THE COASTAL BARRIERS

Plate 9 – Outer barrier and Bunga Arm (N Rosengren)

The coastal barriers consist of large masses of unconsolidated sand, with subordinate silt and clay deposits, lodged upon the coastal shelf in the East Gippsland embayment in such a way as to enclose a chain of coastal lagoons. As has been indicated, they rest upon a shelf that slopes seaward from about 8 to more than 20 metres below present sea level. There are essentially three, partly overlapping, barrier formations (Figure 18). The first, on the northern side of Lake Wellington and Lake Victoria, is termed the prior barrier, since it developed at the head of the embayment before the lakes were enclosed. The second, the inner barrier, extends across the mouth of the embayment, enclosing Lake Wellington, Lake Victoria, and Lake King, but it is interrupted by a gap just east of Perm Whale Head. The third, the outer barrier, stands up to 2 kilometres seaward, separated by a tract of shallow lagoons, sandflats, and salt marshes, and extending for the whole length of the Ninety Mile Beach.

The barriers are surmounted by beach ridges and dunes (Figure 1 and 19), with ridge crests mainly parallel to the curved outline of the Ninety Mile Beach, but also including parabolic forms. Stages in barrier evolution may be traced with reference to the pattern of ridges, for the dune and beach ridges parallel to the Ninety Mile Beach mark the alignments of former shorelines, the barriers having been widened by progradation on the seaward side. Successively-built foredunes show a sequence of dune soils and vegetation indicative of increasing age profile and vegetation evidence as a general indication or relative age within the dune terrain.

On the East Gippsland coast the dunes and beach ridges consist mainly of quartz sand, with only a small proportion of shelly material. The proportion of carbonates n the sand on the Ninety Mile Beach rarely exceeds 10%, and it is probable that the dunes and beach ridges on these barriers were built from similar material. The characteristic succession of soil and vegetation features across parallel dunes and beach ridges of quartzose sand leads to the development of deep podzols profiles and vegetation communities rich in heath species on the oldest sites (Burges & Drover 1957; Turner, Carr & Bird 1962). The leaching of carbonates from the upper layers of a newly-built beach ridge or dune by percolating rainwater is followed by the removal of the iron oxides that give fresh sand grains their initial yellow colouring, and organic materials derived from the decomposing litter produced by dune vegetation, together with some of the leached iron oxides, are washed down through the sand to accumulate as an illuvial horizon of lightly-cemented sandrock (termed ‘coffee-rock’), generally close to the level of seasonal fluctuations of the water table. A typical sample of coffee-rock from old parallel dunes on the inner barrier was found to contain 1.93 % organic matter and 0.13 % ferric oxide (Fe_2o_3).

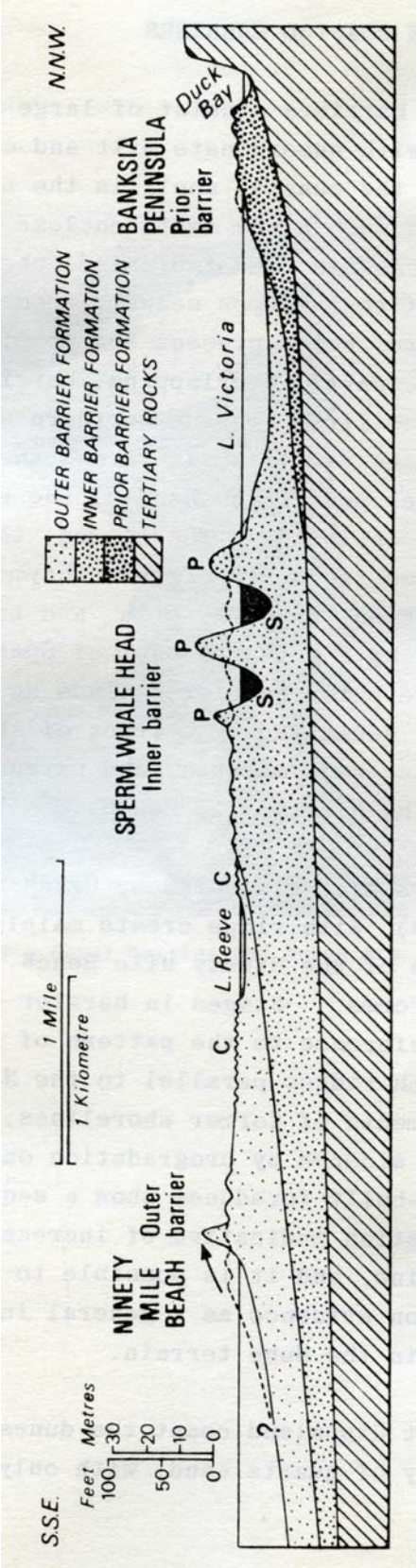
S.S.E.
N.N.W.
Feet
Metres
100
50
0
30
20
10
0
NINETY MILE BEACH
Outer barrier
1 Mile
1 Kilometre
C
C
L. Reeve
SPERM WHALE HEAD
Inner barrier
P
P
P
S
S
OUTER BARRIER FORMATION
INNER BARRIER FORMATION
PRIOR BARRIER FORMATION
TERTIARY ROCKS
L. Victoria
BANKSIA PENINSULA
Prior barrier
Duck Bay

Figure 18

This is essentially the process of podzolisation, and the end-product, a deeply-leached "A" horizon over an illuvial sandrock "B" horizon, can be termed a ground-water podzol (Stephens 1962). Similar podzol profiles have been described from old quartzose dunes on the east coast of Ling Island (Jennings 1959a). The process is accompanied by, and to some extent depends on, a vegetation succession (Figure 20) that begins with the grasses (chiefly *Festuca littoralis*, *Spinifex hirsutus*, and the introduced marram grass, *Ammophils arenaria*) which trap wind-blown sand to build foredunes at the back of a prograding beach. Growing foredunes remain grassy, but once a newer foredune develops, cutting off the supply of wind-blown sand from the beach, growth ceases and the grasses are replaced by 'dune scrub' communities, dominated by *Leptospermum laevigatum*, with coast acacia *Acacia longifolia* var. *sophore*, and the coastal banksia *Banksia integrifolia*, common. Leaching of sand beneath the dune scrub extends typically to depths of up to a metre, the surface sand having a pH value (of the soil solution) of 5.5 to 6.5, compared with about 8.0 for fresh yellow dune sand, no shelly material remaining in the upper layers. On older beach ridges and dunes the scrub gives place to 'dune woodland', with eucalypt trees (notably *Eucalyptus viminalis, E. botryoides,* and *E. nitida*), and an undergrowth of bracken (*Pteridium esculentum*). Here the depth of leaching may attain 3 metres, the grey leached zone being underlain by a layer stained brown by the accumulation of organic matter and iron oxides, but not yet with the consistency of coffee-rock. Surface sand has pH values of 5.0 to 6.5, and acidity increases the coastal banksia gives place to the saw banksia, *Banksia serrata*. On the oldest communities of heath shrubs such as *Epacris impressa, Hibbertia acicularis, Astroloma humifusm, Amperea xiphoclada,* and the local species of heath myrtle, *Thryptomene micrantha,* which is abundant on Sperm Whale Head. This vegetation community could be described as 'heath woodland', but locally the heath is almost treeless. The sand is deeply leached and strongly acid (pH less than 4.0 at the surface), and there is generally a firm coffee-rock horizon at depth.

If attention is confined to beach ridges and dunes that lie parallel to the Ninety Mile Beach, this succession is recognisable on the East Gippsland barriers. The outer barrier bears a series of up to 13 high (6 – 10 metres above sea level) and closely-spaced (20 – 50 metres between ridge crests) parallel dunes, those on the seaward side bearing grasses and dune scrub, while those on the landward side bear dune woodland, with sand leached to a depth of several feet. At Sperm Whale Head the inner barrier includes a series of low (2 – 5 metres above calm-weather lake level), widely-spaced (100 – 150 metres) beach ridges and subdued dunes, bearing woodland and heath vegetation, with deep leaching and advanced development of ground-water podzol profiles. On Banksia Peninsula, part of the prior barrier, the parallel ridges have similar spacing and dimensions to those on Sperm Whale Head, and again there is woodland and heath on deeply podzolised sand terrain. It is inferred from this evidence that these sections of the inner and prior barriers are considerably older than any part of the outer barrier.

