Changes on the Coastline of Port Phillip Bay

Eric Bird
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Introduction

The coastline of Port Phillip Bay is about 260 km long, extending from the headland at Point Lonsdale around to the similar headland at Point Nepean (Bird 1993, 2010). The two headlands border the entrance to Port Phillip Bay, which is just over 3 km wide at high spring tides. The Port Phillip Bay coastline attained roughly its present shape about 6,000 years ago, when the sea rose to its present level (with a brief interval when it was a metre or two higher: (Hills 1940), having been much lower for prolonged periods during the Pleistocene Ice Age. The bay had existed during earlier periods of relatively high sea level, and had become constricted by the deposition of large quantities of sand, forming the dunes of the Nepean Peninsula, the ridges of the Point Lonsdale foreland and the extensive shoals of the Great Sands in the southern part of the Bay. Between 18,000 and 6,000 years ago sea level rose (largely as a result of the partial melting of the world’s glaciers and ice sheets), and flooded back into Port Phillip Bay, submerging the Great Sands, invading the valleys of the Yarra and other inflowing rivers, and establishing a coastline. This was actually close to an older coastline, dating from a Pleistocene phase (between 80,000 and 120,000 years ago) when sea level stood close to its present level: it is thought that the cliffs on hard granodiorite at Mount Martha were originally shaped during this earlier period (they have changed very little by weathering and erosion during the Holocene), and that the sand ridge along Wells Road, behind Seaford, may also have formed then. Nevertheless, the features of the present coastline are almost entirely the work of processes effective during the past 6,000 years (Bird 2010a).

The coastline that formed 6,000 years ago included cliffs where the sea came against high ground, as on parts of the north-east, east and south-east of the bay and around the Bellarine Peninsula. Beaches were deposited in the intervening low-lying sectors, and consisted of sand (and local gravel) derived from cliff erosion or swept in from the sea floor: the Yarra and other inflowing rivers carry mainly silt and clay, with only small quantities of sand, and have contributed little to beaches, except locally, as at the mouth of Werribee River. Some beaches were built forward (prograded) by the deposition of successive parallel beach or dune ridges, as on the shores between Mordialloc and Frankston and from Safety Beach to Sorrento on the south-east coast. Much of this sandy deposition occurred as sea level, having been a metre or two higher, dropped back, probably about 4,000 years ago. Waves then moved sand in from the sea floor to widen beaches, while cliffs that were no longer reached by wave action became degraded to sloping, vegetated bluffs, as on the Sandringham coast and at Ricketts Point. As indicated (see page 37), there are also sloping vegetated bluffs that are artificial, having been landscaped behind sea walls built to halt coastline recession, as on the coast south from Black Rock.
Changes on the Coastline of Port Phillip Bay

Introduction

There is little evidence of the nature and form of the coastline when the first European settlers arrived in 1835\(^1\), but it can be deduced that changes had proceeded, notably the recession of cliffs cut in soft sedimentary rocks. Beaches that are backed by parallel beach or dune ridges had clearly advanced seaward (prograded) intermittently, each ridge marking a former coastline, but generally this advance seems to have halted by the time European settlers arrived, except locally, as on the ends of growing spits (such as Swan Island). After 1835 changes proceeded, with increasing modifications by the early settlers, particularly around the Yarra mouth and at the head of the bay.

Evidence of coastline changes can be obtained from cartographic surveys, air and satellite imagery, ground photographs and historical descriptions. Early accounts and charts provided by Matthew Flinders in 1802 and the 1803 survey by Charles Robbins, Charles Grimes and James Fleming (Perry 1985) are not sufficiently accurate to be used to identify the pattern and extent of subsequent coastline changes. More accurate maps and charts of the coastline were produced, for example by Henry Cox between 1861 and 1864, as well as the geologists A.R.C Selwyn and J.B. Jukes, but it is often difficult to decide precisely what was mapped as the coastline. This could be the crest or foot of a cliff, the seaward limit of vegetated land, the upper or lower limit of a beach, or the high tide, mid-tide or low tide line. In the 1930s the Australian Survey Corps produced a series of one-inch-to-the-mile topographic maps, six of which covered the coastline of Port Phillip Bay but the small scale of these maps makes it difficult to detect and measure subsequent changes on the coastline.

The Foreshore Erosion Board was appointed by the Victorian Government on 9 May 1935, and consisted of A.D. Mackenzie, D.J. McClelland and A.E. Aughtie, three civil engineers. For many years there had been persistent agitation by bayside municipalities for action to be taken to protect the foreshores of Port Phillip Bay against erosion. During 1923 Mackenzie had made a detailed study of the coast between Sandringham and Mordialloc. His report emphasised the hazard of masses of earth falling from seriously undermined cliffs, the reduction in area of foreshore reserves and recession of the coastline towards the coastal highway. About 15 years previously (ca. 1908) several municipalities had requested foreshore protection works, predicting erosion that had in many places subsequently taken place.

Erosion was classified as (a) serious, requiring urgent attention; (b) taking place to a lesser degree; and (c) slow – for future consideration. The board found that ‘generally, over the sections of the eastern shore of Port Phillip Bay faced by cliffs, where erosion is active, the recession of the shore line is about one foot per annum’, a figure based on a comparison of J.B. Mason’s chart of Beaumaris Bay (1899) with the 1936 coastline, which showed that there had been average recession of the coastline between Charman Road and Antibes Street, Mentone, by 50 feet (15.24 m) in 47 years. It should be noted that the coastline in this sector consisted of cliffs cut in soft Red Bluff Sand, and that recession would have been much slower on the nearby Black Rock Sandstone cliffs of Beaumaris Bay. The Report of the Foreshore Erosion Board recorded examples of active coastal erosion and attempts at coast protection (which indicate that there had been erosion) by municipalities around Port Phillip Bay, and many of these examples are included in this review. It was clear in the board’s 1936 report that erosion had occurred on many sectors of the bay coastline since the 1860s, but few of the reports included measurements on particular sectors.

More reliable indications of coastline change can be obtained from air photographs (dating from 1931 for some parts of Port Phillip Bay, later in the 1930s for others). There have been many local surveys, supplemented by ground and air photographs and more recently satellite imagery, and it is possible to demonstrate changes that have occurred on selected parts of the coastline since the 1890s. Such changes are partly the direct or indirect consequences of human activities (notably the building of shore structures such as breakwaters, harbours, sea walls and groynes) and partly natural (in that they would have proceeded in the absence of such activities): it can be difficult to separate the two, but shore structures on the beaches bordering Port Phillip Bay have certainly had major impacts on the coastline.

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\(^1\) The coastal region had long been occupied by Aboriginal tribes. There was an early European settlement at Sullivans Bay, Sorrento, in 1803-4, but 1835 marks the beginning of permanent European settlement with the establishment of Melbourne.
The Report of the Foreshore Erosion Board (1936) included a brief description of processes thought to cause coastline erosion. These included wave action, wind action, denudation of foreshore vegetation, land drainage, removal of material from the foreshore and settlement (i.e. subsidence or submergence).

Their account of wave action dealt primarily with impacts on sea walls. Attempts to halt coastline recession by dumping brushwood, boulders or rubble, or by constructing timber, stone or concrete walls began in the northern part of Port Phillip Bay in the mid-19th century (notably at Port Melbourne, South Melbourne and St Kilda), and had proceeded sporadically. Many early structures had failed, and there was a trend towards larger and more solid walls that could withstand the impact of storm waves. The Foreshore Erosion Board advocated the building of more extensive sea walls to counter coastline erosion.

The effects of wave action on cliffs were then considered. cliffs were undermined by wave scour and then collapsed, but it was noted that slumping could occur on cliffs that had not been undermined. The role of tides and tidal currents in coastline erosion was emphasised by the Board, particularly in the southern part of the bay, but R.A. Keble stated that ‘the tidal effect in Port Phillip Bay is feeble and the currents inappreciable’.

Wind action was noticeable where backshore vegetation had been removed, and could be countered by planting marram or similar grasses or constructing brush fencing to trap sand. Coastal vegetation impeded erosion and the Foreshore Erosion Board advised that it should be protected and restored.

Vertical erosion on cliffs was caused by runoff, notably where pipes or culverts discharged water over a cliff or where percolation of water down impervious strata led to landslides.

Sand, gravel and rock had been extracted from several beaches for use in building and road making, but this contributes to erosion and the Foreshore Erosion Board recommended that it should stop.

In the same Report (1936) R.A. Keble thought that changes in land or sea level were not important causes of coastal erosion around Port Phillip Bay because there was no evidence of recent changes affecting alignments and levels of roads, footpaths, railways, building structures and particularly drainage and sewer levels.

The following sections summarise present ideas on tides, waves, storm surges and other processes in Port Phillip Bay (Black and Rosenberg 1992, Holdgate et al. 2001, Provis 2007).
Tides

Port Phillip Bay is subject to tidal movements and meteorological systems that generate winds, waves, storm surges, rainfall and runoff, and river flooding. The processes that have shaped the bay coastline have probably been consistent over the 6,000 years since the Holocene sea level rise came to an end, acknowledging that sea level (having been much lower between about 80,000 and 6,000 years ago) was 1–2 m higher before it fell to its present level about 4,000 years ago. There have been frequent storm surges, episodes of river flooding and periods of flat calm.

Tides arrive as very long oceanic waves that pass eastward through Bass Strait and sweep round Tasmania to enter Bass Strait from the south-west. The rising tide comes into Port Phillip Bay through Port Phillip Heads and high tide moves up the bay, over the Great Sands and through tidal channels, then across the deeper central area to reach the head of the bay about three hours later and Geelong after about 3.5 hours (Figure 1). The tide turns at Port Phillip Heads, and water then drains out across the Great Sands and down through the tidal channels. Mean spring tides at the Point Lonsdale tide gauge have a range of 1.6 m, but this is diminished by friction with the sea floor in the southern shallows, and in the upper part of the bay it averages 0.6 m, as recorded on the Williamstown tide gauge. Neap tide ranges at Point Lonsdale are about 1.06 m and at Williamstown about 0.4 m. Maximum tide ranges (between highest and lowest astronomical tides) attain 2.86 m off Port Phillip Heads, 1.24 m at Geelong and 1.0 m at Williamstown.

These tides generate currents, stronger at springs than at neaps, and most powerful through Port Phillip Heads and along the tidal channels. Tidal currents generally have little effect on beaches, but they can deepen nearshore water as tidal channels migrate shoreward, so that waves become stronger, and may erode bordering beaches. The beaches on the northern coast of Point Nepean have been (and are being) depleted because of nearshore deepening (and hence larger waves) rather than the direct effects of tidal scour. Alternatively, tidal currents can deposit sand shoals in the nearshore area, thus reducing incident wave energy and providing a source of sand for shoreward drifting by waves to prograde a beach.

The Foreshore Erosion Board Report (1936) referred to the southern end of Port Phillip Bay being subject to the action of the ‘tidal stream’, which becomes dissipated by the time it reaches the northern end of the bay. ‘This is amply demonstrated by the action of groynes, which are more responsive on the southern section of the bay than on the northern beaches.’ It is not clear what was meant here, but the beaches on the southern coast of Port Phillip Bay have been emplaced and shaped (as well as eroded) by wave action, not tidal currents.

Figure 1. Co-tidal lines show the advance of a high tide into Port Phillip Bay.
Waves on Port Phillip Bay include ocean swell entering through Port Phillip Heads and waves generated by local wind action on the bay (Jones 1988, Provis 2007).

Ocean swell is produced by storms in the Southern Ocean, and enters Bass Strait from the south-west. Typically swell has wave periods (the time for successive wave crests to pass a fixed point) of 12–16 seconds. Swell moves in through the entrance at Port Phillip Heads, particularly during high tides and when it is reinforced by southerly or south-westerly winds. It is soon diminished and shortened by friction with the shallow sea floor, but runs on further in deeper channels. Patterns of ocean swell on air photographs show that it generally passes into Lonsdale Bight, through to the shore at Queenscliff, and occasionally to the SE shore of Swan Island. On the eastern side of the entrance it is refracted round into Nepean Bay to break on the beach south from Observatory Point. When the swell is strong it extends further, to the shores of Swan Island north of Queenscliff and along the coast from Observatory Point to Rye on the eastern side. In calm weather ocean swell produces long period, low waves that are constructive, washing sand from the sea floor up on to beaches, but strong swell can generate higher and steeper waves that break destructively, withdrawing sand from a beach to the nearshore, particularly in Lonsdale Bay and on the beach south from Observatory Point. These alternations of beach erosion and accretion are known as ‘cut and fill’.

Waves are also generated in Port Phillip Bay by winds blowing over the sea. They move downwind, their dimensions depending on the length of fetch (open water) across which they move: up to 67 km within Port Phillip Bay. Winds from the western quadrant (NW-W-SW) are dominant, but there are also winds from other directions, and there is a contrast between the summer and winter regimes. Bowler (1966) observed that ‘notherlies and north-westerlies are prevalent in autumn, winter and spring, but southerlies and south-westerlies are prevalent in summer’.

Waves generated by onshore winds shape beaches, both in plan and profile, and where they arrive to break at an angle to the shoreline they produce longshore drift (Figure 2). On the east coast of Port Phillip Bay waves arriving from the south-west produce a northward drift, lowering and narrowing beaches at their southern ends and raising and widening them at their northern ends. This is reversed when waves arrive from the north-west, driving beach sand southward. On beaches between Brighton and Rye there is a seasonal alteration of longshore drift: in the summer half-year (November to April) a dominance of southerly and south-westerly winds produces waves from these directions which generate northward drifting (Figure 3), while in the winter half-year (May to October) a dominance of westerly and north-westerly wind and wave action generates southward drifting (Figure 4). The seasonal alternation is well displayed on Black Rock Beach, which is wide at the northern end and narrow at the southern end in late summer and autumn and becomes narrower at the northern end and wider at the southern end by late winter and spring. There are variations in the extent of northward and southward drift from year to year: in the summer of 1999–2000, when southerly winds were exceptionally frequent, the southern half of Black Rock beach almost disappeared, while the northern half became unusually wide. On most of the east coast beaches the seasonal alternation is more or less balanced, but some show a net annual northward drift and others a net annual southward drift. Using heavy minerals as tracers, Baker (1963, 1964) found that there was a net southward drift of sand on the sea floor (as distinct from on beaches) from St Kilda to Ricketts Point and beyond, and that this had formed a submerged lobe of sand south of Table Rock Point.

