INFRASTRUCTURE VICTORIA

SECOND CONTAINER PORT ADVICE

GEOMORPHOLOGY

NEARSHORE AND SHORELINE GEOMORPHOLOGY AND PROCESSES

PREDICTED IMPACTS OF CHANNEL UPGRADES

PREDICTED IMPACTS OF BAY WEST PORT DEVELOPMENT

PREDICTED IMPACTS OF PORT OF HASTINGS DEVELOPMENT

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PREPARED FOR: AECOM

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PURPOSE

The Victorian Special Minister of State has asked Infrastructure Victoria to provide advice on the future capacity of Victoria's ports, focusing on the need for, timing and location of a second container port. Currently all container shipping into Victoria is through the Port of Melbourne, which is Australia's largest container port. The Infrastructure Victoria Study is preparing advice on the ultimate capacity of the Port of Melbourne, when the port will reach capacity and when a second container port will be required. The Special Minister of State has also asked Infrastructure Victoria to assess two possible sites for the second container port, one at Hastings in Western Port and one at Bay West in Port Phillip Bay.

SCOPE OF WORK

Port Phillip and Western Port

- Predict impacts of channel upgrades (on nearshore and shoreline geomorphology and processes)
- Predict impacts of Bay West port development (on nearshore and shoreline geomorphology and processes)
- Predicted impacts of port of Hastings

REPORT STRUCTURE

This report is in three parts.

<u>Part 1</u> describes the geological and landform context of Port Phillip and Western Port.

<u>Part 2</u> describes shore zone geomorphology of Port Phillip.

<u>Part 3</u> assesses potential impacts on shore zone geomorphology of Port Phillip of proposed channel upgrades and Bay West container terminal.

<u>Part 4</u> describes shore zone geomorphology of Western Port

<u>Part 5</u> assesses potential impacts on shore zone geomorphology of Western Port of channel upgrades and Port of Hastings container terminal.

EXECUTIVE SUMMARY

This document provides detail of the geology and coastal geomorphology of Port Phillip and Western Port as a basis for assessing potential impacts of channel upgrades and development of a second container port. The two bays are contained in the Melbourne Zone, the central of the ten structural zones of Victoria. The Melbourne Zone basement is a

thick sequence of Ordovician to Middle Devonian marine and non-marine sediments with several large igneous complexes including granitic intrusions. Outcrop of Palaeozoic basement rock is very limited around the bays and confined to the central Mornington Peninsula and small areas around Stony Point in Western Port. Overlying the Palaeozoic are Mesozoic non-marine sediments and Cainozoic volcanics and sediments. Apart from areas of thick basalt in parts of Western Port, the post-Palaeozoic rocks are generally of low strength due to a combination of initial poor consolidation and subsequent deep weathering.

Tectonics resulting in the Port Phillip Sunkland and Western Port Sunkland has determined the orientation and configuration of both embayments. The Mornington Peninsula is uplifted along Selwyn Fault and Tyabb Fault and Bellarine Peninsula is elevated along Curlewis Monocline and Bellarine Fault. Due to faulting the initially resistant rocks are closely fractured, sheared and often deeply weathered and susceptible to erosion. Both embayments have extensive shorelines backed by low terrain and capped by weakly consolidated sediments.

Both embayments are sheltered from direct ocean swell and are fetch-limited. Tidal currents are highly significant as agents of sediment transport in southern Port Phillip and across much of Western Port where the large tidal range has developed a complex ebb-flood incised channel system.

Much of the pre-1840's shoreline of Port Phillip is now obscured or extensively modified by engineering works including widespread application of beach re-nourishment in Port Philip. Although major direct shore modifications in Western Port are confined to the Stony Point - Hastings area, much of the northern and north-east shoreline and the bay floor have been indirectly altered by draining formerly extensive freshwater wetlands that has triggered physiographic change in stream channels and sediment discharge to the bay.