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 most clearly seen in the blowouts which have formed in the foredunes behind the Ninety Mile Beach, where the wind is excavating hollows on the seaward margin of dunes cur back as a unvegetated cliff of crumbling sand as the result of marine erosion (Plate 9P. blowouts of this type may become enlarged as parabolic dunes, with advancing noses of spilling sand and trailing arms held in place by a sparse cover of vegetation. Subsequently, parabolic dunes may become stabilised by vegetation. On Sperm Whale Head (Figure 21) they bear dune scrub and show less advanced podzol development than adjacent undisturbed parallel dunes under woodland and heath vegetation indicating that the parabolic dunes here are considerably younger than the parallel ridges. Active blowouts on the outer barrier are locally spilling over into the lagoon (Bunga Arm; Cunninghame Arm) to the rear. They have migrated in a direction determined by the wind resultant, their axes (bisecting the angle between the trailing arms) lying parallel to a resultant determined graphically when vector lines are shown from each direction. The wind-resultant for the Gippsland Lakes district (268º) is shown in Figure 5. As Jennings (1957) showed, the orientation of coastal parabolic dunes is related to the resultant of <u>onshore</u> winds, derived from this total resultant by taking into account of shoreline orientation. On the Ninety Mile Beach there is a progressive change in the direction

of blowout axes in relation to the variations in the onshore wind resultant as the orientation of the curving shoreline changes (Figure 22). On Sperm Whale Head, the parabolic dunes migrated eastwards in relation to the onshore wind resultant for the southern shore of Lake Victoria (Figure 21).

Blowouts and parabolic dunes may be initiated in various ways, where the vegetation cover which held parallel dunes in place is damaged or destroyed. Locally repeated burning, over-grazing, excessive trampling by animals, and other forms of direct and indirect human interference have led to the formation of blowouts, but the majority of blowouts and parabolic dunes on the East Gippsland barriers were initiated marginally by fluvial or marine erosion; a phase of aridity, by weakening the vegetation cover, could lead to mobilisation of dunes, but this does not explain the partial rearrangement seen on these barriers. The foredunes on the outer barrier have been modified by blowout development following accentuated marine erosion on the Ninety mile Beach in recent decades. As these develop (Figure 23) they are obliterating the parallel pattern, but this is evidently unprecedented, for the older parallel ridges show no sign of earlier modification from the seaward side in this way. On the inner barrier the development of blowouts was initiated by erosion of the inner margin, now the shoreline of Lake Victoria and Lake King. The blowouts grew into large parabolic dunes, but these were arrested and fixed in position by the revival of a vegetation cover when the phase of rearrangement came to an end.

The prior barrier

The prior barrier is traceable from the northern side of Lake Wellington, eastwards to Banksia Peninsula and Raymond Island, with the relic of a possible continuation at Tambo Bluff, west of Metung. It formed originally in front of the cliffed coast (now the marginal bluff) behind the East Gippsland embayment, and its probable configuration at this early stage is shown in Figure 25A, with Toms Creek flowing into a lagoon behind its western half, and the outlet from Forge Creek (Newlands Backwater) deflected north-eastwards through what is now McMillan Strait, at Paynesville, to open into the northern part of Lake King. This reconstruction is based on the pattern of beach ridges which form the ground-plan of the now dissected prior barrier; low (up to 6 metres), widely-spaced (100 – 150 metres) ridges with subdued topography and a slight seaward fall (Figure 19). The highest ridge, on the landward side, is a foredune surmounting a beach ridge of sand and shingle. As the intervening swales are about 2 metres above the calm-weather level of Lake Victoria, it is deduced that sea level at the time of ridges and swales ran parallel to a smoothly-curved shoreline, shaped by refracted ocean swell during a phase or progradation, but the configuration of the barrier has been much modified by subsequent dissection, a side strait having been cut south of Paynesville, separating Raymond Island from Banksia Peninsula, while broad embayments intersect the northern shore of Lake Victoria. In addition, there are outgrowths of more recent origin, in the form of recurved spits and cuspate forelands, the largest of which had grown southwards to separate Lake Wellington from Lake Victoria, leaving only the channel of McLennan Strait as a connection. Widening of this spit by progradation on the eastern shore of Lake Wellington has yielded a series of parallel ridges, across which can be traced a sequence of leached soil profiles, deepening inland as grasses and shrubs give place to scrub and woodland in a succession indicating increasing age (cf. Figure 20) On the northern shore of Lake Victoria there are several cuspate forelands (e.g. Storm Point, Waddy Point, Wattle Point, Point Turner on Banksia Peninsula, and Point Scott on Raymond Island) still being enlarged by the addition of successive beach ridges of sand and shingle on their eastern flanks (Plate 10), with ridge crests up to 0.5 metres above calm-weather lake level. The beach material arriving on these points has been derived largely from erosion of the intervening embaymnets.

It is thus necessary to make a distinction between the prior barriers as it originally formed, on a coast exposed to ocean waves in Pleistocene times (Figure 25A), and the existing depositional terrain north of Lake Victoria, which has been developed by the dissection and re-shaping of the original barrier, both during low sea level phases (cf. Figure 25C), when streams incised it, and after the formation of the inner barrier when its southern margins became subject to re-shaping by lagoon waves and currents along the shore of Lake Victoria. Moreover, the surface features of the original prior barrier have been modified by the development of parabolic dunes, notably on McLennan Isthmus (the low-lying land between

Lake Wellington and Lake Victoria) and in the country to the west of Waddy Point. Swales between the trailing arms of these parabolic dunes are occupied by lagoons and swamps. On Waddy Point the three east-west ridges, separated by such lagoons, are the arms of parabolic dunes: the noses have been removed by subsequent erosion on the lake shore.

