Oblique aerial photographs facing south, showing parts of the spit, high tide flats and Blackman Bay lagoon.



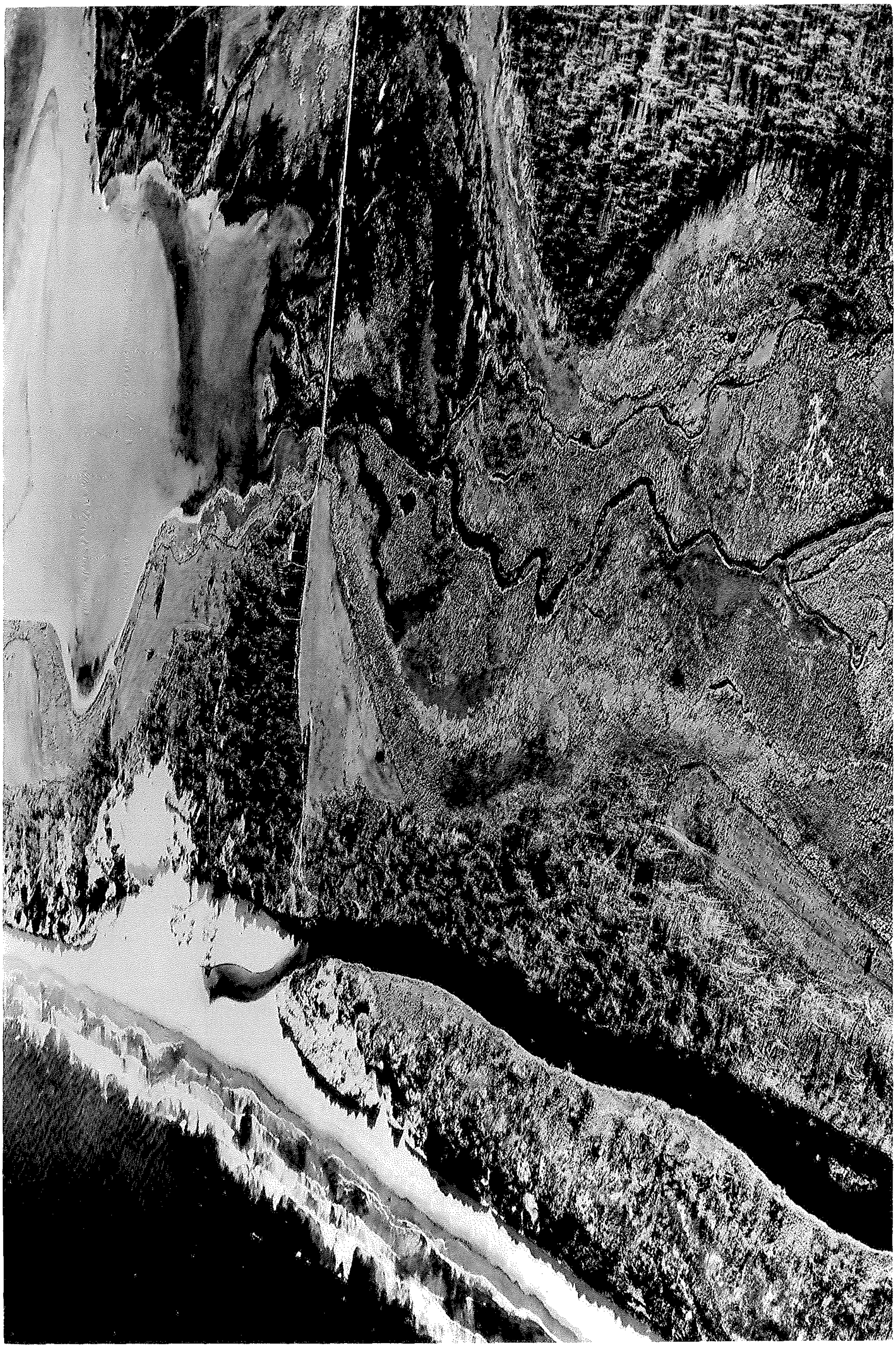


Plate 5

The Llanherne shoreline and platform near profile C (see Figures 2 and 4).