On the southern coast of Port Phillip Bay, from Rye to Point Nepean the seasonal alternation on beaches with a northerly aspect is weaker than on the east coast of the bay because southerly wind and wave action is excluded. Shelly Beach at Portsea shows...
eastward longshore drift in the winter months, when north-west winds tend to predominate, generally exceeding the westward drift during the summer, when there are more winds from the north-east. Eastward drift is predominant along the coast from Point Nepean past Portsea to Sorrento.

On the south-western coast of Port Phillip Bay between Point Lonsdale and the northern point of Swan Island ocean swell and locally generated waves produce a predominant northward drift. This has led to accretion on the southern side of the harbour breakwater at Queenscliff and the growth of spits and migration of sand lobes on the east coast of Swan Island to the north.

On the north-eastern coast of the Bellarine Peninsula wave action from the north-east produces divergent longshore drift on either side of the sector between Indented Head and Grassy Point. There is southward drift past St Leonards, indicated by the southward growth of the spit at Edwards Point, and westward drift past Portarlington, indicated by the growth of a sandy foreland at Point Richards. On the north coast of the Bellarine Peninsula waves from the north-west generate eastward drift, and west of Point Richards this becomes stronger than the westward drift, as indicated by accretion on the western side of the Clifton Springs harbour. The beaches are meagre, however, and the longshore drift has caused only minor changes, with only slight growth of the foreland at Point Richards in recent decades.

On the west coast of Port Phillip Bay, from Point Wilson to Williamstown, wave action is generally weaker than on the east coast, which is exposed to the prevailing south-westerly, westerly and north-westerly winds. Waves from the south produce north-eastward drift, alternating with occasional south-westward drift by waves from the east and north-east. Changes in the form of the spits at the Sand Hummocks indicate variations in longshore drift, and north of Point Cook the predominant longshore drift is northward, resulting in the growth of spits past Skeleton Creek to Laverton.

The outlines of Mud Islands, out on the Great Sands, have been shaped by waves from all directions.

Some beaches, notably between Mordialloc and Frankston and from Dromana to Rye on the east coast of Port Phillip Bay, are backed by a series of parallel beach or dune ridges that formed during intermittent progradation of a sandy coastline when sand was being supplied to the coast, mainly from nearshore sources. The separation of ridges is probably due to erosion during occasional major storms, when the seaward ridge was trimmed back and a new ridge added in front of it during subsequent calmer weather. As has been noted, these parallel ridges are no longer being added to the coastline, which now shows gradual recession, with the formation of backshore cliffs cut into the sand ridges. This is a fairly recent change, because the outer (seaward) sand ridges show little weathering or soil development, and are therefore quite young. The sequence occurs on many sandy coastlines around the world, and indicates the curtailment of sand supply to the shore (Figure 5).

The profiles of bayside beaches vary with ‘cut and fill’ cycles, due to erosion by steep, short period storm
waves which withdraw sand to nearshore sand bars, followed by accretion as gentler, longer waves in calmer periods move sand back on to the beach. These cycles operate on a time scale varying from a few days to several months. However, on the south coast of Port Phillip Bay between Observatory Point and Portsea, and between Sorrento and Rye, some of the sand withdrawn seaward during storms is lost into deep tidal channels that run parallel to the coast and close inshore, and cannot be returned to the beach in calmer periods.

Wave action approaching the shore can be modified and diminished by nearshore topography, including reefs and shore platforms, and also by marine vegetation, notably seagrass beds. Waves can be reflected from rocky shores and sea walls or boulder ramparts: vertical sea walls are strongly reflective, sloping structures less so. Wave energy is partly absorbed by shingle or coarse sand beaches: in the 25–26 April 2009 storm the sea wall at Black Rock, unprotected by a beach, was badly damaged, while the same waves had little impact on the coarse sandy Black Rock Beach, a short distance to the north (Bird 2010b).

Figure 5. Sequential evolution of beaches backed by parallel sand ridges, as on the east coast of Port Phillip Bay between Mordialloc and Frankston and from Dromana to Rye.

A – During the later stages of sea level rise, about 6,000 years ago, sand drifted in from nearshore shallows to form backshore beach and dune ridges.

B – Shoreward drifting continued after the sea level rise came to an end, as long as there were nearshore shoals.

C – As the sea floor sand supply diminished shoreward drifting came to an end and the formation of parallel backshore beach and dune ridges ceased.

D – With continued lowering of the concave sea floor profile, larger waves reached the shore and accretion gave place to erosion. The diagram does not show the nearshore sand bars that persist on these coasts, but the present wave regime does not drift sand shoreward from these, except for small quantities of shelly sediment that are insufficient to offset erosion.
Storm surges

Storms have occurred frequently on Port Phillip Bay, particularly in the winter months, and major storms have produced storm surges, when sea level is temporarily raised by the combined effects of onshore gales and reduced atmospheric pressure, large waves break upon the shore, reaching higher levels than usual. Beach erosion has been severe during storm surges, when sand is withdrawn from the beach to the sea floor. It may be returned during subsequent calmer weather, but this has not always happened, some sectors showing continuing recession. Severe erosion can also occur on cliffs during storm surges.

The largest storm surge recorded was on 30 November–1 December 1934 when sea level in the northern part of Port Phillip Bay rose temporarily about a metre as the result of:

1. the passage of an intense barometric depression from west to east through Bass Strait and Tasmania, the low pressure resulting in a raised sea level;
2. the associated storm, with westerly gales backing south-west then south, producing strong wave action and raising sea level downwind;
3. prolonged heavy rain in Victoria, leading to extensive river flooding, notably in the Yarra River, which discharged a large amount of water into northern Port Phillip Bay.

The outcome of these three factors was an increase in sea level during successive high tides registered at the Williamstown tide gauge of 1.12 m and 1.23 m above the normal calm weather high tide limits. The high tides were the highest on record, and have not been equalled subsequently. However, in the southern part of Port Phillip Bay the storm surge was smaller: at Point Lonsdale the high tides were only about 0.25 m above predicted levels. This was partly because of the large quantities of water delivered by the Yarra River, and partly because westerly and southerly gales and resulting storm waves drove water northward and north-eastward. No doubt sea water from Bass Strait was driven in through Port Phillip Heads, but the comparatively small sea level rise recorded on the Point Lonsdale tide gauge indicates that the southern and western parts of Port Phillip Bay escaped the strongly augmented sea level that occurred in the north and north-east. The westerly and south-westerly gales would nevertheless have generated storm waves on the east and south-east shores, although the relatively shallow water over the Great Sands would have diminished the energy of breaking waves on these shores.

Reports in local newspapers were concerned mainly with damage to coastal and shore structures in the northern part of Port Phillip Bay, on the coast between Williamstown and Frankston, by flooding and the impact of large waves (Figure 6). There were references to sand being swept from beaches to the backshore (across coast roads), which indicates that beaches were eroded, and to masses of rock falling from cliffs, notably at Black Rock. This was ‘a once in 200 years storm’, but lesser storm surges have been recorded every few years, and according to the Report of the Melbourne Harbour Trust (1964) there were three surges in 1934.

Other processes

Rainfall in the catchment of Port Phillip Bay generates runoff and river outflow, producing currents that cause erosion and deposition at and near river mouths and outfall drains. As has been noted, prolonged heavy rainfall generates river floods, mainly on the Yarra River and the discharge of large quantities of water into Port Phillip Bay, raising sea level locally and temporarily.

Runoff from cliff faces has cut rills from which sediment is washed down to the shore. At Black Rock Point, for example, the cutting of rills in the sandstone cliffs produces downwashed fans of sand and silt that are dispersed by wave action during subsequent high tides. Saturation of rock outcrops in coastal cliffs results in seepage of groundwater, which can lead to slumping of rock material on to the shore (Bird 1990a). This is also dispersed by wave action during subsequent high tides. These effects are in addition to erosion caused by waves attacking the cliff base. Sediment derived from cliff erosion by these processes is delivered to adjacent beaches, as at Red Bluff (Sandringham) and Black Rock Point,
Processes in Port Phillip Bay

Changes on the Coastline of Port Phillip Bay

locally in Beaumaris, Mount Eliza, Balcombe Bay, Mount Martha, the dune calcarenite* cliffs from White Cliffs to Point Nepean and near Point Lonsdale, and on parts of the Bellarine Peninsula. Formerly cliffed sectors that have been stabilised by sea walls and landscaped to vegetated coastal slopes are no longer subject to these processes, and no longer yield sediment to beaches.

Shelly material (whole and broken shells and sand produced by comminution of shell gravel) derived from marine organisms that live on the shore, or on the sea floor, has been delivered to beaches on several sectors of the Port Phillip Bay coastline. The beach at Seaford, for example, is receiving shelly material washed onshore (Figure 7). Shelly beaches are also found on the west coast of Port Phillip Bay between Corio Bay and Altona, where the basalt basement decomposes to silt and clay, with only small amounts of grey or black volcanic sand formed by rock disintegration, and sources of quartzose sand are meagre. Shelly sand is deposited on the beach in Hobsons Bay and on the shores of the Bellarine Peninsula, and shelly material is present in the sand washed up from the Great Sands on to the shores of Mud Islands. Apart from shelly sand and gravel there is very little fresh sediment arriving on Port Phillip Bay beaches.

Some beaches contain gravel (pebbles and cobbles) derived from the disintegration of nearby rock outcrops. These include ironstone gravels derived from ferruginous sandstones outcropping in cliffs and rocky shores between Point Ormond and Beaumaris, between Frankston and Balcombe Bay, and on the Bellarine Peninsula; basaltic gravels derived from disintegrating outcrops of Pleistocene lava on the west coast between Corio Bay and Williamstown; and calcrite (limestone) gravels from hard bands in Pleistocene dune calcarenite between Rye and Point Nepean and from Point Lonsdale to Shortland Bluff.

Calcareous sand and gravel dominates beaches in the south-east of Port Phillip Bay, derived from Pleistocene dune calcarenites of the Nepean Peninsula, which outcrop in cliffs between Point Nepean and White Cliffs near Rye. The same is true of beaches in the south-west of Port Phillip Bay, derived from the dune calcarenite outcrops at Point Lonsdale and Shortland Bluff, and from similar sand washed in through Port Phillip Heads. The Great Sands in the southern part of Port Phillip Bay are also predominantly calcareous, related to the dune calcarenites of the Nepean Peninsula, and the sandy ridges encircling Mud Islands are of calcareous sand derived from these shoals. It is not known whether the Great Sands have been a source of sediment on the south coast of Port Phillip.

*Dune calcarenite, also known as aeolianite, is a rock formation consisting of consolidated calcareous sand dunes.

Bay, or whether the calcareous beach and nearshore sand between Sorrento and Dromana has been entirely derived from the Nepean Peninsula. Some calcareous sand may have drifted from the Great Sands on to the east coast, but it is unlikely to have crossed the deep tidal channels in the southern part of the bay. It is possible that South Sand has contributed fine calcareous sediment to the sand bars along the coast between Rye and Rosebud at some stage in the past, but there is little evidence that sand is now drifting across the Sorrento Channel and Capel Sound. There is a contrast between the calcareous sand beaches of the southern shores of Port Phillip Bay and the quartzose and basaltic sands derived from local outcrops on the western and eastern shores.

It will be obvious that the volume of sand in a beach depends on the balance between supply of sand and reduction by weathering and erosion. In recent decades the supply of sand to most of the beaches bordering Port Phillip Bay has been exceeded by reductions due to weathering and erosion. Since 1975 many depleted beaches around Port Phillip Bay have been renourished artificially, using sand brought in from the sea floor or delivered from the hinterland. Figure 8 shows the locations of 30 beach nourishment projects on the shores of Port Phillip Bay between 1975 and 2010. Without such nourishment many of the beaches around Port Phillip Bay would now have been much depleted. A review of beach renourishment projects in 2001 found that ‘the majority of the beaches that have been renourished are in nearly as good a condition as when they were first constructed. Only a few need topping up with sand and only four need to be rebuilt’ (Vantree 2001). The situation is much the same in 2010, except that some further depletion has occurred.
Changing sea level

These processes have been at work with the sea at or close to its present level. There have been minor and temporary changes of sea level during occasional storm surges, and tidal movements are subject to variations related to astronomical conditions (such as the SAROS 18.6 year tidal cycle, which reached peaks in October 1987 and April 2006) and meteorological effects (such as higher sea levels when barometric pressure falls).

It is possible that sea level has risen slightly in Bass Strait during recent decades, and that this rise has been transmitted into Port Phillip Bay.

The National Tidal Centre (2010) reported changes in tides consistent with those predicted for the Channel Deepening project at Port Phillip Heads (2008–2009). These were an increase of about one cm in the height of high tides and a similar lowering of the level of low tides in Port Philip Bay. The centre also reported that analysis of tidal records for the last decade indicates that changes of up to 50 cm in sea level occur naturally from summer to winter months. Changes of up to 30 cm in the average sea level occur from year to year due to climatic variability, such as El Niño–Southern Oscillation (ENSO) events. These variations must be taken into account when drawing conclusions from tidal data.
Recent changes on the Coastline of Port Phillip Bay

Changes on the coastline of Port Phillip Bay are described in a clockwise sequence from Point Lonsdale round to Point Nepean. For much of the bay coast this sequence follows the direction of predominant or net longshore drifting (and thus ‘goes with the flow’, from the features of a source area downdrift towards areas of accretion). The exception is the final sector, between Sorrento and Point Nepean, where the predominant drift is eastward, and it is necessary to explain this before resuming the clockwise (there westward) sequence of coastal sites (see page 46).

Point Lonsdale to Queenscliff harbour

The headland at Point Lonsdale is fringed by receding cliffs cut in Pleistocene dune calcarenite, bordered by a shore platform that is exposed at low tide. The dune calcarenite occupies a triangular low plateau, and there are ridges of the same rock type that are remnants of successive spits that formed in front of a Late Pleistocene coastline, marked by the bluffs that extend from Collendina to behind Swan Bay (Figure 9). One of these runs north of shallow Lake Victoria and resumes after an interruption in the plateau of southern Queenscliff, culminating in the cliff at Shortland Bluff (Gill 1948). Along the southern shore (facing Bass Strait) a sandy beach, exposed to ocean swell and waves generated by south-westerly winds and backed by scrubby dunes, extends east from Ocean Grove to the Point Lonsdale headland, and on the eastern side in Port Phillip Bay is Lonsdale Bay, backed by another sandy beach and scrubby dunes, and exposed to waves (including ocean swell) coming in through Port Phillip Heads.
Recent changes on the Coastline of Port Phillip Bay

Wave action on the beach between Ocean Grove and the Point Lonsdale headland generates a predominant eastward drift of sand along the shore. This passes intermittently (notably when there is strong south-westerly wave action at high tide) round the headland at Point Lonsdale, both along the beach beneath the cliffs and along the sea floor outside the shore platform (Figure 10). Sand then drifts northward, driven by refracted ocean swell and waves generated by south-easterly and southerly winds, past the jetty (built in 1890) and along the shore fronting dune calcarenite cliffs (across planed-off outcrops of dune calcarenite) (Figure 11) and the adjacent sea floor, round on to the beach at and north of Point Lonsdale town.