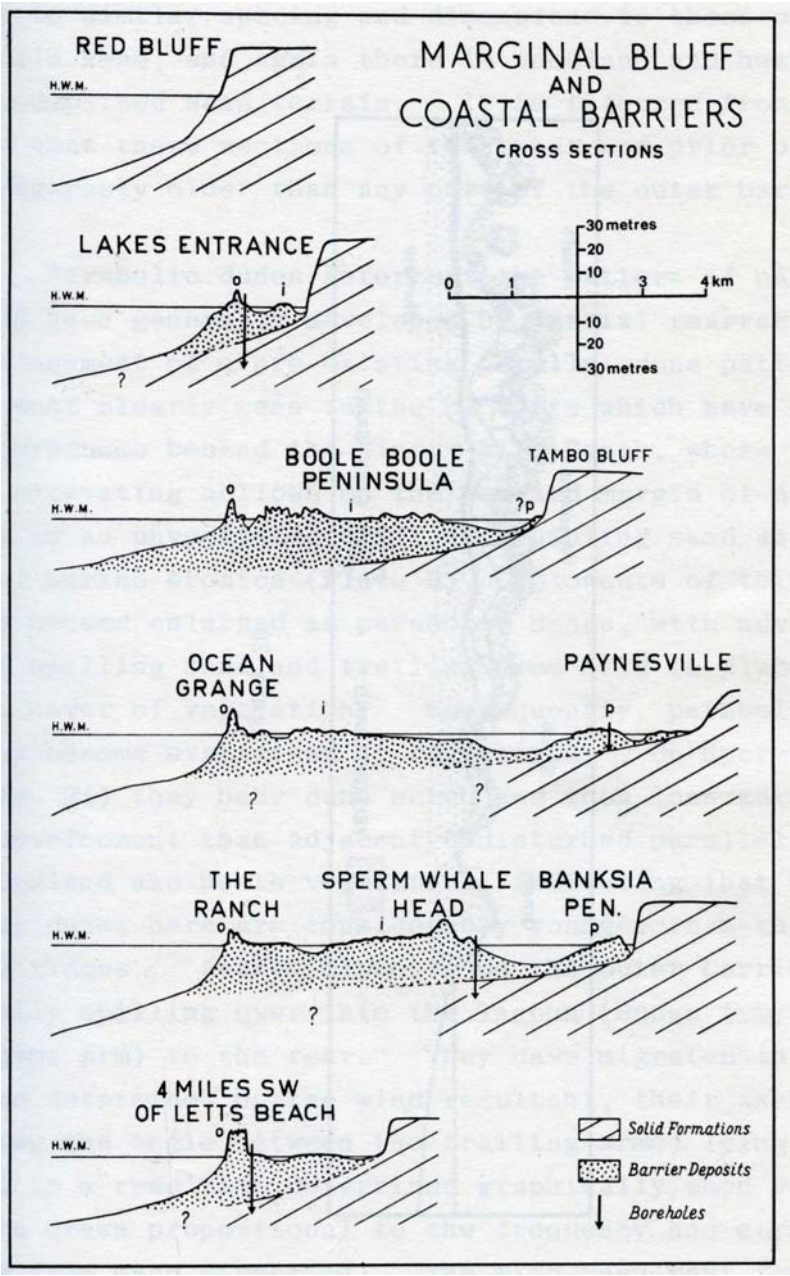

Figure 19

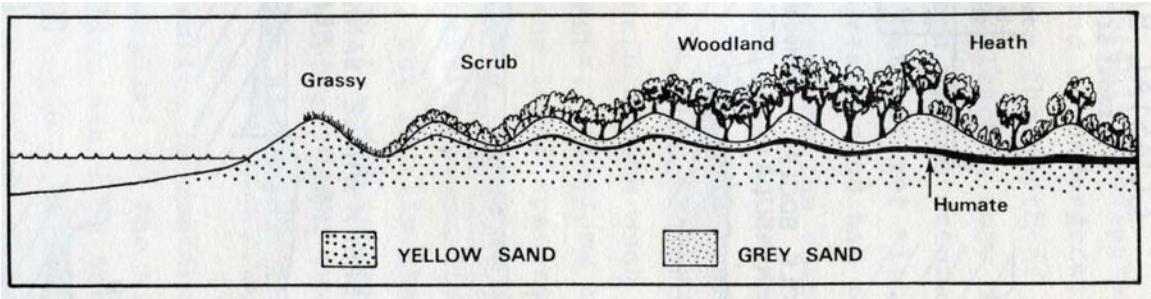

Figure 20

It is thus difficult to delineate the area that was occupied by the prior barrier when it first formed. Surviving fragments of the original prior barrier are those which retain a ground pattern of ridges built parallel to an ocean shoreline: they are found within Banksia Peninsula and Raymond Island. Typically, such relict areas have heath vegetation on podzolic soil profiles, with illuvial sandrock beneath a deeply leached layer, indicative of the prolonged phase of pedogenic weathering since late Pleistocene times. Locally the illuvial sandrock has been exposed by later erosion, as on the southern and eastern shores of Raymond Island, and in the deposits exposed in low cliffs along the shore east from Tambo Bluff, and it is deduced that the prior barrier was formerly more extensive in these areas.

There is no doubt that in late Pleistocene times, when sea level was lower and climatic conditions cooler, more vigorous runoff brought large quantities of fluvial gravel down to the coast. When the prior barrier originally formed, these fluvial deposits, including gravels, evidently occupied the nearshore zone, and were re-worked by wave action as the barrier developed.

Cliff sections at Tannin Point and Toms Point, on the north shore of Lake Victoria, show stratified deposits by dune sands with a leached horizon above slightly indurated red-brown illuvial sandrock. The stratified deposits show current bedding, and are evidently of fluvial origin, being relics of a Pleistocene river terrace 3 to 4 metres above present lake level in front of the subdued marginal bluff wast of the mouth of Tom Roberts Creek. The status of this terrace requires further investigation, for it is not clear whether some protective land lay to seaward (an interfluvial ridge or earlier barrier system that has since disappeared) or whether it is part of a coast during a phase of higher sea level in Pleistocene times. Whatever the explanation, it was partly overrun by the sea in the course of the formation of the prior barrier, the rearranged sands of which now cap these cliff sections. Derived gravels have been incorporated into the prior barrier, and are exposed in the low cliff section on the eastern shore of Banksia Peninsula, to the south of James Point.

The inner barrier

The inner barrier is also of composite origin and has had a long and complicated history. The ground plan of sandy beach ridges and dunes at its south-western end, south of Lake Wellington, shows that is originated as a recurved spit, which was prolonged north-eastwards across the mouth of the embayment, and afterwards widened by the addition of successive parallel beach ridges and low foredunes on the seaward side (Figure 1). The parallel ridges are well preserved on Sperm Whale Head (Figure 21), where their altitude, dimensions, and spacing are similar to those of the prior barrier on Banksia Peninsula. The swales are also about 2 metres above the calm-weather level of Lake Victoria, and the dunes show deep podzol profiles with coffee-rock at depth, and a heath woodland vegetation, all suggestive of an age comparable with that of the prior barrier. Cliff sections along the Lake Victoria shoreline at Sperm Whale Head and east of Loch Sport show the well-defined red-brown illuvial coffee-rock formation overlain either by leached sands *in situ*, or by younger dune sands, or both (plate 11).

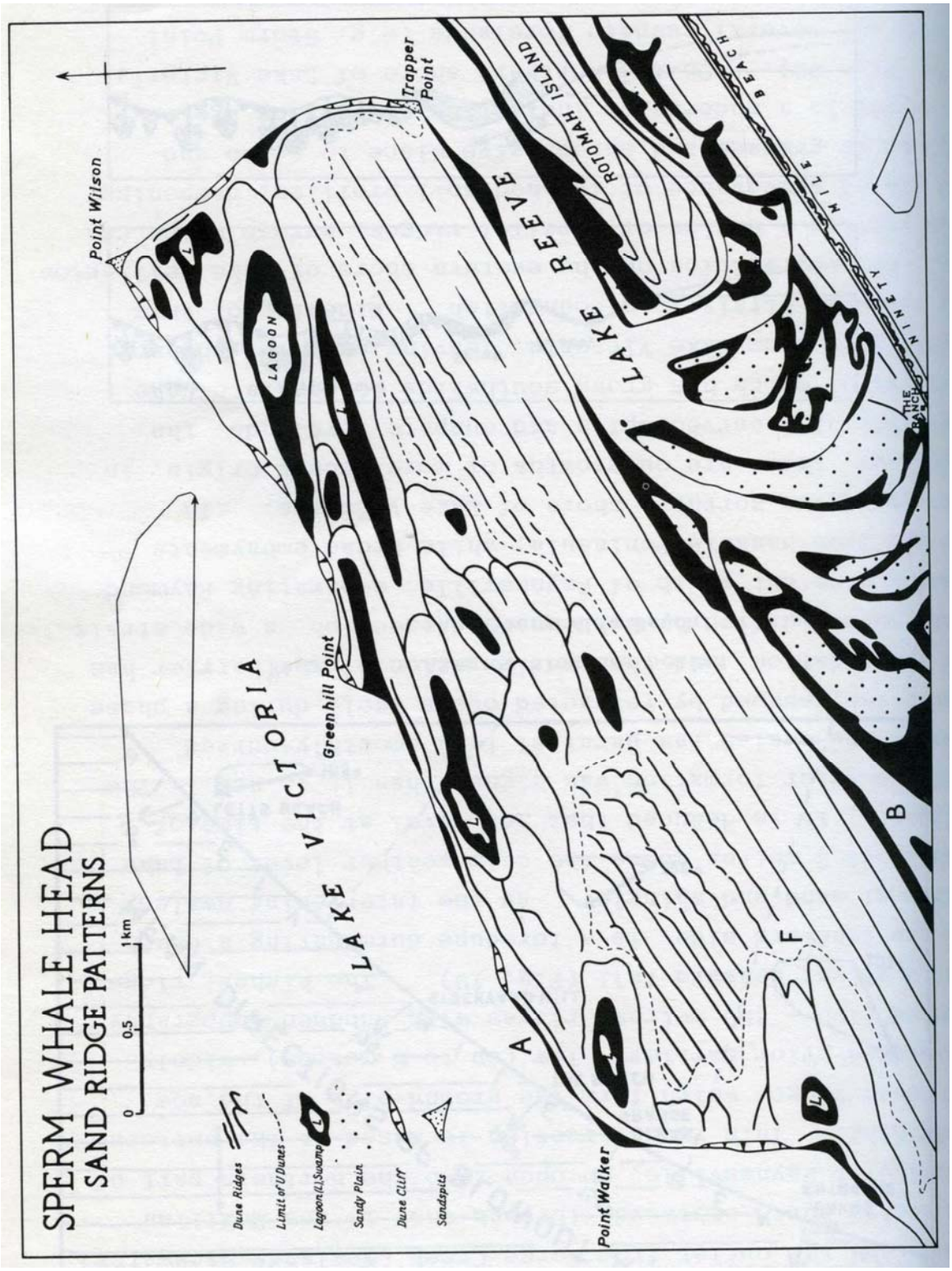
SPERM WHALE HEAD
SAND RIDGE PATTERNS
0
0.5
1 km
Dune Ridges
Limit of U Dunes
Lagoon (L), Swamp
Sandy Plain
Dune Cliff
Sandspits
Point Wilson
Trapper Point
LAGOON
LAKE VICTORIA
Greenhill Point
LAKE REEVE
ROTOMAH ISLAND
BEACH
NINETY MILE
THE RANCH
A
B
D
F
Point Walker