The coast of both bays has a diversity of coastal landforms ranging from locally high and steep hard rock cliffs to low-angle wide intertidal mudflat and mangrove wetlands. Fourteen coastal landform categories are recognized and mapped and grouped into Coastal Geomorphic Units (48 in Port Phillip and 27 in Western Port). A Shore Zone categorization is developed that includes the intertidal to backshore to use as a measure of sensitivity of the coast to change. Using a combination of substrate composition, sediment texture, width and

slope of intertidal zone, 27 intertidal shoreline zonal classes are recognised. The response of the shore zones to channel widening and/or deepening is assessed for both bays.

Shorelines in Port Phillip are more responsive to wind-driven wave changes than to an increase in water level and wave type associated with the proposed channel and port project. It is concluded that in Port Phillip, shore zones will show no measureable geomorphic change to any small changes in wave form, wave energy and/or rise in sea-level associated with channel widening or deepening.

The proposed new container port and associated infrastructure in Port Phillip would be a substantial and rapid physical change in the nearshore configuration of western Port Phillip. As a new island it would function as a very large offshore breakwater. Changes in waves, currents, sediment movement and subaqueous and shoreline geomorphology would result including updrift deposition and downdrift. The effect of changed wave energy and onshore-alongshore sediment transport will result in sediment accumulation as bars and a cuspate foreland landward of the terminal in the wave shadow zone between Wedge Point and the mouth of Werribee River. Sediment volumes cannot be determined in this study but are not expected to be significant. Further north, beaches will receive less sediment but will also be subject to much reduced wave action and less potential erosion due to the breakwater effect of the terminal.

Shorelines in Western Port include long sectors of intertidal mudflat and mangrove that are more responsive to changes in water level and wave power than coarse-sediment and rock shore zones. This is a function of the higher component of fine-grained sediment and potentially greater mobility of the sediment due to shallow water and the greater effectiveness of strong tidal and wind-driven currents. The low earth cliff shorelines southeast of Main Drain - Bunyip River are the most vulnerable to changes in tide and wave conditions. The very small change in tide and/or wave processes associated with the proposed dredging and container terminal structure compared with ambient processes suggest no measureable geomorphic change could be expected with proposed channel changes and port development.

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1 CONTEXT: SOUTHERN VICTORIAN GEOLOGY AND STRUCTURE

The landscape framework of Port Phillip and Western Port was established by tectonic and rock-forming events across southern Victoria since late Precambrian times. Cayley *et al.* (2002), Cayley (2011) and Moore (2016) showed that the basement under central Victoria is an extension of the Selwyn Block—a north-south zone of Neoproterozoic to Cambrian (~600 to 560 million years old) metasedimentary and metavolcanic continental crustal rock—extending from northern Tasmania across Bass Strait to northern Victoria (Figure 1). Although of limited outcrop in Victoria the Selwyn Block has played a major role in defining the structure of the Melbourne Zone and is a partial source of magmas that produced Devonian granitic and associated volcanic rocks in south-central Victoria.