Photographs held in the Latrobe Library (Figure 12) show that in 1890 Front Beach (facing Lonsdale Bay) at Point Lonsdale town was a broad sandy beach in front of low cliffs of dune sand, but by 1900 this had diminished, and an underlying rock platform was exposed (E.L. Richard, pers. comm. 1980). This change

Figure 9. The Point Lonsdale peninsula, showing the Late Pleistocene coastline and the dune calcarenite ridges truncated on the coast at Point Lonsdale and Shortland Bluff. Holocene sand dunes back Lonsdale Bay and extend from Queenscliff north to Swan Island and Duck Island.

Figure 10. An air oblique view of the Point Lonsdale coast, looking west towards Barwon Heads, taken in September 1973. © Neville Rosengren.
Recent changes on the Coastline of Port Phillip Bay

Figure 11. Sand drifting northward from Point Lonsdale pier over a shore platform of truncated dune calcarenite (November 2010). The sand is sparser here than it was on postcards from the 1950s and in 1973 (compare Figure 10).

was considered by some to be due to intensified shore processes due to the removal of pinnacles to improve navigation in the channel through Port Phillip Heads in 1881 and later works by the Ports and Harbours Branch to form a wider and deeper waterway into Port Phillip Bay. The Foreshore Erosion Board (1936) acknowledged that such changes had occurred, but considered them very minor and unlikely to have affected sea level or marine processes in Port Phillip Bay. However ‘no sound deduction can be made, due to the lack of precise survey data indicating the actual physical characteristics of the area prior to the initiation of operations’. It was more likely that the depletion of Front Beach at Point Lonsdale resulted from the intermittency of sand drift round the Point Lonsdale headland to the south, for there were reports of the beach recovering temporarily during the early years of the 20th century.

Figure 12. Point Lonsdale beach was wide in the 1890s. State Library of Victoria.
Recent changes on the Coastline of Port Phillip Bay

Figure 13. A storm in 1934 washed away Front Beach at Point Lonsdale and exposed the underlying dune calcarenite rock. Foreshore Erosion Board 1936.

Figure 14. Erosion of the dune cliff at Front Beach, Point Lonsdale in a 1934 storm damaged beach huts. Foreshore Erosion Board 1936.

Figure 15. Point Lonsdale beach in March 1936 after the construction of wooden groynes. Beach huts line the backshore cliff, cut in dune sand. Foreshore Erosion Board 1936.
Storms in 1934 stripped Front Beach at Point Lonsdale and exposed underlying outcrops of dune calcarenite rock (Figure 13), as well as cutting back the cliff of dune sand and calcarenite (Figure 14). Six groynes of local rock and timber were inserted in 1935 in an attempt to retain a sandy beach in front of the low cliff at Point Lonsdale (Figure 15), but the Foreshore Erosion Board (1936) found that these failed to retain a wide beach. A masonry sea wall built in 1939–40 halted backshore cliff recession, but the dune-fringed coast to the north was then cut back into cliffs up to 20 feet (6 m) high. There was depletion of the beach in front of the masonry wall because of wave reflection, and although sand continued to drift intermittently round from the Point Lonsdale headland, wave reflection from the sea wall prevented its deposition on the beach, and much of it drifted past northward on the sea floor towards Queenscliff. A 1950 postcard shows a lowered beach between derelict groynes (Figure 16).

Figure 16. Front Beach at Point Lonsdale in 1950. The beach had a low profile, mostly submerged at high tide, and the wooden groynes were derelict. State Library of Victoria.

Construction of a masonry wall between 1939 and 1943 initiated a series of coast protection works (Figure 17). A timber sea wall was added north from the masonry wall in 1947, and this was concreted and armoured with boulders in 1965, but there was increased erosion, forming a dune calcarenite cliff, behind the next sector of beach. This coastline recession continued because larger waves were arriving through the deepened nearshore off Point Lonsdale Front Beach. To counter this erosion a rubble rampart was added northward in 1966, and extended further along the eroding shore to the north in 1977 (Figure 18). Beyond each extension of coast protection works the coastline was set back as a dune cliff by intervening erosional recession (Figure 19). Numerous timber groynes were built along the shore in front of these protective structures, but they proved ineffective in retaining a beach. In 1982 Front...
Beach at Point Lonsdale was still low between wooden groynes, and at high tide there was very little beach in front of the masonry wall (Figure 20). In 1999–2000 the timber groynes were replaced by three large stone structures, alongside which there has been some sand accretion, particularly on their southern sides, where northward-drifting sand accumulated and built up to spill over the groyne and over the backshore sea wall (Figures 21, 22).

Figure 20. Front Beach at Point Lonsdale in 1982 with wooden groynes. At high tide there was very little beach in front of the masonry wall.

Figure 21. Point Lonsdale Front Beach in November 2010, showing the three large stone groynes, alongside which there has been some sand accretion.
Recent changes on the Coastline of Port Phillip Bay

At the northern end of the 1977 boulder rampart a cliff up to seven m high formed in dune sand, and receded (Figure 23). This sloping backshore cliff was planted with vegetation and is now (2010) fairly stable (Figure 24), with no obvious change since the photograph taken in November 1999. As the beach curves eastward the erosion diminishes, the cliff passing into a steep but vegetated backshore slope, occasionally trimmed back at the base (Figure 25). It is possible that the diminished erosion is because sand continues to arrive across the floor of Lonsdale Bay and maintain the beach. There are certainly extensive sand patches on this sea floor, interspersed with planed-off outcrops of dune calcarenite. At the southern end of Swanston Street, Queenscliff, steps descend a dune to the beach, which is backed by a sloping grassy dune, undercut at the base (Figure 26). Coastline recession has been slow here, even though this part of the coast faces the dredged entrance channel through Port Phillip Heads.

The coast north from Shortland Bluff consists of a cliff cut in dune calcarenite and a rocky shore with only a meagre beach. Sand certainly drifts past this sector and on to the wider beach at Queenscliff, where the cliff passes northward into a scrubby bluff, the former coastline behind a depositional lowland. The beach north to the Queenscliff Jetty has been relatively stable, with only a minor bluff at the landward edge of the backshore terrace indicating occasional erosion.

Figure 22. Sand accretion beside the northernmost groyne at Point Lonsdale has built a high, wide beach, but there is little sand in front of the masonry sea wall to the north.

Figure 23. Dune cliff at the northern end of the boulder rampart built in 1977 on the shore of Lonsdale Bay had receded by November 1999.

Figure 24. The site of Figure 23, showing little change from November 1999 to November 2010.
Recent changes on the Coastline of Port Phillip Bay

Figure 25. A grassy dune slope with minor basal cliffing in the sector set back by erosion north of the limit of the boulder rampart in Lonsdale Bay (November 2010).

Figure 26. Grassy dune slope with minor basal cliffing on the north coast of Lonsdale Bay.

In 1935 breakwaters were built to maintain the entrance to Queenscliff harbour, and after that sand drifting northward began to accumulate against the southern breakwater. The entrance to Queenscliff harbour was cut through a narrow spit that had grown north-east off the coast of Swan Island: this spit then decayed. Previously sand lobes had migrated up the east coast of Swan Island (Figure 27) and round to its northern shore, but there was some erosion on the east coast of Swan Island as longshore drift was cut off (Riedel and Fidge 1977).

It has been estimated (Riedel and Fidge 1977) that longshore drift of sand northward to the east coast of Swan Island consisted of a steady component of about 100,000 cubic m per year, augmented by occasional lobes of sand of 200,000–500,000 cubic m per year over one or more years at intervals of about 20 years, as indicated by their appearance on the 1910, 1949 and 1961 air photographs. It was assumed that the periodic arrival of sand lobes on this coast was the result of phases when larger quantities of sand entered Port Phillip Bay, but this was not demonstrated or explained.

Successive air photographs (e.g. 1943, 1961, 1968, 1984, 2010) show stages in the evolution of the coast at Queenscliff and Swan Island. As sand accumulated the beach south of the breakwaters at Queenscliff widened until 1960, when it began to drift across the harbour mouth and form shoals to the north. To prevent such drifting the southern breakwater had been lengthened in 1947, and again in 1956. It was further extended in 1966, by which time the adjacent beach had widened to form a triangular sandy foreland: buildings were then constructed on this new land. Sand continued
Recent changes on the Coastline of Port Phillip Bay

Bellarine Peninsula

Swan Bay is a shallow embayment sheltered by Swan Island in the south and the Edwards Point spit in the north. On its western shores are salt marshes with rushes fringed by mudflats. The Swan Bay shore of the Queenscliff peninsula has only narrow beaches.

Edwards Point is a spit that has grown southward in stages related to southward drift of sand and some gravel (Barson 1973). The gravel was derived from The Bluff (Miller Point), a slowly eroding cliff of brown, mottled sandstone south of St Leonards (Rosengren 1988). Southward drift continues on this coastline as the result of the predominance of waves from the north-east quadrant, and is indicated by the longshore migration of successive lobes of sand and gravel.

At St Leonards converging waves have shaped the growth of a cuspatate sand spit in the lee of the outer harbour pier, which includes an extended boulder reef. Waves generate longshore drift of sand from beaches to the north and south, which have consequently been depleted. The harbour is backed by low bluffs that pass northward into cliffs of brown sandstone (exposing the Moorabool Viaduct Formation, of Pliocene age), and the sandy beach continues as far as Indented Head. Here a small cliffed promontory interrupts the beach, and the shore is gravelly, littered with boulders. The Foreshore Erosion Board (1936) reported that rocky material had been removed from the shore of Indented Head about 6 years previously for road-building, resulting in erosion and reduction of the headland. The sandy beach resumes on the western side of the promontory.

As the coastline curves north-west past Indented Head to Point George and Grassy Point the predominant north-east waves produce a divergence of longshore drift (Figure 29). The sandy beach between Indented Head and Grassy Head is narrow, with gravel and rock platforms exposed on the shore, although there are some nearshore sand bars. Predominant longshore drift is southward from Indented Head and westward from Grassy Point, and variable between the two. The shore curves out to Point George, which has a narrow sandy beach with small lobate salients and gravelly spurs running out seaward into a wide nearshore shallow zone. The coast turns to face ENE, and is bordered by parallel sand bars. The sandy beach to the west varies in width in front of a low bluff and minor cliffs along The Esplanade, and at Oxley Road there is evidence of westward longshore drift.

At Portarlington the sandy beach is generally wider, and there has been accretion on either side of the pier, as well as the formation of a shoal in the lee of Portarlington Harbour breakwater. There was beach renourishment on a 1300 m sector west of the harbour.

to spill into the harbour entrance, forming a sand bar that diverted the channel northward. Sand dredged repeatedly from the harbour entrance was dumped on the northern side, resulting in the formation by 1984 of a large sand spit with successively built recurves (Figure 28). This has since grown northward, and by 2010 it had become attached to the eastern shore of Swan Island in a broad lobe with successive ridges marking stages in its growth. As such a lobe moves alongshore there is first a widening of the beach (progradation), then a narrowing by erosion as it passes on. As it reaches the northern shore of Swan Island it drifts round to form a westward spit. The accretion on Swan Island represents a ‘sink’, a depositional area at the limit of northward longshore drift.

The south-west coastline of Port Phillip Bay between the Point Lonsdale headland and Swan Island has thus changed considerably because of predominant northward longshore drift in response to waves (including ocean swell) coming in through Port Phillip Heads. There have been modifications related to the building of sea walls and groynes, to the interception of drifting sand by the Queenscliff harbour breakwaters, and recurrent dredging of the entrance to Queenscliff harbour and the dumping of dredged sediment to the north.

Figure 28. Coastal configuration at Queenscliff in 1984, when a recurved spit had grown out north from the harbour mouth. This spit later became attached to the east coast of Swan Island, to the north, as a depositional lobe, migrating north-eastward. Crown Copyright Reserved.
Recent changes on the Coastline of Port Phillip Bay

Figure 29. Longshore drift on the east and north-east coasts of the Bellarine Peninsula. Sand drifting north from Point Lonsdale is deposited on Swan Island. There is a drift divergence near Point George on the north coast, with sand and gravel moving south to Point Edwards and west past Portarlington to Point Richards.

in 1986. Westward longshore drift has delivered sand to prograde the eastern flank of the cuspate foreland at Point Richards, and to form a wide shoal extending out on its western side. However the western shore of Point Richards is exposed to wave action from the west and NW, and longshore drift is predominantly from west to east. A longshore spit on this western shore has successive recurves indicating north-eastward growth: in 1984 it was about 80 m wide and 750 m long, and by 2010 it had grown about 100 m NE, enclosing a small lagoon. To the north shelly sand has accumulated against a groyne beside the Point Richards harbour.

Corio Bay

The north coast of the Bellarine Peninsula has sectors of steep and cliffed coast with some landslides, as at McAdams Lane, and incised gullies (Rosengren 1988). The crumbling cliffs are about 20 m high along to Beacon Point, with a narrow beach of shelly sand behind a wide shallow nearshore area with sand bars and seagrass meadows (Figure 30). Between Point Richards and Clifton Springs an eastward longshore drift is predominant. This is indicated by sandy beach accretion on the western side of the boat harbour breakwater at Clifton Springs (Figure 31), and by interception of drifting sand on the western sides of groynes. The cliffs become vegetated bluffs, and pass behind successive dells (amphitheatres), where the narrow beach is to be widened by renourishment between two groynes. The beach west of Clifton Springs boat harbour is of shelly sand fronting low receding cliffs, and fades out westward below scrubby bluffs (Figure 32).

Figure 30. The eroding cliff at Beacon Point, Clifton Springs, looking east. There are narrow beaches of sand and gravel, and a wide shallow nearshore area with sand bars.