Figure 21

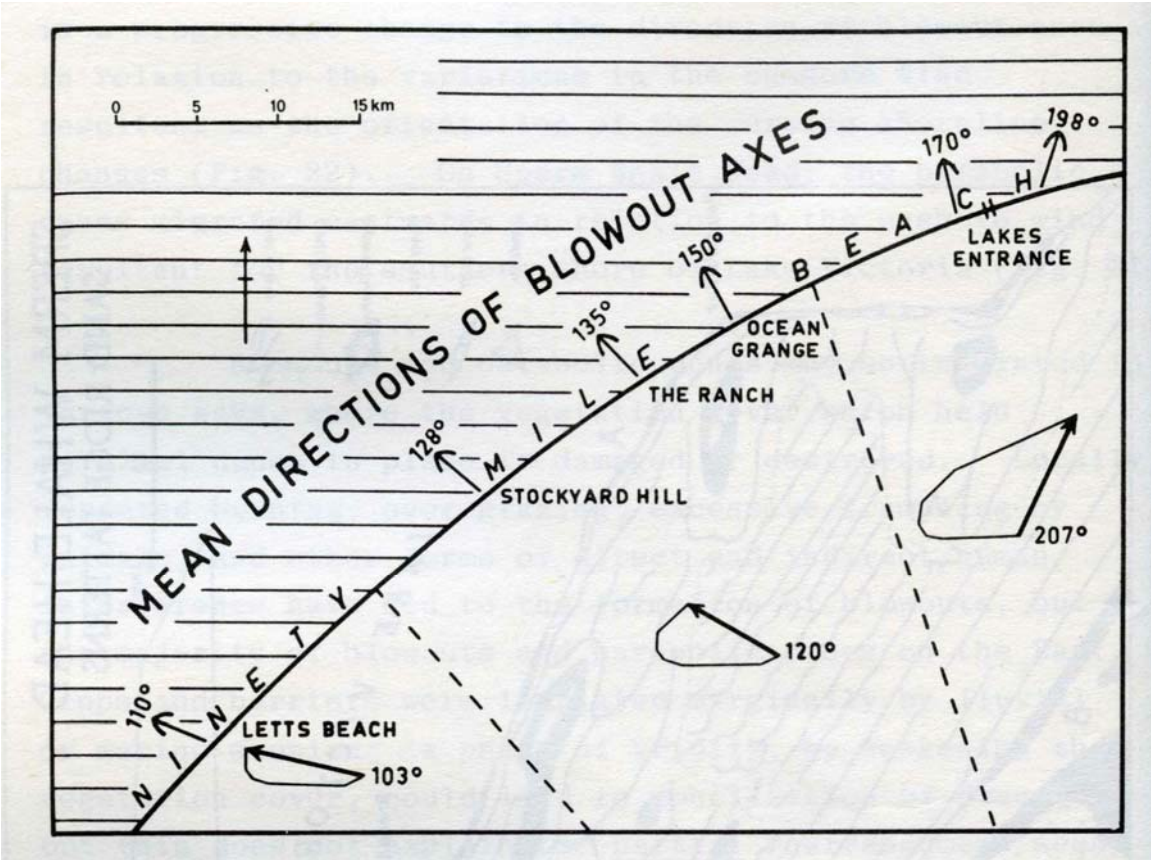

Figure 22 – Axes of blowouts behind the Ninety Mile Beach

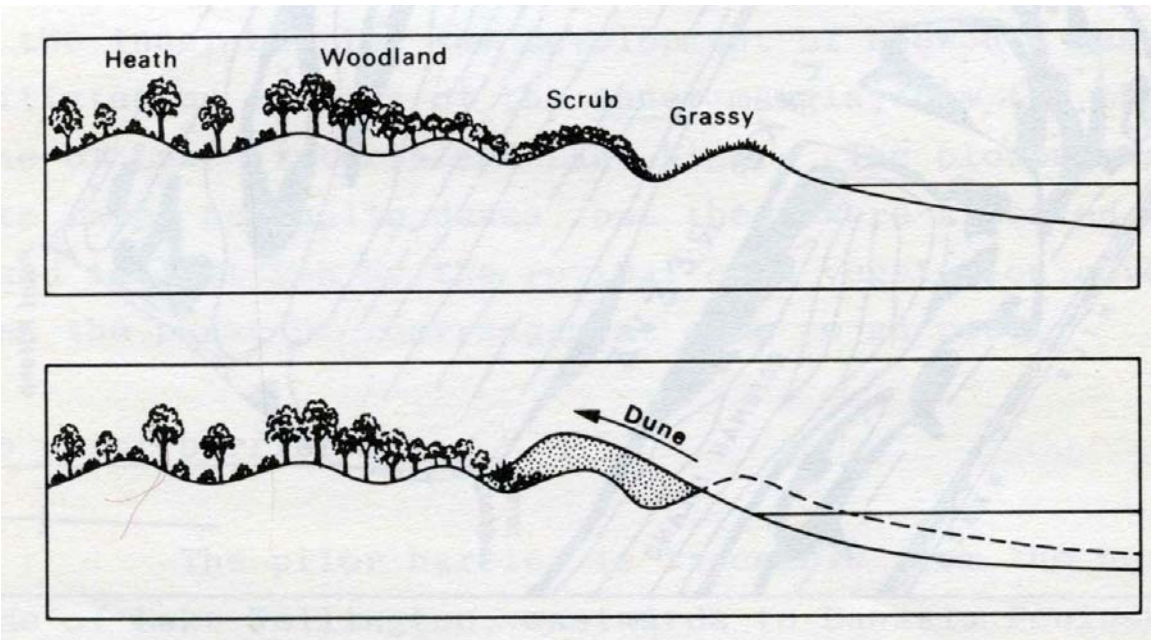

Figure 23 – Morphology and vegetation on a prograding (above and retrograding (below) sandy shoreline

It appears that the recurved spit which was prolonged to form the original inner barrier grew out across the mouth of the embayment soon after the initial deposition of the prior barrier, in such a way as to enclose an intervening lagoon along the present alignment of Lake Victoria (Figure 25B).