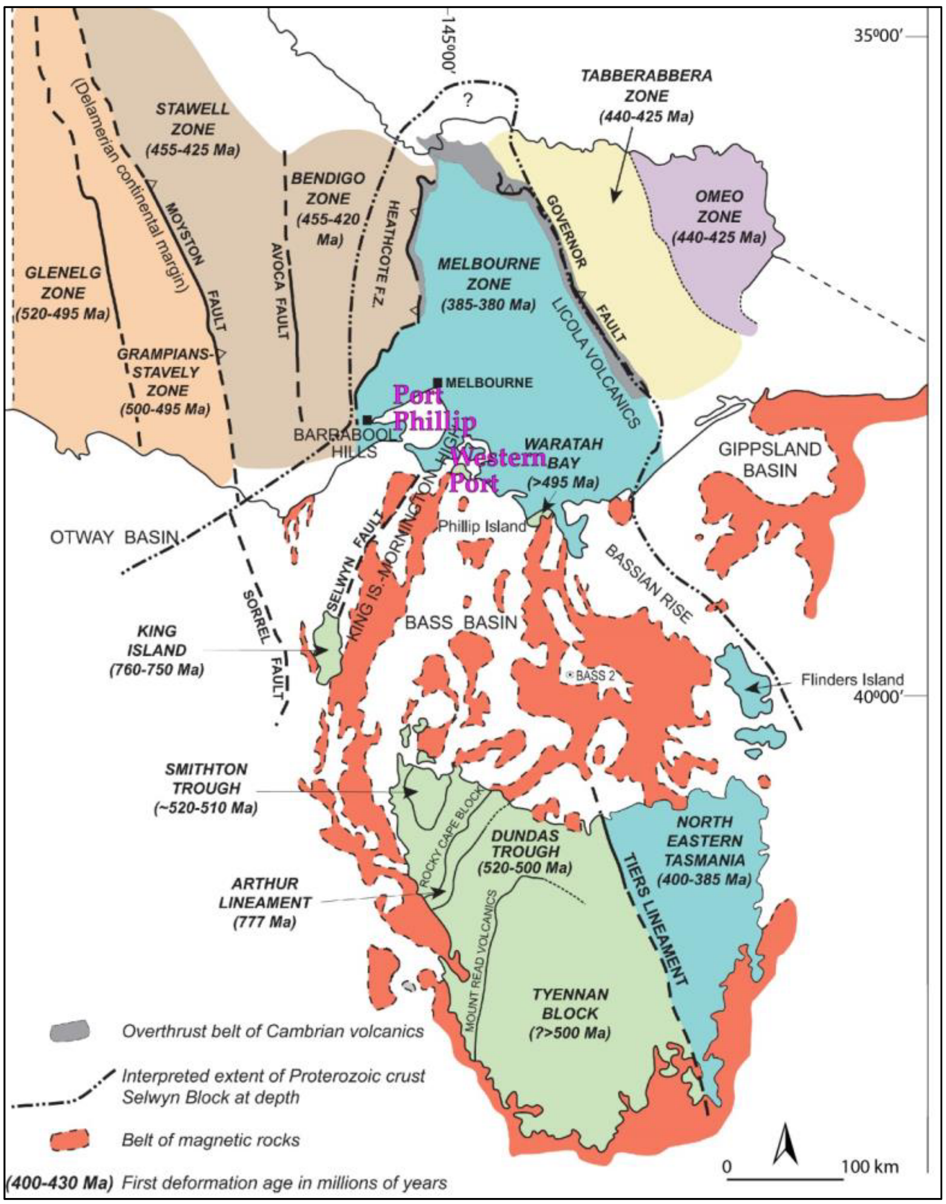

Figure 1. Port Phillip and Western Port in relation to the Selwyn Block (after Cayly *et al.* 2002).

The Melbourne Zone—central of the ten structural zones of Victoria (Gray *et al*. 2003)—is a sequence of Lower Silurian to Middle Devonian sedimentary rock formations up to 10 km thick (the Murrindindi Supergroup) overlying Ordovician sediments of the Sunbury Group and Castlemaine Group. The Murrindindi Supergroup is mudstone dominant with lesser sandstones and is folded and faulted along north-trending strike. These rocks crop out in the Melbourne area and to the north and east where they are intruded by the Dandenong, Acheron and Cerberean Igneous complexes, and large granitic bodies including the Tynong Batholith and You Yangs Batholith (Figure 2).