Around the next promontory is McDermotts Beach, a wide beach of shelly sand with many mussel (Mytilus) shells from the nearby mussel farms. Further west the beaches are sparse and intermittent as the coast curves NW to Point Henry Pier. A peninsula extends north to the Alcoa Aluminium Works, and ends in a cuspate foreland of shelly sand and gravel formed by convergent drifting, running out to Point Henry (Figure 33). This continues northward beneath Corio Bay as an undersea spit, cut through by the dredged Hopetoun Ship Channel that leads to the port of Geelong. Formerly receding cliffs on the western side of the Point Henry peninsula have been stabilised as a grassy slope.
Recent changes on the Coastline of Port Phillip Bay

Figure 31. The beach of shelly sand at Clifton Springs Boat Harbour, where eastward longshore drift has been intercepted by a groyne.

Figure 32. A sandy beach on the north coast of Bellarine Peninsula west of Clifton Springs.

Figure 33. Cuspate spit of shelly sand and gravel at Point Henry.

Figure 34. Gravel beach below a bluff of Quaternary clay over limestone at Limeburners Point, east of Geelong.

The southern shores of Corio Bay have salt marshes, converted to salt pans (Cheetham Salt Works) in Stingaree Bay. The coast runs out beside a promontory to Limeburners Point, and west of a small harbour a cliff cut in Quaternary clay over limestone descends to a narrow beach of limestone gravel (Figure 34).

The Geelong coast is largely artificial, with former cliffs stabilised behind sea walls and port structures. Generally there is very little beach in front of the sea walls at high tide, but at low tide the foreshore consists of fine sand, strewn with seaweed and seagrasses. Beaches at Rippleside and St Helens were renourished in 1984, and Eastern Beach in front of the promenade in 1984 and 1990. To the north there have been minor changes on the shelly sand spits at the mouth of Limeburners Bay (Point Aboena) and on the sparse shelly beaches in embayments along the north shore of Corio Bay to Point Wilson.
Recent changes on the Coastline of Port Phillip Bay

The west coast

The west coast of Port Phillip Bay, between Point Wilson and Williamstown, is low-lying and faces generally south-east. It is thus sheltered from the prevailing westerly winds. The coastal features are less bold than those of the more exposed east coast of Port Phillip Bay. Coastline changes during recent decades have been generally slight, with gains or losses of no more than a few metres.

Accretion of beach ridges of shelly sand has continued on either side of the jetty at Point Wilson, and in the past decade the beach on the northern side has advanced further, having received sand and shells washed in from the sea floor. To the north the configuration of the Sand Hummocks, shelly sand barrier spits that almost enclose a lagoon in an embayment bordered by salt marshes and low basalt ledges, has varied on air photographs taken since 1947 (Jurkowski 1980). The pattern of recurved ridges indicates phases of spit growth. The southern spit has grown northward, supplied by longshore drift of shelly sand in that direction, while the northern spit has grown southward, supplied by longshore drift generated by waves arriving from the east. Occasionally waves have washed over the spits, forming lobes on the landward side. The two spits have generally converged towards a central tidal inlet, but they are narrow and have been breached occasionally during storms, notably near their southern and northern ends. In 2010 there were five inlets, separating barrier island segments.

North of the little basalt promontory at Kirk Point there have been alternations of northward and southward longshore drift on beaches of shelly sand, a predominance of northward drift being indicated by the growth of longshore spits at and north of Beacon Point and at the mouth of Little River, which has delivered small quantities of sand to the shore. A sandy beach has widened on the western side of a breakwater at the mouth of a drain from the Werribee Treatment Complex west of Wedge Point but there has been little change in recent decades along the shore from Wedge Point to the mouth of Werribee River, which included sectors of slowly receding crenulated low cliff behind a muddy shore (Condon 1951). The Foreshore Erosion Board (1936) described receding cliffs up to 15 feet (4.5 m) high, cut in friable red-brown deltaic clay and dissected into a series of semi-circular bights: ‘The cliff had receded 50 feet into the reserve in six years, and east of the river similar cliffs had receded 30 feet in the previous nine years’.

South of the Werribee River some former cliffs have been stabilised as grassy slopes. Longshore drift to the north-east has built a beach culminating in a small spit on the southern side of the mouth of Werribee River. Formerly shell grit was excavated from this beach, but fortunately this activity has ceased (Vantree 2001).

On the northern side of the Werribee River a sandy beach extends eastward from the boat ramp and curves round northward as Werribee South Beach, a looped sand ridge in front of a swale and a grassy rising slope (Figure 35). This probably includes sand that came down the Werribee River and was deposited on the sea floor, before being washed up on the northern shore; there has also been local renourishment with sand dredged from the navigation channels (Vantree 2001). The sandy beach fades out northward in front of a boulder-armed former cliff 1–2 m high along Beach Road. This is interrupted by a cove with a sandy beach (Figure 36). As Duncans Road turns inland the boulder-armed bluff continues to the north-north-east, rising to 4–5 m and bordered by gravels and basalt outcrops. Towards Crawfords Road the coast turns to the north-east and there is a sandy beach along the high tide line.
Changes on the Coastline of Port Phillip Bay

Cliffs formerly cut into the soft sediments of the Werribee delta are now mostly boulder-armoured, but one persists on the small headland south of Campbells Cove (Figure 37). The Campbells Cove coast has a line of backshore shacks on a cliff-base ledge, some with piers and protective structures on the shore. The sandy beach is narrow and shelly, fronted by a shallow sea with parallel sand bars and some seagrass areas (Figure 38). The coastline has shown little change on successive air photographs.

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East of Camerons Cove the beach is narrow, consisting of fine sand backed by low dune ridges built by southerly winds. There are numerous parallel nearshore sand bars. Beyond the RAAF base the beach has continued to receive shelly sand drifting E and NE along the shore, and has widened slightly in recent decades. It is fronted by dissected lava flows and basalt boulders (Figure 39). Point Cook Homestead and associated buildings stand on a foreland of fine grey sand, with many Aboriginal midden shells, overlying the basalt. A sandy bay curves out behind the boulder-strewn shore to Point Cook (Figure 40).

Figure 37. Cliff cut in Werribee delta sediments south of Campbells Cove.

Figure 38. The beach is narrow in Campbells Cove. View north towards Point Cook.

Figure 39. The sandy beach near the Point Cook Homestead is fronted by basalt boulders formed by the dissection of a Pleistocene lava flow.

Figure 40. The shallow bay extending north towards Point Cook has a narrow sandy beach fronted by basalt boulders and sand bars.
Recent changes on the Coastline of Port Phillip Bay

At Point Cook the coastline turns north behind Altona Bay, and there has been long-term deposition of shelly sand drifting from the south, as well as sand washed in from nearshore sand bars. This is one of the major ‘sinks’ where beach sediment has accumulated at the limits of longshore drifting along the coasts of Port Phillip Bay. There has been northward growth of successive spits enclosing lagoons and marshes as far as the mouth of Skeleton Creek (Appleby 1989). The present beach is narrow, and northward and southward longshore drift has supplied sand to spits that have grown from either side of the mouth of Skeleton Creek. To the north at Laverton is another set of elongated sand spits, and a predominant northward drift has resulted in the formation since 1960 of a longshore spit with multiple recurves that has migrated along the outer shore. By 2010 this had extended almost to the mouth of Laverton Creek, to the south of which a beach 80–100 m wide has formed in the past two decades. This is an example of coastal progradation resulting from recurrent longshore spit growth.

North of Laverton Creek the beach is narrow in front of a coastal lowland that contains sandy ridges that formed about 5,000 years ago. (Hills 1949, Gill 1961) They were possibly emerged sand bars. The Foreshore Erosion Board (1936) described the coastline as having a stone rubble sea wall on the western side of Altona Pier, with sand accreted alongside a bluestone groyne. The beach had steepened and the coastline was receding, threatening the road. Seaweed had been dumped to stop wind-drifting of sand. A sea wall was then constructed, and the modern beach widens along Altona esplanade, where it was renourished in 1982, 1989 and 1990, the augmented sector being reduced as sand was lost by northward and southward drift. There is a groyne at the northern end, and another one was under construction at the southern end in November 2010, when lorry-loads of imported sand were again being used to augment the beach (Figure 41).

The beach narrows again northward past Seaholme, passing behind scattered basalt boulders and outcrops of a dissected lava flow on the shore. The beach remains narrow in front of the marshy Altona Coastal Park, though bordered by a wide zone of nearshore sand bars partly exposed at low tide. The beach widens again towards the mouth of Kororoit Creek, where south-westerly wave action has built a small spit.

The beach east of Kororoit Creek has received fine sand washed in from nearshore bars, but the shore then becomes rocky along the coast of the Jawbone Conservation Reserve, which follows a lava flow. Outcrops of hard basalt reflect wave action, preventing onshore movement of sand, and very little sand drifts alongshore, so that there is almost no beach here, apart from patches of fine grey sand amid the basalt boulders and outcrops along the shore (Figure 42). Jawbone Bay contains sandy Eastern Beach within and behind the basalt shore, and at its eastern end basalt boulders have been assembled to form walls enclosing a small harbour at the end of Bayview Street. The Esplanade then runs behind Gloucester Reserve, a grassy park with a walkway protected by a boulder rampart.
Recent changes on the Coastline of Port Phillip Bay

The Foreshore Erosion Board (1936) found that erosion was still occurring locally at Williamstown, although basalt rubble collected from the shore had been piled up to protect several sectors of the coast. Williamstown Beach, renourished in 1982, is a wide sandy beach in a bay, held in place by a groyne at the northern end (Figure 43). To the east Hatt Reserve is a park with an irregular coastline behind basalt reefs (dissected lava flows) without a sandy beach. The rocky shore continues round Point Gellibrand, where the basalt outcrops are interspersed with areas of angular gravel. There is a sector of sandy beach at high tide on the coast to the north, and there are narrow sandy areas at Shelly Beach and between projecting basalt reefs to the east (Figure 44). The backshore is a former cliff, protected by placed boulders to form a steep shore ramp, which passes into Breakwater Pier at the SE end of Hobsons Bay. As the coastline turns northward beside Hobson Bay there are the extensive Williamstown Docks. The Yarra River flows out beside a training wall, with Webb Dock a reclaimed area on its eastern side.

The east coast

East of Webb Dock Sandridge Beach extends to Princes Pier, and is subject to eastward and westward longshore drift as waves arrive from the south-west and south-east. Early maps show multiple beach and dune ridges backing the Sandridge coastline at the head of Hobsons Bay, indicating long-continued progradation of a sandy beach bordering the Yarra delta. The natural beach widened westward, and was backed by scrub and woodland when the European settlers arrived in 1835. By 1902 the vegetation had been cleared or destroyed, and marram grass was planted to stop wind-blown sand drifting inland (Hoare 1927).

Early maps and descriptions indicate that the sandy ridges passed inland to the west of Sandridge Beach, behind a small swampy delta at the mouth of the Yarra River, which was soon modified for navigation and dock construction, with training walls at the river mouth. The shore was swampy until land was reclaimed for Webb Dock to the west. After that waves from the south-west were excluded from Sandridge Beach, so that longshore drift became predominantly westward. The beach widened further in that direction, and was depleted by erosion to the east. This erosion has been countered by inserting groynes in front of the promenade and renourishing Sandridge Beach.

The Foreshore Erosion Board (1936) noted that in about 1910 erosion prompted the City of Port Melbourne to build a concrete sea wall behind 132 ft (40.2 m) of beach that then gradually disappeared.
Recent changes on the Coastline of Port Phillip Bay

Basalt boulders dumped to form groynes in 1921 were flattened by the sea and failed. Subsequently the sea wall has been extended.

East of Station Pier a sandy beach extends south-east to St Kilda, in front of a sea wall along Beach Street and Beaconsfield Parade. The Foreshore Erosion Board (1936) reported that sea walls and groynes were constructed from 1898 onwards to halt coastline recession. The beach has been depleted during storms (large quantities of sand were swept from the beach across Beaconsfield Parade during the November 1934 storm surge), and parts of it have been artificially renourished, including a 900 m sector at Middle Park in 1976 and 2001. Subsequent storms, notably in February 2005, have depleted the beach and necessitated supplementary renourishment. On the other hand, some beach sectors have been widened, with grassy vegetation colonising low backshore dunes, as near Lagoon Pier, Port Melbourne, and opposite Cowderoy Street backshore vegetation has matured to scrubby woodland (Figure 45).

To the SE a large triangular sandy deposit accumulated after the construction of an offshore breakwater at St Kilda Harbour in 1953, linked to the land by St Kilda Pier. The re-shaping of the beach in the lee of offshore breakwaters built to shelter a boat harbour resulted in depletion of the adjacent beach towards St Kilda Pier. Triangular segments of beach have accumulated alongside groynes built in front of Catani Gardens.

The Foreshore Erosion Board (1936) found that from 1865 the lower esplanade at St Kilda had been repeatedly washed away by storms. A stone wall was then built, and improved and extended in 1889. Some coastal land was reclaimed in 1892, and a new sea wall added in 1899.

South of St Kilda Pier the sandy beach extending to the St Kilda Marina has been maintained artificially, with renourishment in 1981 and 1984. The coast bordering the marina has been protected by a boulder rampart, which reflects wave action and has prevented the deposition of beach sand. South of the mouth of Elwood Canal the boulder rampart passes into a masonry sea wall that runs round Point Ormond, and the beach remains sparse until a groyne marks the beginning of Elwood Beach, which faces south-west and narrows south-eastward. A retaining wall was built to protect Elwood Park in 1908, and subsequently reinforced (Foreshore Erosion Board 1936).

Seasonal alternations of longshore drift occur on Elwood Beach, which generally widens the northward end during the summer and the southward end during the winter. An 800 m sector of beach was renourished in 1983, held by the groyne at the northern end. The beach is backed by a sea wall, and to the south the Elwood Diversion Outlet is a protruding concrete structure that interrupts the beach. There is usually a triangular sand beach on the southern side of this Outlet, where sand drifting onshore and northward has been trapped, but the beach fades out southward as the coastline curves to face west.