As with the prior barrier, there has been considerable modification of the inner barrier since it first formed, and again the extent of the original inner barrier have proved difficult to determine. Jenkin (1968) proposed interpretations of the evidence that differ form those given by the present author (Bird 1965), and published a geological and geomorphological map that has confused an already difficult issue. In attempting to resolve this, a distinction must be made between the age of a geological formation (i.e. the sate at which it was deposited) and the age of a terrain surface (as young, or younger, than the underlying geological formation). The inner barrier at Sperm Whale Head, for example, consists of a wave-deposited formation, mainly of quatrz sand, of late Pleistocene age, which has been partially re-shaped by wind and wave action to produce areas of topography that are younger; in places of Holocene rather than Pleistocene age. As with the prior barrier, remnants of the original barrier surface are those areas with a ground pattern of ridges built parallel to an ocean shoreline, and typically bearing heath vegetation on deeply-leached sand underlain by illuvial sandrock. Such an area persists within Sperm Whale Head: Jenkin (1968) has it mapped as “Recent” (i.e. Holocene), but it is really a Pleistocene beach ridge system developed upon a Pleistocene barrier sand formation. It can be readily distinguished from adjacent areas that have been re-shaped by wind action to form younger (late Pleistocene or early Holocene) dune topography, but there is a problem in drawing a boundary between the Pleistocene terrain and the lower, more subdued sandy terrain that borders it on the southern side, extending through to the northern shore of Lake Reeve (between F and B in Figure 21). The present author believes this subdued sandy terrain to be the emergent nearshore zone, exposed as the sea retreated in late Pleistocene times, and thus only slightly younger than the original inner barrier, but it could be argued that it is of more recent origin, for there has certainly been some re-shaping along the Lake Reeve shoreline. The eastern margin of Sperm Whale Head, between Point Wilson and Trapper Point, has been abruptly truncated (Plate 12), probably during a low sea level phase when the several rivers that drain into the Gippsland Lakes combined to flow out southward through a incised valley immediately east of Sperm Whale Head (see below).

The most significant modification of the inner barrier on Sperm Whale Head has been by wind action. At some stage the parallel beach ridges and dunes have been partly rearranged into a group of parabolic dunes, which have migrated eastwards from embayments that intersect the Lake Victoria shore of this part of the inner barrier. The parabolic dunes, which locally rise to more than 30 metres above sea level, are stabilised beneath a cover of scrub and woodland, and have soil profiles which show leaching to depth of up to 2 metres, underlain by lightly-cemented layers of sand exposed in cliffs on the shore of Lake Victoria. Soil and vegetation features are in sharp contrast with the adjacent low-lying undisturbed ridges, with their deeper podzol profiles and heath vegetation, indicating that the rearrangement into parabolic dunes took place some time after the original formation of the parallel ridges on Sperm Whale Head. The most important evidence, however, comes from the swales between the trailing arms of the parabolic dunes, which are now occupied by swampy flats, close to calm-weather lake level is high. Borings in these swamps (notably in Killarney Swamp, Sperm Whale Head) have shown that swamp deposits, chiefly organic clays and silts, extend to a depth of at least 6 metres, so that the deflated sandy floor of the parabolic dune lies considerably below the present level of Lake Victoria, and well below present sea level. It is concluded that these parabolic dunes formed when the sea stood at a lower level than it does now, before the Holocene marine transgression brought it to its present general level: the wind regime must have been similar, for the axes of these dunes parallel the present-day wind resultant. The swales flooded by this transgression were then filled to calm-weather lake level by the accumulation of swamp deposits, while the parabolic dunes, no longer activated by wind-drifted sand, were colonised be vegetation and stabilised in their present outlines.

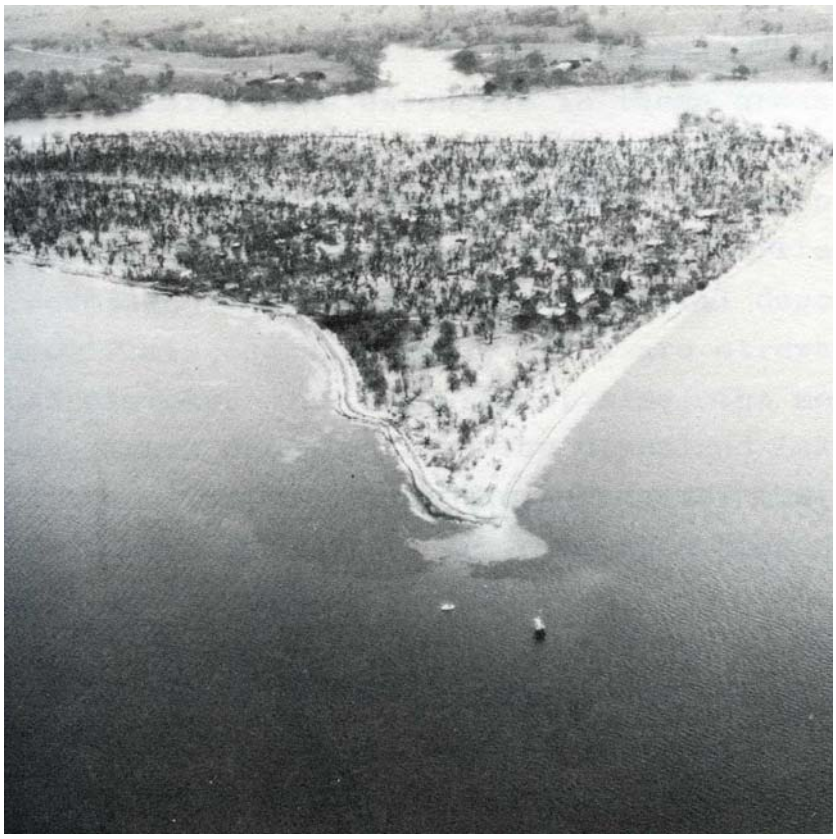

Plate 10 – Point Turner, Banksia Peninsula (N Rosengren)

Plate 11 – Cliffed dune section, Sperm Whale Head (ECF Bird)

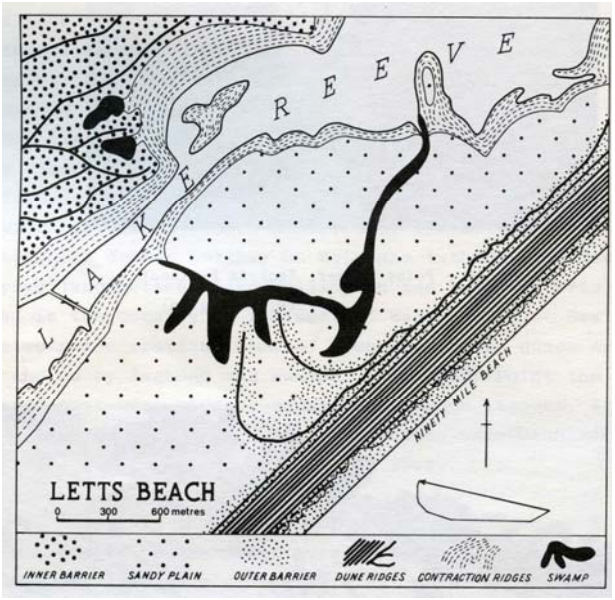

Figure 24

It is deduced that the modification of the inner barrier by dissection and partial rearrangement of parallel beach ridges and dunes into parabolic dunes took place during the “Last Glacial” low sea level phase, late in Pleistocene times. The sea is thought to have fallen below its present level about 75, 000 years ago, and to have oscillated at lower levels until about 20, 000 years ago, when an intermittent rise (the Holocene marine transgression) brought it up to present level, attained about 6, 00 years ago. Thus for about seventy thousand years the basin now occupied by Lake Wellington and Lake Victoria became a furrow, drained by the Latrobe and Avon rivers and such tributaries as Toms Creek and Tom Roberts Creek, which extended their courses and found a barrier east of Sperm Whale Head (Aurora Strait), and thence across the emerged sea floor to the low sea level. At the same time, the prior barrier was breached by the lacustrine ‘low plain’, the emerged floor of a former lagoon (previously enclosed by the prior barrier), and Banksia Peninsula and Raymond Island. Lake King must also have drained away during the low sea level phase, so that the Mitchell, Nicholson and Tambo rivers flowed across its floor, and out through the gap in the inner barrier (Figure 25C). This gap is now occupied by a complex of shoals and channels, and the precise course of the outflow during the low sea level phase is not known, but the presence of coarse gravels under this part of the barrier system at Rotomah Island and north of Ocean Grange is a legacy of Late Pleistocene fluvial deposition when sea level was lower. The parabolic dunes on Sperm Whale Head were evidently formed while meander embayments were being sourced out of the northern flank of the inner barrier by extended Latrobe River, flowing along what is now the floor of Lake Victoria.