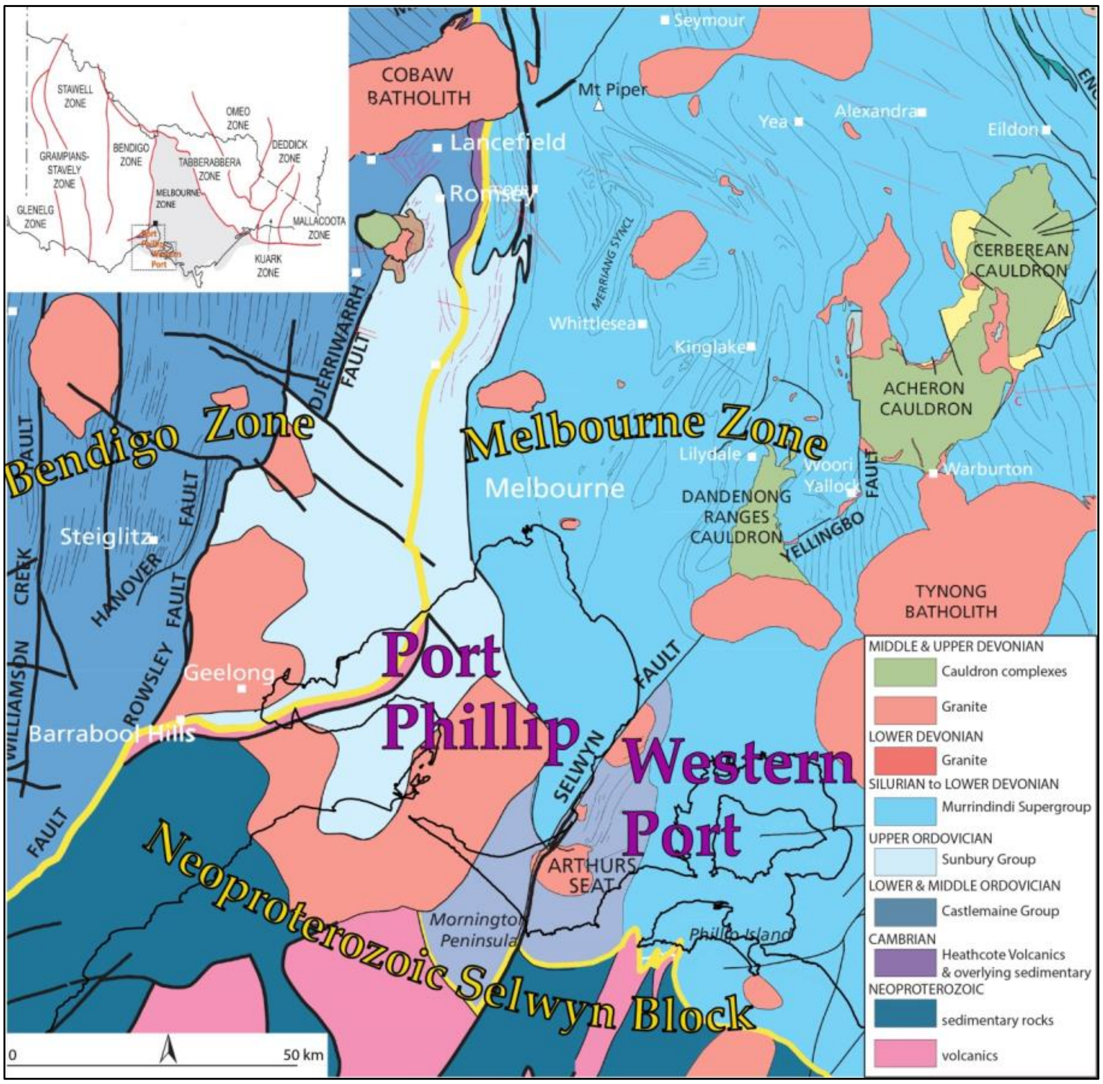

Figure 2. Selwyn Block and Melbourne and Bendigo Zone bedrock geology (After VandenBerg *et al.* 2000).

The Ordovician and Silurian rocks are the bedrock of Port Phillip and Western Port (VandenBerg *et al.* 2000) but coastal outcrop is limited to the smaller granitic bodies of Mt Eliza, Mt Martha and Arthurs Seat on Port Phillip, and Silurian sedimentary beds at Sandstone Island and north of Stony Point on Western Port.

Tectonics is a major determinant of outcrop, and faulting and rock structure has substantial influence on present landforms across southern Victoria. The broad configuration of Port Phillip and Western Port is determined by faulting and the Mornington Peninsula is an uplifted ridge of Palaeozoic sedimentary rocks and granites. Figure 3 and Table 1 summarise the main characteristics of the geological and landform regions surrounding Port Phillip and Western Port.