To the south a low receding cliff was a problem when the Foreshore Erosion Board examined the area in 1935 and recommended that a sea wall should be built to protect it. At that stage there was still a wide sandy beach between Cole Street and Martin Street, Brighton, but there is now very little beach in front of the sea wall built south from Cole Street because of the reflection of westerly wave action and losses of sand southward into Middle Brighton harbour. As at St Kilda the construction of an offshore breakwater in 1954, linked by Middle Brighton Jetty, has resulted in the formation of a triangular sandy foreland bearing low grassy dunes. Stages in the evolution of this sandy foreland are shown in Figure 46. It is the outcome of convergent longshore drift by north-westerly and south-westerly waves arriving on either side of the offshore breakwater (Figure 47) and resulting in the depletion of beaches to the north and south. The beach on the southern side has been artificially restored to carry a cycle path past the Royal Brighton Yacht Club, but south of the Middle Brighton Jetty there is very little beach in front of the sea wall until the Park Street groyne. The sea wall between Middle Brighton and Green Point replaced a series of earlier timber structures and some previous

Figure 45. Grassy and scrubby dunes on a prograded beach sector, Cowderoy Street, St Kilda (August 2003).
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Middle Brighton Beach faces west south-west and is generally wide alongside the Park Street groyne, where sand accretion each summer extends it almost to the outer end. It narrows southward and ends in Holloway Cove, on the northern side of the Green Point promontory. To the south a scrubby bluff rises behind a woodland backshore and a line of beach huts. The beach is subject to seasonal alternations of longshore drift, but the net movement of sand is northward, as indicated by the growth of a spit across Holloway Cove in the summers of 1987–88 to 1989–90, when sand drifted north past Green Point from the recently renourished Brighton Beach (see Figure 53). This spit briefly enclosed a lagoon, and was then driven back on to the earlier beach.

Figure 46. Evolution of triangular spit in Middle Brighton harbour 1951–1998. The pecked green lines indicate the low tide shoreline. A boulder wall has been added below part of the pier running to the outer breakwater, and the spit is now longer, narrower and sharper.
Green Point was bordered by low receding cliffs when 19th century surveys were made, and after the Foreshore Erosion Board (1936) recommendation a boulder rampart was constructed, with a sea wall on the southern side. Figure 48 shows the situation in 1950. The west-facing shore has no beach because of wave reflection by the boulder rampart, although there was a transitory beach here in 1987–88 while sand was drifting past northward from Brighton Beach into Holloway Cove.

The coast between Green Point and Picnic Point faces south-west. On Cox’s chart (1861) it was shown as having low cliffs bordered by a beach. The cliffs were receding, cut in soft sandy clay (Red Bluff Sand formation) (Figure 49, A). The beach was doubtless subject to seasonal alternations of longshore drift, northward in the summer half-year and southward in the winter half-year. The Foreshore Erosion Board (1936) reported serious erosion on cliffs 15 feet (about 4.6 m) high in soft clay and sandstone between South Road and New Street, and it was realised that cliff recession would soon threaten Beach Road (Mackenzie 1939). South of New Street the sloping cliffs, gullied by runoff, increased in height to 30 feet (just over 9 m).
In 1939–44 a masonry sea wall and undercliff walk were constructed between Green Point and the Hampton Life Saving Club, and the vertical cliffs landscaped to a stable artificial slope and planted with vegetation (Figure 50). Subsequently the beach became depleted because it was no longer receiving sand from the receding cliff. Seasonal alternations of longshore drift continued, the beach widening towards Green Point each summer, and towards Picnic Point each winter (Figure 49, B).

A pier was built on the north side of Picnic Point in 1882, and in 1909 an offshore breakwater was built to shelter it. In 1949–54 a large stone breakwater was built out from Picnic Point to form Sandringham harbour, and south-westerly wave action was then excluded from the southern part of the beach. Sand that drifted southward each winter became trapped in the lee of this breakwater, where the sandy beach soon widened (Figure 49, C). The preceding topography (1911) is shown in Figure 51. The cliffs became vegetated bluffs and a depositional plain formed as the beach prograded into the harbour. By 1971 the beach was backed by a grassy backshore, and this has since become an area of scrub and woodland (Figure 52). The outcome was that by 1985 the beach between Green Point and Hampton was narrow, and in places absent, in front of the sea wall, while Sandringham Harbour had been much reduced by beach progradation. An attempt to restore the beach at Hampton by dumping fine sand dredged from Sandringham harbour in 1975 had quickly failed, the fine sand being washed away by wave action.
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In response to beach depletion in 1986 a groyne was built in the middle of the beach compartment at New Street and the beach northward to Green Point was renourished in 1987 (Figure 53, A: September 1987). This beach responded first to southward drift (Figure 53, B: November 1987) when some sand spilled south over the New Street groyne, then northward drift (Figure 53, C: March 1988), when the beach towards Green Point widened and sand drifted round to Holloway Cove to the north. The beaches south of the New Street groyne remained sparse, but in 1997 there was renourishment of beaches, and additional groynes were built at Hampton to contain them and minimise southward drift into Sandringham harbour. These beaches show changes related to seasonal longshore drift, the...
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Figure 54. The southern end of the artificial beach emplaced north from the New Street groyne in 1987 became depleted, exposing the masonry wall (December 2010).

Figure 55. Undercut bluff, southern Sandringham Beach (April 1990).

Figure 56. The renourished beach between Red Bluff and Royal Avenue in 1995.

northern beach having been reduced to the extent that a sector of sea wall north of the New Street groyne is now exposed to wave attack at high tide (Figure 54), but the central and southern beaches remain in place in 2010 (Figure 49, C).

Picnic Point was a headland with receding cliffs of Red Bluff Sand over Black Rock Sandstone when the Foreshore Erosion Board made its survey in 1935. Some attempts had been made to stop erosion with timber structures in 1905, and between 1939 and 1954 it became enclosed by sea walls, the harbour breakwater and land reclaimed for Sandringham Yacht Club, and it is now an artificial promontory. To the south of Picnic Point in 1935 there were eroding cliffs 40 feet (about 12 m) high, which have become relatively stable scrub-covered bluffs because a wider protective beach has formed. These cliffs diminished to 8 feet (2.4 m) between Bay Road and Tennyson Street, where the cliff of Black Rock Sandstone rose to a more gradual slope on Red Bluff Sand: a profile that can still be seen in a sector where the Black Rock Sandstone outcrop interrupts the sandy beach at high tide. Further south the cliffs passed into vegetated bluffs that extended towards Red Bluff.

South from Picnic Point a beach compartment extends past Sandringham to Red Bluff. This also faces south-west, and shows the same response to seasonal alternations of longshore drift as in seen between Green Point and Picnic Point. The northern end of the beach, sheltered by Picnic Point and the Sandringham harbour breakwater, remains fairly wide, but depletion of the southern end of the beach, between Royal Avenue and Red Bluff, resulted in undercutting of the backing bluff by storm waves and the formation of unstable, receding cliffs (Figure 55). To halt this erosion the 600 m beach was renourished in 1993, using a 30 m long groyne at Royal Avenue, built in 1990, to prevent the sand drifting away northward each summer (Figure 56).

This was successful in halting cliff erosion, even though seasonal alternations of longshore drift continued on the renourished beach, but the beach north of the Royal Avenue groyne as far as Southey Street then became depleted, with undercutting and erosion of the backing bluff (Bird and Cuttriss 1999). In 2006 another groyne was built at Southey Street, and the beach between this groyne and the Royal
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Avenue groyne was renourished in 2009. The beach north of the Southey Street groyne, extending past Sandringham to Picnic Point, has been subject to seasonal alternations of longshore drift, and in summer becomes narrow in the southern part but wider to the north.

At Red Bluff there is a cliff in the Red Bluff Sand formation overlying Black Rock Sandstone. The cliff in Red Bluff Sand is dissected by gullies cut by runoff and seepage, but coastline recession has been impeded by the basal outcrop of harder Black Rock Sandstone (Figure 57).

Half Moon Bay is a short, slightly curved sandy beach facing west between Red Bluff and Black Rock Point. It has shown little change in recent decades, apart from a limited response to seasonal alternations of longshore drift. At the southern end cliff erosion was halted in the 1940s by building a sea wall in front of the Life Saving Club.

Black Rock Point has a sector of rilled cliff cut in the soft Red Bluff Sand formation, fronted by a shore platform on the harder Black Rock Sandstone (Figure 58). This platform reflects wave action and has prevented sand moving onshore, but there is a narrow beach of fine sand that has been washed down the cliff face, and some coarser sand that has drifted in alongshore from Black Rock Beach to the south. The cliff has been receding as the result of occasional slumping (Figure 59), rilling by runoff after heavy rain, downwash from seepage, and occasional storm waves reaching the cliff base and washing away downwashed sediment. Cliff recession between 1945 and 1992 is illustrated in Figure 60 (Bird and Rosengren 1986).

Black Rock Beach, between Black Rock Point and Quiet Corner, faces south-west and is also subject to seasonal alternations of longshore drift. The beach widens at the northern end during the summer (Figure 61), and narrows during the winter (Figure 62), but is always wider in the northern part (north of the Black Rock Life Saving Club) than in the southern part.

A survey by Cox in 1862 showed the beach backed by bluffs, except in the southern part, between Black Rock village and Quiet Corner, where there were cliffs up to 6 m high cut in the soft Red Bluff Sand formation (Figure 63). These were receding, with
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Figure 60. Cliff recession at Black Rock Point 1945–1992.

recent slumping, and a sharp promontory at Quiet Corner was dissected into stacks. An air photograph taken in March 1931 shows a beach of almost uniform width extending south-east from Black Rock Point and round the headland at Quiet Corner. In the November 1934 storm surge there was slumping on these cliffs and recession of the cliff crest. Sand blocks that had fallen to the shore soon disintegrated, and fine sand was soon dispersed. Coastline erosion during this storm surge prompted the setting up of the Foreshore Erosion Board, and this was one of several sectors where cliff recession was estimated to be about a foot (30.5 cm) per year along the cliffs of ferruginous sandstone and sandy clay between Sandringham and Parkdale (Mackenzie 1939).

Figure 61. Northward longshore drift widens the northern end of Black Rock beach in summer (April 2000).

Figure 62. Southward longshore drift depletes the northern end of Black Rock beach in winter (November 2000).
The cliffed coast between Black Rock and Central Avenue, south of Quiet Corner, was protected between 1939 and 1944 by the construction of masonry sea walls with undercliff walks (Figure 63). The cliffs were then landscaped to stable slopes of about 25° and planted with vegetation. Wooden groynes were inserted, and were considered in 1946 to have retained beaches, but these beaches became depleted and the groynes were derelict by 1955.

The Black Rock coastline has since been relatively stable, apart from the seasonal alternations of longshore drift on the beach. Each winter sand drifts southward in front of the sea wall (Figure 64), and each summer the sea wall is exposed as sand drifts away to the north (Figure 65). The sea wall has been damaged by late summer storms, when it is unprotected by a beach (Figure 66).
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There is evidence that Black Rock beach has lost sand, both seaward and occasionally northward past Black Rock Point. The southern limit of the beach each winter was as far as Quiet Corner until the 1970s (Figure 67), but in recent years it has not extended this far. There is no longer sand between groynes that were inserted to retain a beach at Quiet Corner in the 1940s, and these groynes are now derelict. In 1969 an attempt was made to replenish the beach by dumping lorry-loads of sand north of Quiet Corner (Figure 68), but this was soon dispersed by wave action, and had no discernible long-term effect on the beach system.

South of Quiet Corner the cliffs passed into steep scrubby bluffs behind a beach that faces south-west and extends south to a small promontory at Banksia Point. The beach is here protected by reefs and shore platforms of Black Rock Sandstone exposed at low tide. After the masonry wall was constructed south of Quiet Corner the adjacent beach disappeared, and by 1980 the beach to the south had been sufficiently depleted to allow storm waves to undermine the bluff and produce basal cliffing (Figure 69, A). To halt this a 500 m sector of beach was renourished in 1984 (Figure 69, B). The north-west limit of this artificial beach changed little, but by 1989 (Fig. 69, C) the renourished beach had been cut back, and sand had drifted south-east to Banksia Point and beyond, southward longshore drift in winter being stronger than northward drift in summer. This contrasts with Brighton Beach, where the northward drift is stronger, because of a difference in aspect in relation to the wave regime: the beach at Brighton faces west, whereas the beach between Quiet Corner and Banksia Point faces south-west (Figure 70). Having lost sand southward this beach has narrowed, but it remains in place sufficiently to protect the base of the bluff from storm wave attack.

At Ricketts Point a sandy foreland stands in front of bluffs marking an earlier cliffed coastline. The foreland has three cuspate salients formed by wave refraction around segments of wide nearshore shore platforms of Black Rock Sandstone. There has been little change in the outline of the beach here. It consists of fine sand, with only a small sector of backshore cliff about 50 cm high beside a wooden ramp structure near the northern end of the beach. This has been recently protected by sandbags.

East of Ricketts Point the beach in Watkins Bay was renourished in 1986, and is fairly stable. A short sector of cliff has been protected by a masonry sea wall. At Table Rock Point the Black Rock Sandstone rises to from a vertical cliff, and as the coastline turns from south-east to north-east the cliffs of Beaumaris Bay follow the south-west to north-east trend of the Beaumaris monocline. These cliffs, in relatively hard Black Rock Sandstone, have receded only slowly, but the sandstone is well jointed and occasional rock falls have produced heaps of rocky talus. Sandy beaches are generally absent, except in a small cove just past Table Rock Point. A former beach of gravel with some sand was reclaimed for the Beaumaris Motor Yacht Squadron in the 1960s.

The vertical cliffs of Black Rock Sandstone end at Mentone Corner, where the coastline resumes its south-east trend. Softer Red Bluff Sand descends to the shore on the downthrow (south-east) side of the

Figure 67. Air oblique view of Quiet Corner, Black Rock, in October 1973, showing the southern limit of Black Rock beach at the end of the 1973 winter.

Figure 68. An early attempt at beach renourishment at Black Rock by the dumping of sand on the shore north of Quiet Corner in December 1969. It quickly dispersed, and was insufficient to maintain a beach in front of the sea wall during the summer.
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Figure 69. The beach south of Quiet Corner, Black Rock. A – beach depleted after sea wall construction in 1939, B – renourished beach in July 1984, C – modification of renourished beach by November 1989, X – Northern limit of beach drifting.

Beaumaris monocline, and formed pale receding cliffs. The features of the coast in 1887 were recorded in Tom Roberts’ painting ‘Slumbering Sea, Mentone’. The Foreshore Erosion Board in 1936 identified this as a sector needing protection, and a basal sea wall was built in 1939, and extended southward in 1960–1971. This stabilised the coastline from Mentone Corner to Parkdale, and a sea wall was also built to stabilise cliffs south-east to Rennison Street. The cliffs were landscaped to coastal slopes and planted with vegetation, while the beach in front of the sea wall was depleted by wave reflection (Figure 71). Mentone Beach was replaced in 1978 and slowly diminished until it was renourished in 1984 (Goss 1985) (Figure 72). There had also been renourishment of a 1.1 km beach SE towards Parkdale in 1981. The Mentone-Parkdale beach shows seasonal alternations of longshore drift, stronger towards the south, where Mordialloc beach has widened alongside the harbour breakwater. A broad beach now stands in front of an esplanade wall built in 1925/6, which protects an area of low dunes. In 2009 sand was extracted from this broad beach and trucked northward to restore a sector where the beach had been depleted.