The section of the inner barrier east of Sperm Whale Head poses a number of problems. It has been dissected by subsequent denudation, but persists as Boole Boole Peninsula and the chain of islands (Flannagans, Fraser and Rigby islands) which extend eastward to the inner barrier on which the township of Lakes Entrance stands (Figure 15). In addition, the low and widely-spaced ridges on Boole Boole Peninsula pass beneath broad swamps developed at calm-weather lake level, and have therefore subsided in relation to their equivalents on Sperm Whale Head. The low and widely-spaced Parallel ridges on the Boole Boole Peninsula are similar in form to those on Sperm Whale Head, but the intervening swales pass below calm-weather lake level, compared with an elevation of 2 – 5 metres on Sperm Whale Head. The swales are occupied by tracts of swamp land, which widen and coalesce eastwards as the parallel ridges vanish beneath the extensive swamp south of Metung. Borings have shown that they continue, parallel and widely-spaced, underneath the swamp deposits. It appears that this section of the original inner barrier has subsided in relation to Sperm Whale Head, either because of transverse tectonic tilting in the coastal region, or

because of local subsidence, due to the compaction of underlying compressible peats, interbedded at depth beneath Boole Boole Peninsula.

The southern part of the Boole Boole Peninsula consists of a series of high (6 – 10 metres) and closely-spaced (20 – 50 metres) parallel dunes, with woodland vegetation on soils that have been leached to depths of 2 – 3 metres without development of true coffee-rock. These dunes are clearly much younger than the ridges on Sperm Whale Head, or those on the northern part of Boole Boole Peninsula; they correspond in general morphology, degree of soil development, and stage in vegetation succession with the high and closely-spaced parallel foredunes of the outer barrier, as seen as Letts Beach (Below). Although geographically part of the inner barrier, they are of Holocene origin, having been guilt on the subsided southern part of the Boole Boole Peninsula (Figure 25D) during and since the Holocene marine transgression. They extend westwards to Jubilee Head, a complex recurved spit, which flanks a 'tidal delta' of shoals, low islands, and channels marking a former entrance from the sea to the lakes. The later growth of the outer barrier proper outflanked this tract of Holocene foredunes, leaving the southern margin of Boole Boole Peninsula with an extremely fresh appearance; it was clearly a beach, open to the sea, until the outer barrier developed in front of it.

The outer barrier

The outer barrier is surmounted by a series of high (6 – 10 metres) and closely-spaced (20 – 50 metres) parallel dunes, the number of these diminishing north-eastwards from 13 at Letts Beach to two at Ocean Grange and in the Lakes Entrance district. At Letts Beach (Figure 24) the vegetation on parallel dunes shows the early stages from grasses on the unleached sand of newly-built foredunes to scrub and woodland on the moderately leached sand of the inner ridges. Depth of leaching increases from dune crest to dun crest on transects across the outer barrier 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 2 metres and is underlain by sand stained reddish-brown, but without the coherence of true coffee-rock. The absence of heath vegetation and the rarity of the saw banksia (*B. serrata*) on the parallel relative youth. They are evidently of Holocene origin, overlapping in age with the closely-spaced parallel dunes described from the inner barrier on the southern part of Boole Boole Peninsula.

The initiation of the outer barrier is not easily explained. It stands in front of a lagoon, alt marsh, and sandflat tract, behind which lies the older shoreline at the southern edge of the inner barrier. At Sperm Whale Head this older shoreline shows no sign of any recent modification by the waves of the open sea, and near Loch Sport the noses of parabolic dunes that spilled over it before vegetation stabilised then persist, undamaged by marine erosion. The outer barrier must therefore have come into existence in this sector in such a way that ocean waves never returned to the older shoreline. The sea level fell, during the 'last Glacial' phase, Sperm Whale Head was left in high and dry as a broad embankment of sand, modified, as has been shown by the cutting of an outflow channel from the extended rivers, and the erosion of its northern flank, leading to parabolic dune development. The southern shore persisted as a broad sandy slope, leading down to the emerged sea floor; and it may be presumed that this emerged sea floor carried a series of sandy barrier formations stranded as the sea fell. During the Holocene marine transgression the rising waves advanced across this sandy slope, and wave action re-worked the barrier deposits, some of which were collected and carried landward. As the transgression came to an end, about 6000 years ago (disregarding minor oscillations of a metre or two above and below present sea level), the sandy deposits began to accumulate within a shallow zone seaward of the Pleistocene inner barrier as the foundations of a Holocene outer barrier that would eventually be built up to enclose an intervening lagoon, Lake Reeve. It is now realised that fragments of an intervening barrier have survived within the Lake Reeve zone', the most notable being Rotomah Island, a barrier island bearing soil profiles indicating a much greater age than those of the outer barrier, here a short distance seaward. These features are analogous to the chain of Pleistocene calcarenite barrier islands within The Coorong, the lagoon that lies behind the Holocene outer barrier in Encounter Bay, on the South Australian coast (Bird 1973). The East Gippsland outer barrier has been built up near, and in some places against,

these surviving relics of late Pleistocene barriers: it represents a phase of sand deposition and shoreline progradation at he culmination of the Holocene marine transgression.

The significance of shoreward movement of sand during the Holocene marine transgression is now widely acknowledged (Schwarts 1973), and is no longer widely to emphasise that the barrier formations of the Gippsland Lakes owe their origin primarily to this process (cf. Bird 1961). The alignment on which the outer barrier began to develop depended on the relative levels of land and sea along the coastline as the Holocene marine transgression came to an end. West of Ocean Grange the deposition seaward of the inner barrier at Sperm Whale Head, but to the east, where the inner barrier had subsided, outer barrier deposition overlapped a part of the inner barrier on Boole Boole Peninsula.

Stages in the evolution of the outer barrier can be deciphered from comparisons of its form between one sector and another. The multiple parallel dunes on the outer barrier at Letts Beach mark a part of the barrier that originated at an early stage as a barrier island. Traced laterally, the inner ridges curve away successively to terminate in Lake Reeve, the lagoon that lies behind this part of the outer barrier, and in this way the number of parallel dunes diminishes north-eastwards, and also south-eastwards, from Letts Beach (Figure 24). It is deduced that as the Holocene marine transgression came to an end a barrier island came into existence offshore in the vicinity of Letts Beach, and that subsequently this has been prograded, and lengthened by prolongation north-eastwards and south-eastwards until the shoreline took up the present alignment of the Ninety Mile Beach. This is doubtless an oversimplification, the present alignment of the outer barrier foreshadowed by submerged bars, and by other barrier islands that have been incorporated in the present barrier. Growth to the north-east is confirmed by the pattern of curved channels which lead from Lake Reeve into the back of the outer barrier west of Rotamah Island (Figure 21), testifying to the former existence of gaps in the barrier, diverted north-eastwards under the influence of a predominant longshore drifting of sand from the south-west, and finally sealed off. The features are similar to those described by Lucke (1943) from the coastal barriers near Barnegat Inlet, New Jersey, where such gaps migrated and closed under the influence of longshore drifting. As the sand-spit grew north-eastwards, tidal currents through the deflected channels pared away the north-eastern side so that barrier islands were gradually destroyed, then replaced by the growing spit as the outlet channels migrated. Continued growth north-eastward eventually outflanked the tidal delta between Rotomah Island and Jubilee Head, Bunga Arm persisting as an outlet channel until it was deflected far to the north-east and finally sealed. Further extension to Red Bluff deflected Cunninghame Arm in the same way (Plate 2), culminating with the intermittent natural outlet that explorers found in 1841 (Figure 25E).