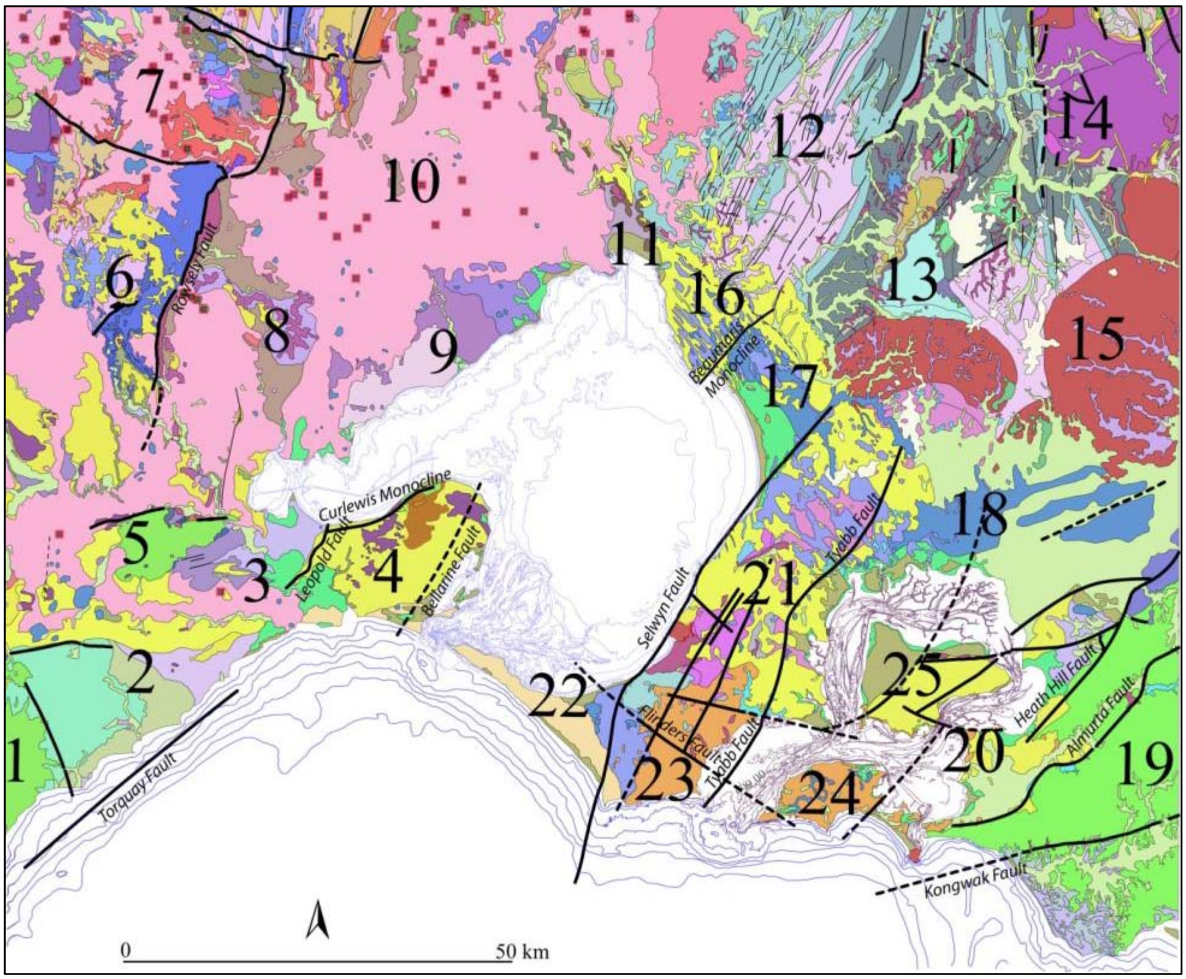

Figure 3. Geological and landform regions of Port Phillip and Western Port and submarine contours. For legend see Table 1 (Geology from Seamless Geology, Geoscience Victoria 2011).