Figure 70. Relationship of longshore drift alternations to coastal aspect. A – balanced longshore drift on south-west facing beach orthogonal to wave resultant, B – northward drifting exceeds southward drifting on W facing beach (as at Brighton, Figure 53), with possible northward losses at X, C – eastward drifting exceeds westward drifting on S facing beach (as at Quiet Corner, Fig. 69), with possible eastward losses at Y.
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South of the Mordialloc Harbour breakwaters the beach is set back because of interception of southward drift and consequent beach depletion (Figure 73). A grassy backshore terrace has been trimmed back, and its seaward margin is now held by emplaced sandbags (Figure 74). The beach faces westward, curving slightly as it extends for about 17 km south to Frankston, interrupted only by the artificial outlet from Patterson River, cut in 1879, and minor structures such as the Riviera Outfall, a concrete structure at Carrum.

The Foreshore Erosion Board (1936) observed that beach width had been reduced by erosion on sectors of this coastline, and some backshore property owners had built walls or sheet-piling to protect their properties. Along much of its length the beach is backed by dune ridges parallel to the coastline and up to 15 feet (5 m) high, covered by grasses, scrub or woodland, on a barrier that has prograded during the past 6,000 years. Its seaward advance has been curtailed during the past century, with episodes of shoreline recession during major storms: the beach is now typically backed by a low (generally up to 1 m) sand cliff, undercut when storm waves break against it. Overall there has been slow recession as sand is withdrawn seaward from the beach, and to counter
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this a 2.8 km sector of the beach was renourished at Aspendale in 1978–79. There are seasonal alternations of longshore drift, indicated at the Riviera Outfall site at Carrum by accretion on the southern side when waves arriving from between south and west-south-west in the summer half-year drift sand northward, and on the northern side when waves arriving from between west and north-west in the winter half-year drift sand southward (Bird 2009).

The sandy beach continues along the Seaford Foreshore Reserve, backed by a low cliff at the outer edge of coastal dunes, indicating slight recession of this part of the coastline (Cullen 1973). Until 1973 there were numerous footpaths through the coastal dune woodland to the beach, and blowouts formed along these, representing some loss of sand landward. Subsequently the reserve was fenced to restore the vegetation cover and beach access was confined to a few walkways.

At the southern end of Seaford beach there is an interruption by a breakwater at the mouth of Kananook Creek (Bird 2006). The sector south of this has shown predominant northward drift, following the loss of the beach in front of the sea wall towards Olivers Hill, so that the beach has been set forward on the southern side of the Kananook Creek breakwater (Figure 75). As net annual longshore drift at Seaford is southward and at Frankston northward there is a zone of convergence south of Seaford pier, a minor ‘sink’ marked by a widening of the sand bar zone.

The coastline between Olivers Hill at Frankston and Balcombe Bay consists of a succession of beaches between cliffs of ferruginous sandstone and sandy clay resting on granodiorite, calcareous clay, and basalt. South of Olivers Hill the coast consists of scrub-covered bluffs in weathered granodiorite, with only minor basal erosion but some local slumping. A sandy beach extends past the mouth of Kackeraboite Creek and a sector of high, steeply-sloping cliff cut in weathered granodiorite (Figure 76). The beach is wide in Daveys Bay, where the backshore bluff is protected by boulder ramparts placed to counter basal erosion.

To the south is a cove with a sandy beach, backed by slowly receding cliffs, and at its southern end there has been a recent rock fall on the cliff bordering Pelican Point (Figure 77). South of Pelican Point a scruffy bluff with minor basal undercutting runs behind a sparse sandy beach and shore platform of
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ferruginous sandstone. The beach widens at the southern end, in Canadian Bay, in front of cliffs that are now almost stable, partly scrub-covered, with a basal apron of grassy downwash (Figure 78). Half Moon Bay, to the south, is a cove with a sandy beach backed by cliffs cut in Baxter Sandstone (Figure 79). Its northern shore is boulder-armoured.

Ranelagh Beach is broad and sandy, with some ferruginous gravel. It is backed by numerous beach huts, and runs across the mouth of a wide valley, which also interrupts the shore platform, apart from some minor reefs. The beach ends southward against a cliff of sandstone and clay below the end of Earimil Road. Steep bluffs continue behind Moondah Beach, which shows seasonal alternations: during the winter sand drifts southward to widen the beach at Manyung Point, leaving the northern end narrow, so that waves sweep under beach huts; while in summer the southern sector narrows, and waves break against the toe of a landslide and a cliff and rocky shore on Manyung Point. Much of Moondah Beach is backed by a low grassy terrace on either side of Gunyong Creek, its seaward margin trimmed back by occasional storm waves, indicating a slow erosional trend.

Sunnyside North Beach also shows seasonal alternations, with underlying rocks and gravel exposed at the northern end in late winter and the southern end in late summer. It is backed by a scrub-covered slope with overgrown landslides that have been trimmed back along the shore. A boulder rampart protects the car park at the seaward end of Sunnyside Road, where there is a sandy beach running south to the mouth of the Manmangur Creek valley.

South of Manmangur Creek the sandy beach fades out, and cliffs are cut in granodiorite and fronted by boulders and gravel. This continues past Caraar Point in front of a steep scrubby slope, and the shore becomes sandy, extending along Mills Beach. At the southern end of Mills Beach a masonry wall protects grassy parkland and the backing bluff declines to the valley of Tanti Creek, which flows out on to an intertidal delta of sandy outwash beside a promontory with cliffs in ferruginous sandstone. The Foreshore Erosion Board (1936) described a 360 ft (110 m) sector of ironstone boulder rampart, placed to protect the cliff on the southern side.

The Mornington coast has vegetated bluffs on Baxter Sandstone, exposed in minor cliffy headlands. Shire Hall Beach is wide and sandy, and runs past a sandstone headland to Mothers Beach (Figure 80),

Figure 78. Beach accretion at Canadian Bay, Mount Eliza, has halted cliff recession, with the formation of a grassy basal apron of downwashed sediment (November 2010).

Figure 79. Sandy beach fronting cliffs of Baxter Sandstone in Half Moon Bay, Mount Eliza. In the foreground boulders have been placed to protect the cliff from erosion (November 2010).

Figure 80. Shire Hall Beach at Mornington (November 2010).
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where the bluffs curve round to Schnapper Point, which protrudes northward. Mornington harbour jetty runs out to the NE. Here the bluffs pass into sandstone cliffs, fronted by boulders of ferruginous rock and protected by a sector of sea wall. Royal Beach is a sandy beach in a clifffy cove and Fishermans Beach occupies a wider bay. The Foreshore Erosion Board (1936) described Fishermans Beach as backed by eroding vertical cliffs 20–25 feet (6–7 m) high at the western end, then lower gently sloping cliffs reduced to an average height of 5 feet (1.5 m). At its northern end the sandy beach fades out in front of a curved segment of masonry wall with some boulders and at its southern end the beach ends as another masonry sea wall curves out beside Linley Point. The cliffs have been landscaped to vegetated bluffs. The north face of Linley Point is a sandstone cliff protected by a car park behind the sea wall. The sandstone cliff emerges on the end of Linley Point, and runs southward, curving back behind Marina Cove, where the shore is strewn with boulders and gravel and there is no sandy beach.

Cliffs and bluffs line the coast southward past Fosters Beach, where the Baxter Sandstone and Marina Cove Sand rises southward and the underlying Balcombe Clay is exposed in the lower cliff (Gostin 1966). Rainfall percolating down through the permeable sandstones reaches the top of the impermeable clay and lubricates the interface, causing instability. There have been landslides, forming irregular topography with some subsided blocks of sandstone and clay, separated by elongated hollows parallel to the coastline. It is possible that some landslides have been triggered by earthquakes along Selwyn Fault, which runs close to the coastline from Olivers Hill, Frankston, south to McCrae. One such tremor occurred in the Mornington area in 1932.

Generally the steep coast consists of slowly receding, partly vegetated cliffs, and a shore strewn with red-brown ironstone boulders and gravels and no sand, except in a cove below Coral Road. At Fosters Beach a sector of masonry wall and boulder rampart protects the coast (Figure 81) and to the south a gravelly beach runs in front of a subsided hill at Fossil Beach, where an unprotected cliff exposes the Baxter Sandstone and Marina Cove Sand over Balcombe Clay (Figure 82). Further south are more cliffs (Figure 83), then another sector of masonry sea wall faces south-west and ends in a cove where a sandy beach backs a cobble foreshore (Figure 84). A promontory of sandstone and conglomerate with many fallen boulders is then followed southward by sandy Dava Beach. Two sandy cusps project in the lee of offshore reefs, the southern behind Bird Rock, a reef of sandstone. The scrubby bluffs show minor basal cliffing, notably at the southern end where a steep track descends to the shore. The sandy beach ends against Harmon Rocks, a protruding headland with cliffs cut in basalt, and to the south the shore is strewn with boulders.

Further south is Craigie Beach, with a long sector of masonry wall built to halt the recession of steep, high cliffs in Baxter Sandstone over Balcombe Clay (Figure 85). These cliffs are still unstable, with a basal apron of downwashed sand and clay, but the coastline is no longer receding. However, there is very little sandy beach in front of the sea wall, and
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Figure 83. Receding cliffs at Fossil Beach. December 2010.

Figure 84. Masonry wall at Fossil Beach, looking south towards Dava Beach. December 2010

Figure 85. Craigie Beach, Balcombe Bay, showing a cliff protected by a sea wall. The beach has been depleted by reflection scour in front of the wall, except for a sector emplaced by northward drifting in the foreground.

Figure 86. Hawker Beach, Balcombe Bay, showing sandy beach fronting a receding cliff south of the sea wall protection.

only a few posts remain of former wooden groynes. Where the wall comes to an end at Hawker Beach the coastline is set back, and consists of receding low, sloping clay cliffs fronted by a sandy beach (Figure 86). Boulders of Baxter Sandstone mark a small point, beyond which the cliffs pass into vegetated bluffs that run behind a line of beach huts: at high spring tides the sea washes beneath these and reaches the base of the cliff behind.

South of Hawker Beach the sandy beach widens, and is subject to seasonal northward and southward alternations of longshore drift. It continues past the mouth of Balcombe Creek, which is usually sealed off by a sand bank, and ends at the cliffs of weathered granodiorite on Balcombe Point. There has been only minor erosion on this part of the coast, with some cliff recession on Balcombe Point. Between Balcombe Point and Martha Point the hard Mount Martha granodiorite forms steep rocky cliffs that have remained stable, apart from some minor weathering and erosion between low tide and the upper limit of wave swash. Storm waves breaking against these cliffs have very little effect: this part of the coast has shown the least change of any part of Port Phillip Bay.
during the past 6,000 years. Although there is sand on the adjacent sea floor there are no sandy beaches below these cliffs because wave reflection from the hard rock outcrops has prevented deposition of beach sand. Towards its northern and southern margins the granodiorite has decomposed to a sandy clay, and the cliffs are actively receding. There is a shingle beach in Shepherds Drop, consisting of rounded granodiorite pebbles disintegrated from the well-jointed and partly decomposed granodiorite. At Martha Point the steep coast swings east south-east and passes into vertical receding cliffs of granodiorite that has been weathered to a soft sandy clay (Figure 87) (Jutson 1940).

**Safety Beach to Sorrento**

At Safety Beach the weathered granodiorite cliffs come to an end, and a long beach facing north-west, then north, extends about 20 km to White Cliffs near Rye. At the northern end of the beach breakwaters built to define to entrance to the Martha Cove marina have trapped a sandy beach on the northern side (Figure 88), while to the south the beach fluctuates in relation to seasonal alternations of longshore drift. At Safety Beach the drift is northward in summer and southward in winter, but as the beach curves south-west past Dromana the winter drift by north-westerly waves is eastward and the summer drift by north-easterly waves is westward. The extent of seasonal movement varies from year to year. Storms with northerly waves withdraw sand from these beaches.

Safety Beach contains sand derived from the weathered mantle of the Mount Martha granodiorite, exposed in the slowly eroding cliff to the north (Beasley 1971). Along the coast the proportion of calcareous sand, derived from the dune calcarenites of the Nepean Peninsula, increases, and west of Rye the beach sand is predominantly calcareous (Beasley 1969). The long beach between Dromana and Rye is backed by low parallel sand ridges, formed during earlier intermittent progradation, but during the past few decades this has come to an end. This beach has been regarded as naturally stable (Black and Rosenberg 1992), but field evidence of backshore cliffing indicates a slight erosional trend (Figure 89). The beach generally maintains its width, narrowing locally in front of the sea wall at Anthonys Nose. There are wooden groynes across the beach past...
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Figure 90. McCrae Beach, with wooden groynes. This beach has been relatively stable, as indicated by the absence of backshore cliffing. Vegetation is spreading forward on to the beach. December 2010.

Figure 91. Excavation of boat harbour in sand bar zone, south of Rosebud Jetty (October 1977). © Neville Rosengren.

Figure 92. Beach renourishment in progress at Rye, November 2010.

McCrae, which has been relatively stable in recent years (Figure 90).

West of the Rosebud Jetty backshore erosion led to the emplacement of sandbags and beach renourishment in May 2010. Further west the backshore is a wide grassy terrace. Attempts have been made during the past 30 years to dredge a boat harbour (The Gutway) through the multiple nearshore sand bars here, and areas of deeper water persist, with dark seagrass beds and some boat moorings (Figure 91), but sand has accumulated in the outer parts of dredged channels. The coastline has thus been modified, and although some sand dredged from the nearshore zone was used for local beach renourishment the outer edge of the grassy terrace ends in a cliff about 30–40 cm high in several places, indicating an erosional trend (Figure 89). Longshore drift alternates, but is roughly balanced over the year: there is a slight net westward drift at McCrae, and a slight net eastward drift at Rye Pier, where the beach on the western side is usually set forward. Beach renourishment west of the Rosebud township in 1982 resulted in a kilometre-long widened beach, but sand from this was soon distributed alongshore.