Initiation of the present outer barrier as a barrier island near Letts Beach may have resulted from an exceptional local abundance of coastal sand supply, or it may have been prompted by continued tectonic uplift of the land along the seaward continuation of Deadmans Hill ridge, an anticlinical area of Tertiary rocks in a region known to have suffered Quaternary tectonic deformation (Boutakoff 1955). Uplift may still have been in progress when the Holocene marine transgression can to an end, bringing about offshore deposition in the form of a barrier island, and giving the original barrier its lateral tilt, with Boole Boole Peninsula on an adjacent area of tectonic subsidence. Subsequent growth and progradation of the outer barrier was the outcome of continued delivery of large quantities of sand to the coast, spread along the shore by waves and associated currents, and built into successive beach ridges and surmounting dunes by the action of waves and wind. As has been noted, these depositional processes are no longer effective: in the latest phase of outer barrier evolution, progradation has come to an end (Figure 23).

This interpretation of the late Quaternary sequence of barrier evolution requires eustatic movements of sea level accompanied by transverse tilting in the coastal region. It is not necessary to involve a higher eustatic stand of sea level in Holocene times or general 'Recent emergence' to explain the initiation of the outer barrier, but if the Holocene marine transgression indeed attained a higher level 400 – 6000 years ago, and then dropped back to its present stand, this would have facilitated the development and progradation of the outer barrier. Nevertheless, the widely-reported evidence of Holocene emergence on the

Australian coast could be due to widespread late Quaternary epeirogenic uplift rather than eustatic change of sea level.

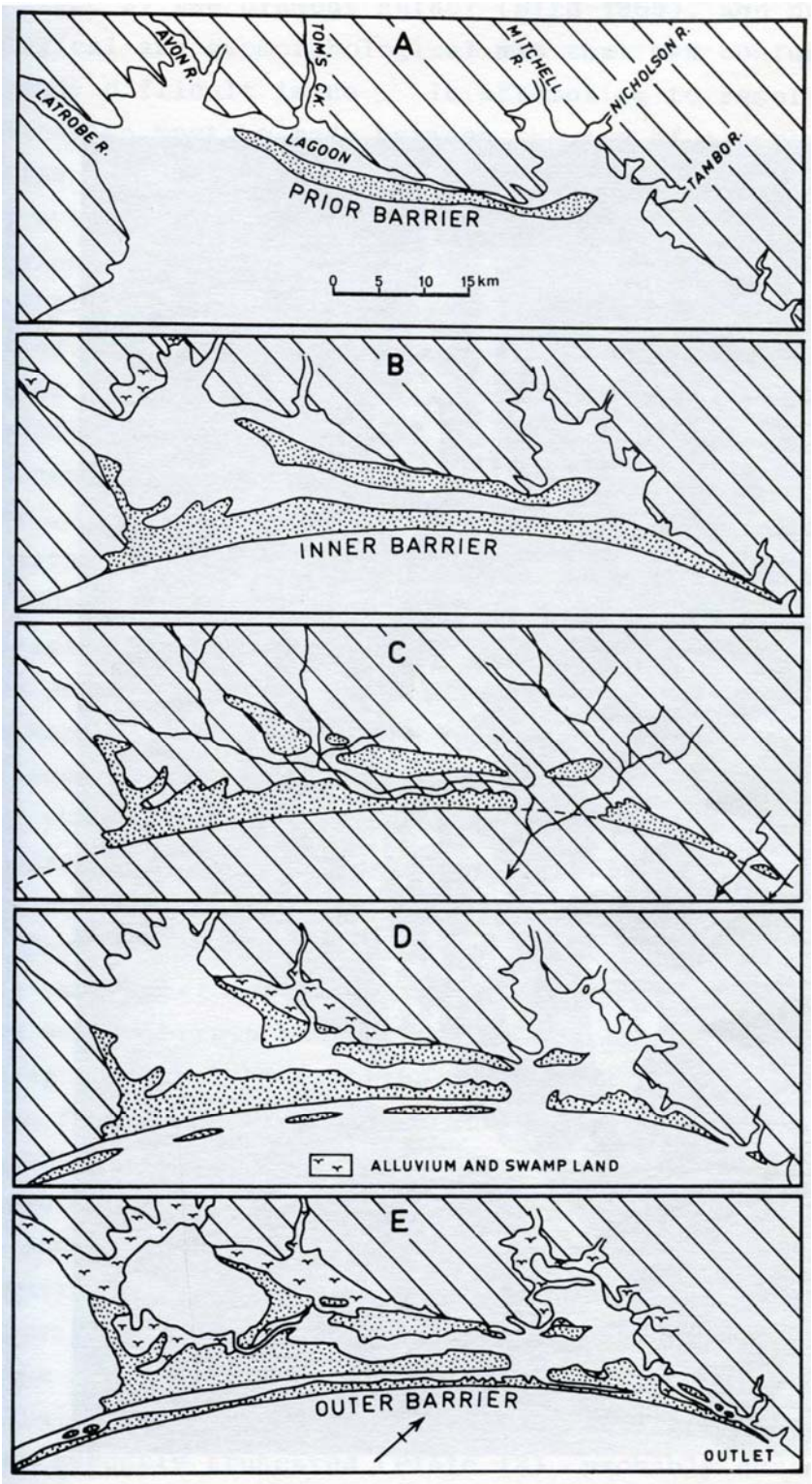

Figure 25 – Stages in evolution of barriers

The age of the barriers has been deduced from geomorphological evidence, taking account of the general chronology of glacio-eustatic sea level oscillations established elsewhere (Fairbridge 1961; Shepard 1961): phase equivalent to the 'Last Glacial' phase, whereas the completion of the inner barrier and the addition of the outer barrier followed the succeeding

(i.e. Holocene) marine transgression. It should be noted that the simple distinction between Pleistocene inner barriers and Holocene outer barriers made by Langford-Smith and Thom (1969) on the New South Wales coast cannot be maintained here, because of the composite form of the inner barrier. The sequence of barrier evolution outlined is based largely on consideration of surface form, weathering profiles, and vegetation features. Intensive coring, backed by radiocarbon dating, is still needed to establish in detail the late Pleistocene and Holocene stratigraphy of this area, and provide a more complete, three-dimensional history of barrier emplacement.

The source of sand

The quantity of sand contained in the coastal barriers is enormous. Addition of a beach ridge 2 metres high and 6 metres wide along the shore of the Ninety Mile Beach would require about 3 million cubic metres of sand, and the total volume of sand in the barriers measures several kilometres. The traditional explanations for the origin of the East Gippsland barriers was that sand had been swept north-eastwards along the coast from the vicinity of Wilson's Promontory by a powerful ocean current (Rawlinson 1863; Howitt 1877; Gregory 1903), following the creation of Bass Strait by the foundering of a 'land bridge' that formerly linked Tasmania to the mainland (Hall 1914), but this hypothesis is not acceptable in terms of modern knowledge of coastal evolution. There is no 'powerful ocean current' off the East Gippsland coast, and the weak tidal currents off the Ninety Mile Beach (Admiralty Charts indicate a 1 knot current north-eastwards as the tide rises and a 1 knot current south-eastwards during the ebb) cannot have brought much sand for barrier construction. To the south-west, where the tide range increases (2.5 metres at the entrance to Port Albert), tidal currents are stronger, but their effects are disruptive rather than constructive: they maintain the channel through tidal inlets that interrupt the barriers east of Corner Inlet.