TABLE 1. GEOLOGICAL AND LANDFORM REGIONS

NUMBER	GEOMORPHOLOGY	GEOLOGY
1	Otway Ranges. Steep dissected ridge and valley terrain. Coastal platforms.	Mesozoic feldspathic sandstone and mudstone.
2	Torquay Embayment. Plateau, low hills, coastal cliffs.	Oligocene to Miocene calcareous and mudstone rocks with some volcanics.
3	Lower Barwon-Connewarre wetlands.	Quaternary coastal and lagoon deposits.
4	Bellarine Peninsula plateau and ridges. Coastal cliffs, bluffs and terraces.	Mesozoic sediments overlain by Older Volcanics and Brighton Group sediments.

5	Barrabool Hills, broad ridges and valleys.	Mesozoic feldspathic sandstone and mudstone.
6	Brisbane Ranges, uplifted plateau and dissected ridge and valley terrain.	Ordovician sedimentary rocks with Brighton Group capping.
7	Parwan Valley - deep eroding fault-bounded valley.	Cainozoic non-marine sediments and residual volcanic cappings.
8	Granite ridges surrounded by colluvium.	You Yangs Granite baholith,
9	Lower Werribee River valley	Quaternary alluvium and coastal deposits.
10	Werribee volcanic plains and hills.	Newer Volcanics plains and valley basalt flows and eruption points.
11	Lower Yarra valley and delta.	Quaternary alluvial, deltaic and coastal deposits.
12	Kinglake dissected plateau and ridges.	Silurian-Devonian sedimentary rocks - strike ridges and valleys.
13	Dandenong Ranges hills and ridges.	Devonian igneous complex - granites and associated volcanics.
14	Healesville-Warburton Ranges	Acheron igneous complex - granites and associated volcanics.
15	Bunyip Ranges - plateau and ridges.	Tynong Granite and contact metamorphic aureole.
16	Brighton Coastal Plain and low parallel sand ridges.	Brighton Group sedimentary rocks and Quaternary sand ridges.
17	Carrum wetland and coastal ridges.	Downfaulted depression and wetlands.
18	Cardinia, Koo-we-rup and Tobin Yaloak drained wetlands.	Late Quaternary swamp and coastal deposits.
19	South Gippsland (Western Strzelecki Ranges) dissected hills, ridge and valleys.	Mesozoic feldspathic sandstone and mudstone.
20	Bass Valley and delta.	Quaternary sediments and costal deposits.
21	Mornington Peninsula Host - low ridges, coastal cliffs and shore platforms, (west), mangrove wetlands (east)	Uplifted outcrop of Ordovician Castlemaine Group, Older Volcanics and Brighton Group sediments.
22	Nepean Peninsula low sand ridges, beaches, coastal cliffs and shore platforms.	Quaternary Bridgewater Formation and unconsolidated dune sands.
23	Flinders Plateau, coastal cliffs and shore platforms.	Older Volcanic lava flows.
24	Phillip Island low hills, coastal cliffs and beaches.	Older Volcanic lava flows, Woolamai Granite.
25	French Island low hills, coastal wetlands.	Small areas of Mesozoic feldspathic sandstone and mudstone. Older Volcanics lava flows.

1.1 Geological & Landform Evolution

The main events in the geological and landform evolution of the south-central Victorian coastal region are:

- *Late Proterozoic -Cambrian:* development of Selwyn Block as an exotic Proterozoic microcontinent.
- *Ordovician - Middle-Late Devonian:* continuous marine sedimentation.
- *Late Devonian:* deformation of earlier formed sedimentary rocks producing the structural overprint of folding and faulting that persists to the present time.
- *Late Devonian*: igneous activity producing granitic batholiths
- *Permian:* widespread continental glaciation and accumulation of glacial meltwater deposits.
- *Mesozoic (Late Cretaceous):* pre-separation of Australia and Antarctica rifting and non-marine sedimentation in Bass, Otway and Gippsland Basins.
- *Palaeogene - Palaeocene to Oligocene:* development of the central sedimentary basins along faulted-subsiding margins (Torquay, Port Phillip Western Port), initially non-marine clastic sedimentation followed by marine carbonate sedimentation.
- *Neogene: Miocene to Pleistocene:* alternating subsidence (transgression) and uplift (regression) with corresponding marine and terrestrial sedimentation including coal deposits in Port Phillip Basin.
- *Pleistocene:* fluctuating sea-levels corresponding to global glacial (low sea-level) and inter-glacial (equal or higher sea-levels).
- *Late Pleistocene:* emplacement and cementation of large coastal carbonate dune sands (Bridgewater Group).
- *Holocene:* establishment of present sea-levels with short episodes of slighty higher and lower sea-level.
- *Anthropocene:* European invasion, introduction of exotic plant and animal species influencing coastal and marine sedimentation and landforms.