The shore between Rosebud and Rye has been modified by local dredging of boat channels, as at Tootgarook Boat Ramp, by occasional localised bulldozing of sand from the nearshore zone up on to the beach (Jones 1972, Parry and Collett 1985), and by periodic beach renourishment in several sectors: in April 1982 a 1.4 km sector between Violet Street and Capel Street was renourished, and there was more renourishment in 1985. Sand from renourished beaches has drifted alongshore to the east and west, so that much of the coastline has been modified (Bird 1990).

Beach renourishment has also occurred at and east of Rye on several occasions between 1975 and 1999, and in 2010 a renourishment project was in progress east of the pier, using yellow-brown sand brought from Warragul (Figure 92).

The beach continues past White Cliffs, an outcrop of dune calcarenite on the Nepean Peninsula (Bird 1982). Blairgowrie beach was renourished in 2010, extending in front of a sector of masonry wall. West of Blairgowrie a cuspatate spit has formed in the lee of an offshore
Recent changes on the Coastline of Port Phillip Bay

breakwater built in 2001 to shelter a boat harbour (Bird 1999). This spit formed in the same way as harbour spits at St Kilda and Middle Brighton, as the result of convergent wave action, drifting sand from beaches to the east and west, which were consequently depleted. In 2010 a dredge was at work extracting sand from the cuspatte spitt and returning it to the depleted beaches to east and west, but it will soon drift back to re-form the cuspatte spitt. Longshore drift alternates seasonally, but is roughly balanced on this sector.

In 1984 a 900 m sector of beach west of Blairgowrie Yacht Club, between Stringer Road and Hughes Road, was renourished, but at the western end, where the shore curves out behind Camerons Bight to dune calcarenite cliffs at the Eastern Sister, sand has been lost, exposing gravel and rock outcrops on the shore (Figure 93).

Sullivan Bay, between clifed dune calcarenite headlands, The East and West Sisters, is wide with a grassy backshore, and has been relatively stable. Beyond the West Sister it diminishes, and has become narrow towards Sorrento Harbour, where it is absent in front of the sector with a wooden wall on Policemans Point. The Foreshore Erosion Board (1936) recorded that the coastline north of Sorrento Baths had brushwood groynes, which were not effective in stopping coastline recession. There was beach nourishment on an 800 m sector here in 1980. The Board noted that between the Baths and Sorrento Pier the coastline was protected by concrete walling and timber sheeting, supplemented by brushwood groynes, which had assisted sand accretion.

At Policemans Point, Sorrento, the coastline turns north-west as Sorrento Pier runs out to the ferry terminal, and dune calcarenite cliffs run northward to Point King. At Sorrento Park, north of the pier, these cliffs were eroding in the early 20th century in a sector where the beach was too narrow to protect them. It is possible that this beach was formerly wide and protective, and that its depletion led to cliff erosion. Reports in The Argus in July 1923 mentioned severe erosion here, reporting that the coastline had locally receded 30 feet (9 m) in the previous 20 years, necessitating realignment of the Point Nepean road. The Foreshore Erosion Board (1936) found that below Sorrento Park the cliffs had been protected by timber sheeting, but this had been destroyed and the cliff cut back 15-20 feet (4–6 m) from the timber sheeting line. The cliffs were 40–50 feet (12–15 m) high, cut in thinly bedded soft dune calcarenite, and sloping at about 50°. More recently the coastline north from Policemans Point at Sorrento has been armoured with boulder ramparts and groynes on either side of the Sorrento boat launching ramp, and numerous wooden jetties run out from the cliffs that extend to Point King (Figure 94).
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Sorrento to Point Nepean

As previously noted, the predominant longshore drift is eastward along the south coast of Port Phillip Bay, from Point Nepean to Sorrento. Sand swept in through Port Phillip Heads and sand eroded from the dune calcarenite cliffs of the Point Nepean National Park is carried eastward by waves generated by westerly and north-westerly winds, and by ocean swell refracted as it passes through the entrance to Port Phillip Bay. The longshore flow of sand has been intermittent, occurring chiefly during stormy periods and high tides, and there is a tendency for beaches to widen as sand is delivered and narrow as it moves on.

Sand drifts intermittently round dune calcarenite headlands such as Police Point, Point Franklin and Point Macarthur, and episodes of natural renourishment of beaches alternate with phases of depletion, when beaches become lower and narrower, and underlying rock may be exposed.

Eastward longshore drift has not produced any sector of long-term accretion comparable with the ‘sinks’ of Swan Island or the Laverton spits, and it is likely that sand has been lost into the Sorrento Channel, which runs parallel to the coast and close inshore. There are also occasional periods of westward drifting, usually in summer, when north-easterly waves are generated by winds from that direction.

North of Sorrento the coast turns westward and the beach between cliffy dune calcarenite headlands at Point King and Point Macarthur is subject to seasonal longshore drift, widening westward in summer and eastward in winter (Bird 1997, 1999). A 1910 (Figure 95) photograph showed it backed by a grassy terrace about 20 m wide, but this was later removed by erosion. Waves generated by passing ships, particularly the Sorrento-Queenscliff ferry, arrive obliquely on this beach and generate some longshore drift. Ferries leaving Sorrento had bow waves that drifted sand westward, widening the beach towards Point Macarthur while those arriving at Sorrento produced eastward drifting on a smaller scale. In 2010 the whole beach was wider than it had been a few years previously, probably because sand has been drifting round Point Macarthur from the prograded Shelly Beach to the west (Compare Figures 95a and 96). This represents the arrival of eastward longshore drift from the eroded beach at Portsea, to the west.
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Figure 97. Western end of Shelly Beach, Portsea. This was depleted between 1935 and 2003, but restored in 2010 when sand from Portsea beach drifted in past Point Franklin.

Figure 98. Point Franklin, with sand drifting round from Portsea beach. December 2010.

Figure 99. Sand drifting round Point Franklin from Portsea towards Shelly Beach, formed narrow beaches in coves beneath the cliffs. October 2010.

Shelly Beach at Portsea also shows eastward longshore drift in the winter months, when NW winds predominate, and westward drift during the summer, when there are occasional winds from the NE. Air photographs taken between 1935 and 2003 show longer term changes (Coastal Engineering Solutions 2003), the western part of the beach having been depleted, largely because nearshore water had deepened as the result of eastward shoal migration (although sea wall construction had worsened the situation), while sand had drifted eastward to widen the beach towards Point Macarthur. This was an illustration of how tidal currents can indirectly cause beach erosion by moving nearshore sand along the coast. However in 2010 the western end of the beach was again wide (Figure 97), and there are indications that sand had drifted eastward round Point Franklin (Figure 98) from Portsea Beach, forming narrow beaches in coves beneath the cliffs (Figure 99).
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In Weeroona Bay at Portsea there has recently been beach erosion, which was severe east of Portsea jetty. The beach had been lowered and cut back during 2009, and unusually high tides in March 2010 were accompanied by a strong westerly swell, which cut a cliff into the backshore dune. In October 2010 works were in progress behind a temporary rock revetment to form a bank of sandbags to protect the shore (Figure 100); in December 2010 this work was completed (Figure 101). Sand is drifting eastward to Point Franklin (Figure 102).
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Historical photographs show that there have been variations in the width and profile of the beach at Portsea, indicating previous phases of erosion. The beach at Portsea pier was wide in 1914 (Figure 103), but in the 1940s and 1950s it was much narrower (Figures 104, 105).

Figure 103. The wide beach at Portsea pier in 1914. State Library of Victoria.

Figure 104. The beach at Portsea pier was narrow circa 1950. State Library of Victoria.

Figure 105. Portsea beach was narrow at high tide in the 1950s, except at the eastern end, which had been widened by eastward longshore drifting. State Library of Victoria.
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Figure 106. Backshore dune cliffing at Portsea led to protection works several years before 2010. This indicates that beach erosion occurred at Portsea on at least one occasion before the depletion in 2010.

Figure 107. A 1921 painting of Portsea beach looking eastward by Penleigh Boyd, showing the eroding cliffed salient west of the pier. There are no artificial structures behind the wide beach in the foreground.

Figure 108. Former cliffed salient west of Portsea Pier protected by a masonry wall built in the 1940s. December 2010.

There had previously been erosion west of the jetty, where a wooden wall, now collapsing, holds a former sand cliff (Figure 106). Further west the salient that was a crumbling cliff on Penleigh Boyd’s 1921 painting of Portsea was protected by a masonry wall built in the 1940s (Figures 107, 108). Beyond this is a line of beach huts (Figure 109), where the beach was very narrow in June 2001 (Vantree 2001). Further west the base of steep scrubby bluffs has been protected by a long masonry wall built in the 1960s and ending against the cliff on the eastern side of Police Point (Figures 110, 111). Five groynes retain some sand, but historical photographs show variations in beach width here.

Figure 109. Beach huts at Portsea, December 2010. The beach had been cut back and lowered in front of a microcliff, and further erosion would threaten the beach huts.

Figure 109. Beach huts at Portsea, December 2010. The beach had been cut back and lowered in front of a microcliff, and further erosion would threaten the beach huts.

Figure 110. Bluff protected by boulders and a masonry wall, west Portsea beach. December 2010.

Figure 111. Masonry wall and groynes, west end of Portsea beach, looking towards the cliff that runs out to Police Point. There is a gap in the beach around Police Point. December 2010.
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Figure 112. A view westward along the beach at the Quarantine Station, Point Nepean National Park in 1909. Public Record Office Victoria.

Figure 113. The beach at the Quarantine Station, Point Nepean National Park was wide in 1909. The pier was dismantled in 1973. Public Record Office Victoria.

Figure 114. An air photograph of the Quarantine Station in about 1922, showing a wide beach. National Archives of Australia: AA1969/147, B5.
It has been suggested that the erosion of Portsea beach in 2010 was caused by the unprecedented heavy swells resulting from stronger ocean swell penetration as a sequel to the recent dredging of a deeper and straighter entrance channel to Port Phillip Bay. This does not explain why the erosion was more severe at Portsea in 2010 than on the coast of Lonsdale Bay around to a sector near Shortland Bluff, which is directly opposite the dredged channel in the Bay entrance. It should be borne in mind that the deepened entrance channel is narrow (400 m wide, running from south-west to north-east –12 per cent of the width of the strait between Point Lonsdale and Point Nepean). Recent analyses by the National Tidal Centre (2010) indicate that the Channel Deepening Project has allowed 2 per cent more sea water to enter and leave on each tide, so that high tides are about a cm higher and low tides a cm lower, but the analyses detected no change in mean sea level in Port Phillip Bay due to dredging. Increased penetration of ocean swell along the narrow deepened channel has probably been minor, its effects being reduced by wave diffraction in the southern part of Port Phillip Bay.

Other factors that should be considered in seeking to explain the recent erosion east of Portsea pier are the reduction in sand supply following the armouring of cliffs on Point Nepean, the intermittency of eastward longshore drifting past the Quarantine Station and round Police Point, and the possibility that tidal currents have driven the shoal in Weeroona Bay eastward, leaving deeper water west of Portsea pier and so allowing larger waves to erode the shore. Discussion of wave processes in the straight between Point Lonsdale and Point Nepean, and eastward to Portsea, in recent years (Cardno 2011) indicates that there were episodes of strong wave action early in 2009. Unusually high waves entering east of the dredged channel could have reached Portsea Beach.

Figure 115. The shore east of the Quarantine Station, Point Nepean National Park, showing outcrops of dune calcarenite and a sand slope descending into a nearshore channel. December 2010.

Portsea Beach ends westward beside the dune calcarenite cliffs bordering Police Point, and there is a gap with the cliff descending into the sea even at low tide, before another beach resumes to the west, running past a sector of receding cliff (Bird 1998) to the Quarantine Station. Photographs show a wide beach at, and on either side of the Quarantine Station in 1909 (Figures 112, 113) and 1922 (Figure 114), but there were later stages when it was narrow in front of a low shore wall, and completely submerged at high tides. In December 2010 the beach at and east of the Quarantine Station was low and narrow in front of a concrete sea wall, and a fence excluded public access. To the east the narrow beach was fronted by shore outcrops of dune calcarenite, with sand declining into a deep nearshore channel (Figure 115). These historical variations (compare Figures 116, 117) indicate alternations in the supply of sand drifting along Ticonderoga Bay from Observatory Point. Predominant longshore drift has been eastward past the Quarantine Station towards Police Point, where the shore fronting dune calcarenite cliffs is rocky, and sand spills offshore. There have been phases when sand moved round Police Point (offshore, across the sea floor) and on to Portsea Beach, but there is little evidence of this in the past few years. A sign at the Quarantine Station cemetery indicates that the graves of people quarantined from the ship Ticonderoga had to be relocated inland in 1952 because the cemetery site had been invaded by shore erosion. This north-facing coastline has not been stable.
Figure 116. The beach fronting the shore wall at the Quarantine station was completely submerged at a high tide in 1957. National Archives of Australia: B6295, 566A.

Figure 117. A relatively wide beach at the Quarantine Station in 1963. An outfall pipe raised on supports crosses the beach; it was not a groyne. National Archives of Australia: A1200, L43272.
At the western end of Ticonderoga Bay near Observatory Point there has been minor beach accretion at the ruined wooden cattle jetty, where a grassy dune ridge was added in the 1970s (Figure 118) (Bird 1982). This was the result of the movement of sand from the beach south of Observatory Point round that point and along the shore to the east, where relics of earlier backshore dune cliffing indicate an alternation of erosion and accretion.

West of Observatory Point the beach that runs south-west to The Bend is backed by a steep receding slope cut into dunes (Figure 119). This part of the coast had previously prograded, with the formation of successively-built parallel dune ridges, but by 1950 the advance had given place to recession, with the formation of a receding backshore. The beach is exposed to waves from the north-west and to ocean swell which enters through Port Phillip Heads from the south-west and is refracted about 90° to approach this shore from the north-west. Typically this swell has a period of about 10 seconds and a wave height about 30 cm, increasing during stormy periods in Bass Strait. Erosion has been intermittent, related to periods when north-west waves and refracted ocean swell arrived on this shore, particularly during unusually high tides.

The beach narrows towards the south-west end, known as The Bend. Here the dune cliff is lower, but more active, with many fallen trees and shrubs. In 2010 there was erosion of the steps that descended to the beach, and the dune fringe was cut back as a cliff by storm waves generated by a northerly wind.