Sand is moved to and fro along the Ninety Mile Beach by waves and associated (wave-induce) currents in the nearshore zone when waves arrive at an angle to the shoreline. As south-westerly winds are prevalent the dominant direction of sediment flow is north-eastwards. There is little evidence, however, to justify the idea that a major source of sand has existed in the Wilson's Promontory district, where the resistant cliffs of granite are eroding very slowly, and cannot have yielded much sand for barrier construction. In any case, the barriers have not grown north-eastwards from Wilson's Promontory. The prior barrier and the inner barrier formed in the East Gippsland embayment, 80 kilometres north-east of the Promontory, and the outer barrier used to terminate at its south-western end in a recurved spit which had clearly grown south-eastwards, towards Wilson's Promontory: in 1961 it was breached from the inner side by a meandering tidal channel at McLaughlins Beach The hypotheses that barrier formation was linked with the creation of Bass Strait is ruled out by the evidence that Bass Strait has been in existence, intermittently, since late Tertiary times, during the rise and fall of Pleistocene eustatic oscillations of sea level (Jennings 1959b), and was finally revived by the Holocene marine transgression; it was already in existence when the sea rose towards the East Gippsland coast, building up the outer barrier during the later stages of that transgression. More generally, there seems no need to link the formation of the East Gippsland barriers on the New South Wales coast, and in Encounter Bay on the South Australian coast, which bear no relation to the formation of straits, or to any such changes in the adjacent configuration of the coast (Bird 1973).

Longshore drifting has played a part in the growth and shaping of the East Gippsland barriers, but the bulk of the sand has been eroded or collected from the sea floor and carried shorewards during marine transgressions. This is clearest by sand accretion even after it had been built up in front of the cliffed coasts and river mouths which might otherwise be regarded as possible sources of sand for barrier construction. The sand evidently came from deposits that were laid down previously as barriers or dunes on the emerged sea floor when the sea withdrew to low levels during Glacial phases on the Pleistocene periods. There is now little evidence of these depositional forms, the sea floor off the Ninety Mile Beach having been smoothed over by wave action during the marine transgressions, but Jennings (1959b) has identified and mapped submarine ridges off the coast of Flinders Island which could be relics of submerged barrier or dune formations that have survived destruction by wave action during the Holocene marine transgression.

The long, low ocean swell, moving towards the East Gippsland coast, continued to carry sea floor sand shoreward even after the Holocene marine transgression came to an end. Such waves 'feel bottom' at depths equivalent to their wave length (i.e. about 200 metres), and as they advance into shallower water their effects on the sea floor become stronger, sand being disturbed as the wave crests pass over the water surface. Laboratory studies of wave motion have shown that a shoreward current develops across the sea floor in these conditions (Bagnold 1947) and it has been suggested that this leads to a shoreward drifting of sea floor sediment (Grant 1943; Van Straaten 1959, 1961). Some such mechanism seem necessary to explain the progradation of the outer barrier on the East Gippsland coast and the addition of successive parallel ridges in Holocene times. Sand carried into nearshore waters becomes available for transportation by breaking waves and associated currents, and would then be carried on to the beach or along the shore. Such shoreward transportation would continue until the sea floor was swept clear of sand, or until the transverse profile attained an equilibrium with the prevailing wave regime.

The more recent onset of erosion on the Ninety Mile Beach indicates a reduction in sand supply, either because of increased storm incidence (which cannot be proved, as climatic records are too brief to establish earlier norms), or because of a slight rise of sea level, or because of a decline in the availability of sand supply from the sea floor (Bird 1976b). Stormier conditions would prevent the depositions of persistent beach and dune forms; deepening of the nearshore water by sea level rise would allow larger, more erosive waves to attack the shore; and a reduction in sand supply would lead to decrease in beach volume as sand was blown landward into dunes or carried away by longshore drifting. Any of these changes could have brought to an end the earlier progradation of the Ninety Mile Beach. The onset of erosion requires a relatively sudden diminution in sand supply, for a gradual reduction would have been recorded in diminishing size of parallel dunes and beach ridges on the prograded outer barrier; and this is not the case (Figure 19).

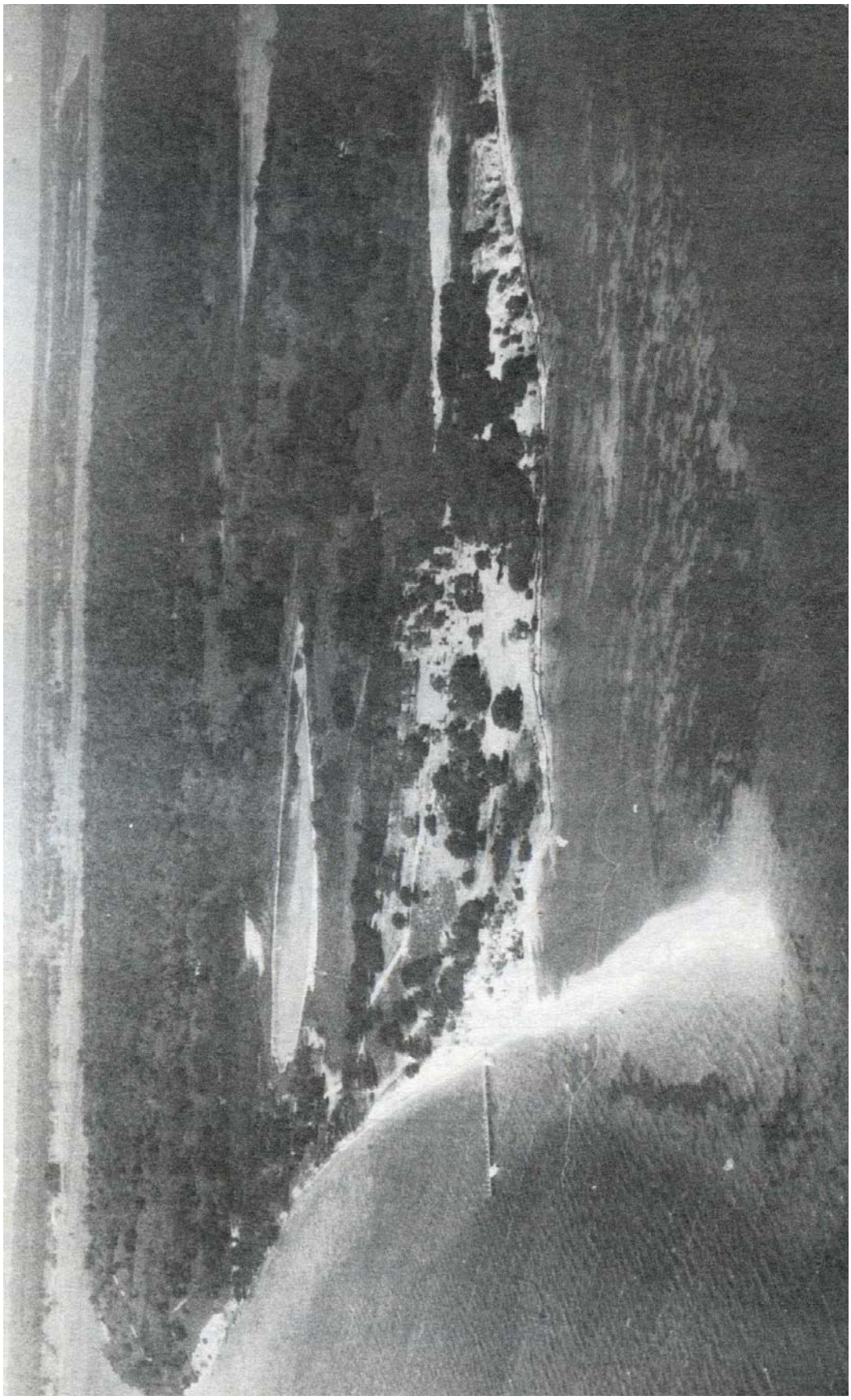

Plate 12 – The eastern shore at Sperm Whale Head (left) and the spit at Point Wilson (N Rosengren)