Apart from small outcrops of uppermost Selwyn Block material such as at Ceres in the Barrabool Hills, and of Mesozoic sediments on the Bellarine Peninsula and South Gippsland, the exposed basement rocks of the Melbourne Zone are Ordovician to Devonian sediments and the Devonian igneous complexes. Basement outcrop is controlled by faulting

and folding. Structural control of inland and coastal landforms—from outcrop to landscape scale—is evident in many places e.g. dipping beds along the Curlewis and Beaumaris Monoclines and fold hinge-aligned ridges and valleys in Siluro-Devonian sediments from Melbourne to the northeast. The igneous geologies are landform positive, such as the You Yangs, Dandenong Ranges, Mount Martha and Cape Woolamai.

1.2 Coastal Configuration

The configuration and geomorphology of the south-central Victorian coast is determined by north-trending faults producing two large depressions—the Port Phillip Sunkland and Western Port Sunkland (Figure 4).

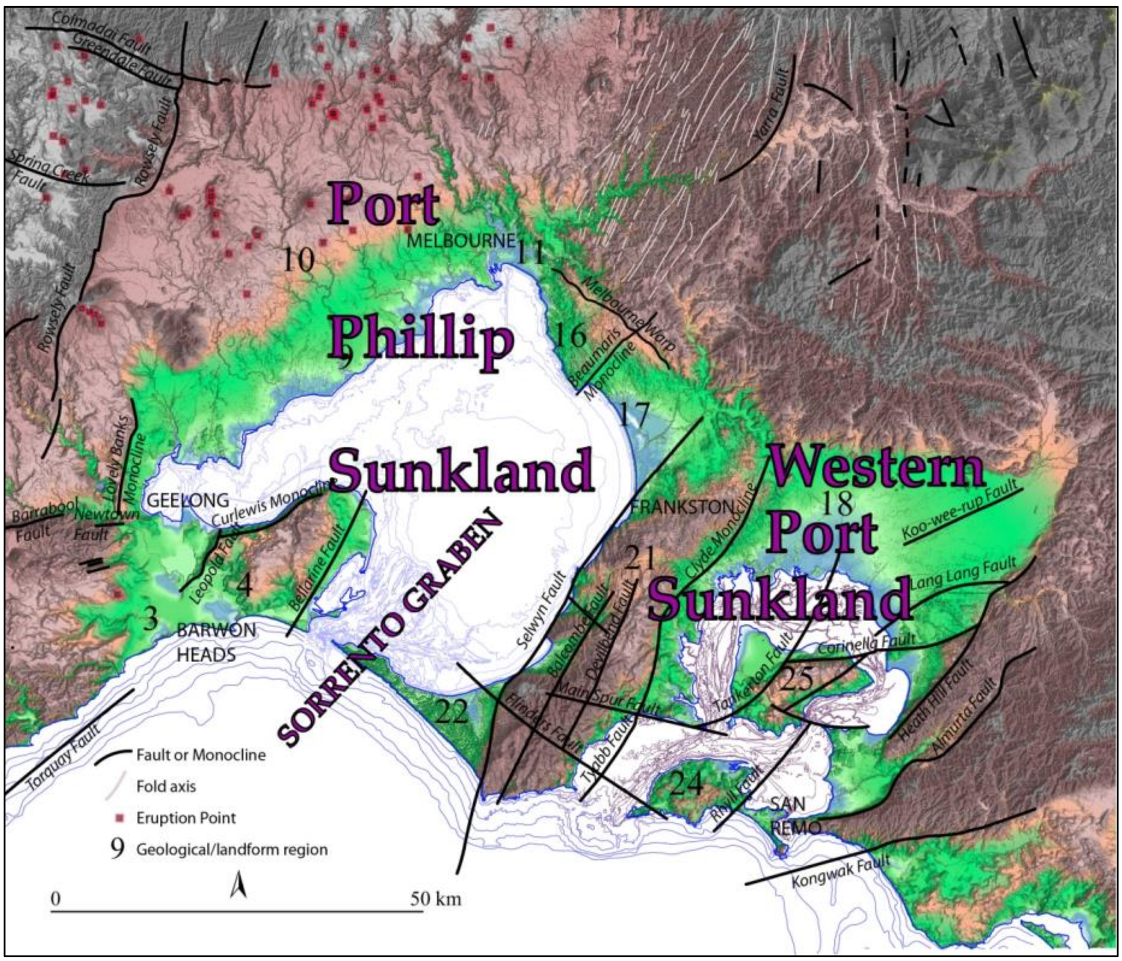

Figure 4. Faults, fold axis and eruption points around Port Phillip Sunkland and Western Port Sunkland. (After Seamless Geology 2011). Geological/landform regions as in Table 1. Bathymetry 10 m interval (Bass Strait), 5 m interval Port Phillip and Western Port.

1.2.1 Port Phillip Sunkland

Port Phillip Sunkland lies in the downthrown block between the Rowsley Fault and Selwyn Fault at the western edge of the Mornington Horst (#21 on Figure 4), a fault-bounded geological and topographical high between the Port Phillip and Western Port

Sunklands. The Rowsley Fault—the western margin of the Port Phillip Sunkland—is a rejuvenated older fault, with considerable vertical movement during the Quaternary. The Selwyn Fault— a steeply dipping reverse fault at the eastern margin—is intermittently active as shown by a shallow earthquake of magnitude 4.5 and maximum intensity of over 5 recorded at Mornington on 3 September 1932 (Joyce and Webb 2003). The Selwyn Fault has clear topographic and geological expression on the Mornington Peninsula coast of Port Phillip, in part due to the erosion and exposure of fault-stressed rocks from relatively high wave energy generated by storms across the north to northwest fetch.