As the dune calcarenite cliffs begin the beach fades out, but it revives in the bay to the west, backed by The Narrows (Figure 120). The beach in this sector was augmented by sand blown across The Narrows to form a dune spilling on to the north shore, but this was subsequently stabilised by vegetation, halting the sand supply to the beach. The receding dune calcarenite cliffs continue westward to Point Nepean, some sectors having been protected by sea walls, thereby diminishing the supply of sand to nearby beaches.
Mud Islands

Mud Islands consist of ridges of shelly sand that rise above high tide level on the Great Sands in the south of Port Phillip Bay. On the seaward side these ridges are bordered by gently-shelving beaches, which are backed by grassy dunes that attain four metres height above high spring tide level. The sandy ridges are interrupted by tidal inlets, and enclose shallow lagoons and salt marshes. The southernmost point is held by an outcrop of shelly beach rock, formed by the carbonate cementation of the beach sediment, but the sand ridges are unconsolidated (Keble 1947, Bird 1973). In 2010 the sandy beaches were interrupted by small tidal inlets at the northern, north-western and southern ends, each flanked by inwashed spits (Figure 121). Low-lying sectors of the sand ridges have been overwashed during storms, forming lobes of sand on to the backing salt marsh.

Mud Islands were first surveyed in 1836, and successive surveys have shown changes in outline, as well as variations in the number, size and location of the tidal inlets (Figure 122). Until 1946 the western island was elongated, and ended south-westward in a recurved spit, but by 1973 this had been truncated and in the last four decades the islands have had a more compact configuration. The sandy area above high spring tides has diminished since 1946. Some shelly sand arrives on the beaches, but they have not prograded, and seem to be fairly stable in 2010, gains having been offset by losses due to drifting of sand to backshore dunes by onshore winds, overwash by storm waves, and weathering, notably the dissolving of carbonate sand by rain water.

At low tide extensive surrounding shoals are exposed. These have included intertidal spits in various directions, most recently out westward from the north-west point. Birds Australia, who visit the islands regularly for bird banding, reported no evidence of changes during the past two years.

Figure 121. An air oblique view northward over Mud Islands in November 1972.

Figure 122. Changing outlines of Mud Islands from 1838 to 1984.
Causes of coastal erosion

The Foreshore Erosion Board (1936) found that two popular explanations had been suggested for coastal erosion in Port Phillip Bay: (1) deepening of the Heads and navigable channels, and (2) prevalence of higher tides than those of earlier years. The board rejected these, but noted that they continued to be persistently put forward.

Blasting of the tall pointed pinnacles in the entrance channel had started in 1881 and from 1901 the Ports and Harbours Branch sought to form a wider and deeper waterway to Port Phillip Bay (Grant and Thiele 1902). Possible effects on tide levels in Port Phillip Bay were investigated from the Williamstown and Geelong tide gauge records. Apart from unusual brief storm surges (notably that of November–December 1934) there was little evidence of change: mean high spring tide at Williamstown in 1874–1888 was 2.37 feet, in 1888–1916 2.35 feet, and in 1916–1935 2.37 feet.

Several possible reasons for the initiation or acceleration of erosion on a beach are listed in the following Table:

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<th>Causes of beach erosion</th>
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<tr>
<td>1 Submergence (rising sea level)</td>
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<td>2 Reduction of fluvial sediment supply</td>
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<tr>
<td>3 Reduction in sediment supply from eroding cliffs</td>
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<tr>
<td>4 Reduction of sand supply from inland dunes</td>
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<tr>
<td>5 Reduction of sediment supply from the sea floor</td>
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<tr>
<td>6 Extraction of sand and shingle from the beach</td>
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<td>7 Increased wave energy</td>
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<td>10 A change in the angle of incidence of waves</td>
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<td>16 Migration of beach lobes</td>
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<td>17 A rise in the beach water table</td>
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<td>18 Removal of beach material by runoff</td>
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Source: Bird (2008)
Causes of coastal erosion

Most of these are exemplified on the beaches of Port Phillip Bay:

Submergence of beaches (1) has certainly occurred during storm surges, and is also relevant where sea level has risen relative to the land, whether as part of a global sea level rise and/or sinking of the land. Deepening of nearshore water allows larger waves to reach the beach, and send swash to a higher level. This essentially covers the two popular explanations of erosion in Port Phillip Bay discussed by the Foreshore Erosion Board (1936).

Reduction of fluvial sediment supply to beaches (2) is unlikely to have led to beach erosion in Port Phillip Bay because the inflowing rivers were not yielding much sand anyway.

Sediment supply from cliffs to beaches has certainly been reduced (3) where sea walls have been built and former cliffs stabilised as vegetated or concrete slopes, as at Hampton.

Dunes have supplied sand to beaches (4) only on a very small scale (as on the northern shore of the Nepean Peninsula, where a spilling dune has been stabilised).

Sediment supply from the sea floor to beaches (5) includes some sand and shelly material arriving on parts of the Port Phillip Bay coastline, and a reduction in this could lead to beach erosion.

Extraction of sand and shingle from beaches (6) was a problem around Port Phillip Bay when the Foreshore Erosion Board reported in 1936, but has generally ceased.

Increased wave energy on beaches (7) certainly operates during storms, but there is no definite evidence that these have increased in severity and/or frequency.

An increase in tide range, due to the 2 per cent greater inflow of water on rising tides through Port Phillip Heads, allows waves to reach a 10mm higher level on beaches for 20 minutes at the peak of the tide. This change is relative to the 0.5m difference in sea level between summer and winter (8).

Depletion of beaches due to interception of longshore drift (9) has occurred beside several groynes and breakwaters, as at Sandringham harbour.

A change in the angle of incidence of waves arriving on beaches (10) has occurred in the lee of offshore breakwaters, as at Middle Brighton and Blairgowrie, resulting in accretion of cuspat spits and accompanying erosion of adjacent beaches.

Obliquely-incident wave attack (11) intensified on beaches at Point Lonsdale after the nearshore was deepened by scour produced by wave reflection from solid sea walls.

Losses of beach sediment to the backshore (12) have occurred where sand has been blown by onshore winds from beaches to backshore dunes, as on the coast at Seaford, but it is unlikely that this has increased. There are also minor, but cumulative, losses of sand from beaches used for recreation because it is carried off adhering to bathers and their clothing, towels and equipment (Bird 1996).

Attrition of beach material (13) proceeds as the result of abrasion of sand and gravel agitated by wave action, so that beaches no longer receiving sediment become lower and flatter in profile, and more easily eroded. This may have happened on the coastline between Dromana and Rye.

Weathering of beach material (14), including solution of carbonates, notably shelly debris, has a similar effect.

Increased scour of beaches by wave reflection (15) has occurred where sea walls have been built, particularly solid, vertical sea walls. The effect has been less severe on sloping walls or boulder ramparts, but any inserted structure can be reflective. In some places a beach has persisted in front of a sea wall because it is maintained by longshore drift.

There are fluctuations in sand supply where lobes of sand have formed and drifted along the shore. Migration of such beach lobes (16) produces an alternation of accretion, as the lobe moves in to a beach sector, and erosion, as it moves on. This is well illustrated on the east coast of Swan Island and on the coast between Observatory Point and Sorrento.

A rise in the beach water table (17) results in saturation of the beach, and wet sand is more readily eroded by waves than dry sand. This is seen where waves cut out coves in the beach in an area of seeping water on either side of an outflowing drain, as on the beach at Mentone.

Removal of beach material by runoff (18) occurs where water flowing down from a cliff or out from a drain sweeps sand down into the sea.
Perspective

When an episode of beach erosion occurs it is regarded as unusual. However, a global review in 1985 found that more than 70 per cent of the world’s sandy beaches had shown net erosion over the previous few decades, less than 10 per cent had shown sustained progradation, the remaining 20–30 per cent having remained unchanged, or with gains offset by losses, or shown no definite trend (Bird 1985). With this perspective, the fact that beach erosion has occurred at Point Lonsdale, Portsea and other places around Port Phillip Bay during the past century is not surprising: beach erosion has been widespread around Australia and around the world’s coastline. The only bayside beaches to have shown sustained progradation (other than beside or behind breakwaters) are those at the downdrift ‘sinks’ on the northern shore of Swan Island and at the Laverton spits.

The causes of beach erosion vary from place to place, but are various combinations of the 18 factors listed here. On many coasts the main cause of beach erosion is (5), a decline in the supply of sand from the sea floor after a prolonged phase of sea level stability. In this context the Foreshore Erosion Board (1936) commented that there was no evidence of sand supply from the sea floor to beaches around Port Phillip Bay. There is certainly plenty of sand on the sea floor offshore, but (apart from shells and shelly debris) it is not now drifting onshore. However, sand formerly drifted in from the sea floor to beaches remote from eroding cliffs, such as the long beaches between Mordialloc and Frankston, and between Dromana and Rye, both of which formerly prograded with the formation of multiple beach and dune ridges. Halting of progradation was here due to a decline in shoreward drift from the sea floor, attributed to the attainment of a transverse nearshore profile that no longer permits sand to move up to the shore. Shelly debris, being lighter, can still drift in from sea floor areas where a shell fauna is present.

The onset of beach erosion is often regarded as having a single cause, when in fact there are several possible explanations. There is also a tendency to implicate human activity such as dredging or the construction of breakwaters: there is no doubt, for example, that harbour structures around Port Phillip Bay have contributed to erosion of adjacent beaches as sand moved in to lee-side areas of accretion. But coastal processes are complex and variable, and identification of the causes of beach erosion requires careful analysis and a long-term perspective.
Conclusions

1. There have been many changes on the coastline of Port Phillip Bay since European settlers arrived in 1835. Some changes have been natural (i.e. they would have happened anyway); others (such as insertion of breakwaters and groynes, or artificial renourishment of beaches) are due directly or indirectly to human activities.

2. The coastline of Port Phillip Bay has changed in response to natural processes with the sea at or close to its present level over the past 4,000 years. There is no possibility of natural stability being attained with the sea at its present level because of the continuing input of energy from winds, waves, storms and tides, generating erosion, onshore/offshore and longshore sediment transportation and deposition. The notion that the bay was undergoing ‘adjustment to the effects of the major sea level rise that occurred after the last ice age’ is chimerical, in that it implies that some kind of theoretical equilibrium would eventually be attained. There is no prospect of this as long as existing shore processes continue to operate.

3. The Foreshore Erosion Board (1936) made it clear that erosion was already a widespread problem in Port Phillip Bay in 1935, when there had already been coast protection works on several sectors in response to erosion. Subsequent changes can be detected by comparing air photographs and satellite imagery of successive dates.

4. Although there have been many descriptive reports, quantitative assessments of rates of erosion have been rare. The historical information is not sufficiently precise to be able to make measurements of coastline erosion around Port Phillip Bay. Nevertheless cliffed sectors have receded, and beaches have diminished in volume and area on several sectors of the bay coastline, except where they have been artificially nourished.

5. Assessments of coastline change are complicated by the existence of sequences of onshore-offshore and longshore sand drift, notably the seasonal alternations of longshore drift that are most pronounced on the north-east and east coasts of Port Phillip Bay. A dominance of longshore drift in one direction is seen on the south-west coast between Point Lonsdale and Swan Island, the west and north-west coast from Werribee River to north of Skeleton Creek, and the south coast between Point Nepean and Sorrento.

6. Coastal erosion has many causes, some of them having operated only locally or occasionally. Coastal erosion could have resulted from submergence and increased wave attack as a result of sea level rise in Bass Strait, transmitted in through the entrance to Port Phillip Bay. Other major causes are a reduction in sediment supply from cliffs that have been stabilised, local depletion of beaches resulting from interception of longshore drift by groynes or breakwaters and increased scour by wave reflection from sea walls.
7. Until 1969 the emphasis in coastal engineering around Port Phillip Bay was on protective works, initially wooden and brushwood structures, then stone and concrete walls of various designs, and boulder ramparts. Sea walls were generally accompanied by groynes designed to form compartments in which beach sand would be retained. Providing they were maintained, these groynes were of some value in retaining beaches, but during major storms sand can be withdrawn seaward, and then carried away by longshore drift. It may be necessary to replenish such beaches artificially.

8. The Foreshore Erosion Board (1936) recommended the extensive building of masonry sea walls to counter erosion, and in the following decade such walls were built on several sectors of the coastline. After 1946 construction of sea walls became sporadic, and erosion was generally gradual, with few major storms. Elaboration and extension of sea walls continued at intervals, as on the coast north of Point Lonsdale, where the 1940 sea wall was extended northward in 1947, 1966 and 1977. In the 1950s a number of harbours were created by building offshore breakwaters, attached to the mainland by jetties, as at St Kilda (1953) and Middle Brighton (1954), and at Sandringham between 1949 and 1954 a similar offshore breakwater was lengthened and attached to the mainland at Picnic Point to form Sandringham harbour. At various dates breakwaters and jetties were built at Mordialloc, Mornington, Queenscliff, St Leonards and Portarlington. All of these structures caused changes on adjacent beaches. At St Kilda and Middle Brighton cuspatte spits formed in the lee of the offshore breakwater, resulting in depletion of beaches to north and south, while at Sandringham sand lost from the Hampton coastline accumulated in the harbour. These changes made it clear that harbour construction could have adverse effects on beaches, but another harbour formed by building an offshore breakwater at Blairgowrie as late as 2001 had the same result, the formation of a cuspatte spit in its lee and consequent depletion of adjacent beaches. Meanwhile, attention shifted from building coastal structures to the management of bayside beaches.

9. Beach management had developed in the United States with the artificial restoration of a sandy beach at Coney Island, New York, in 1922. The success of this and other beach nourishment projects in the United States led to their introduction in the United Kingdom, where a depleted beach was restored at Bournemouth in the 1970s, and in several European countries, South Africa and south-east Asia (Bird 1996). In Victoria beach renourishment was attempted on a small scale at Black Rock in 1969 and Hampton in 1975, and from 1975 onwards there were numerous larger beach nourishment projects on the shores of Port Phillip Bay (Bird 1990b, 1991). Most of the artificial beaches were emplaced in front of sea walls or other earlier shore protection structures, but some, as at Quiet Corner south of Black Rock, were placed in front of eroding cliffs in order to halt coastline recession. Artificial beach nourishment has partly or wholly restored beaches that had been depleted by previous erosion, and if they had not been emplaced the beaches bordering Port Phillip Bay would now be much diminished, and in places lost altogether.

10. Attempts to stabilise a coastline by building solid structures such as sea walls, or dumping boulder ramparts, should bear in mind that a rising sea level is in prospect, and that coastline changes would resume with the sea at a higher level and these structures submerged. On the other hand, beaches can be renourished at higher sea levels, and the use of artificial beaches to halt coastline recession is a better long-term strategy than building solid structures.
References


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