Plate 6

Erosion of the seaward margin of the Llanherne platform, north of Little Boomer Island.

Plate 7

Basalt gravels overlain by sand at Little Boomer Island.

Plate 8

Marion Beach looking south, showing 'cut' beach profile and crumbling foredune cliff after a period of storm wave activity.

Plate 9

Cliff cut into the Milford beach, showing a layer of bedded shells overlain by sand containing Aboriginal midden material.

Plate 10

The Milford bedded shells at the same site as Plate 9. Shells are primarily Katelysia scalarina (Lamarck), Katelysia rhytiphora (Lamy), and Notopisula trigonella (Lamarck).

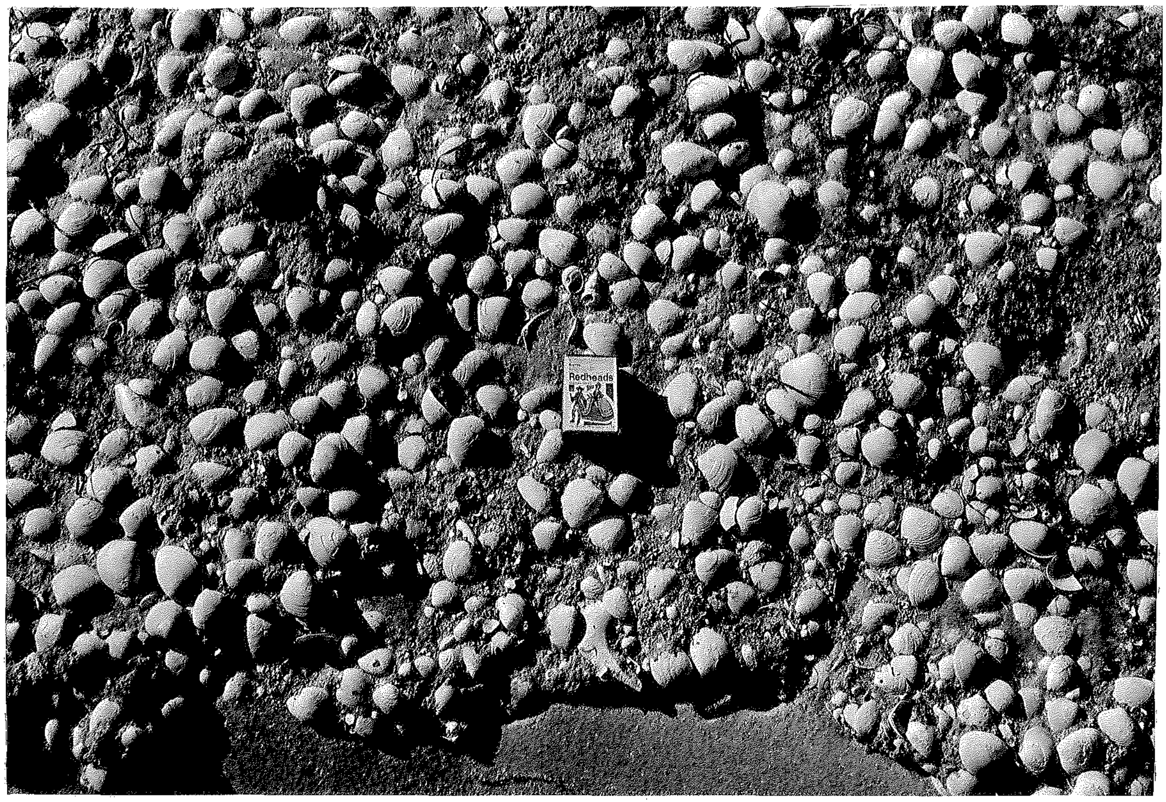

Redheads

Plate 11

Zonation of salt marsh vegetation near the causeway, showing Salicornia, Arthrocnemum and Juncus in the foreground, and Salicornia and Juncus in the background.

Plate 12

Erosion of the *Juncus* marsh along the southern sector of the spit.