As well as being the main component of present landform, the Port Phillip Sunkland has been a depositional basin (the Port Phillip Basin) over the Cainozoic, accruing marine and terrestrial sediment. The thickest accumulation (>1000 metres) is in the Sorrento Graben between the Bellarine Fault and Selwyn Fault (Holdgate *et al.* 2002).

1.2.2 Western Port Sunkland

The Western Port embayment is shaped broadly by a series of north to northeast-trending faults that define the Mornington Peninsula, the Westernport Sunkland and the western margin of the Strzelecki Ranges. Subsidiary east-west oriented faults have produced an elevated central block in the sunkland that is the basis for Phillip Island and French Island. A wide variety of interacting processes including tectonics, exposure of varied lithologies, accumulation of alluvial and aeolian sediments and the development of a range of wetland plant communities including mangrove and saltmarsh has resulted in a diverse coastal and backshore environment. Although crossed by numerous faults (Figure 4, Figure 5), with the exception of Heath Hill Fault and Almurta Fault their topographical expression is more subdued compared with the coastal exposures and geomorphology occasioned in Port Phillip by Selwyn Fault.

1.3 COASTAL GEOLOGY

The high tide shore of both embayments is backed by geological materials innately of low resistance to displacement or erosion. Long sectors of coast are topographically low and comprised of beach and dune sediments including barrier and dune ridges and alluvial and intertidal sands, silts and clays. In Port Phillip, relatively resistant geology is limited to short sectors of granites at Mornington and Mount Martha, Newer Volcanics Group basalt at Williamstown and Point Lillias and outcrop of strongly ferruginous beds of Brighton Group and Beaumaris Sandstone at Beaumaris and western Corio Bay (Figure 5).

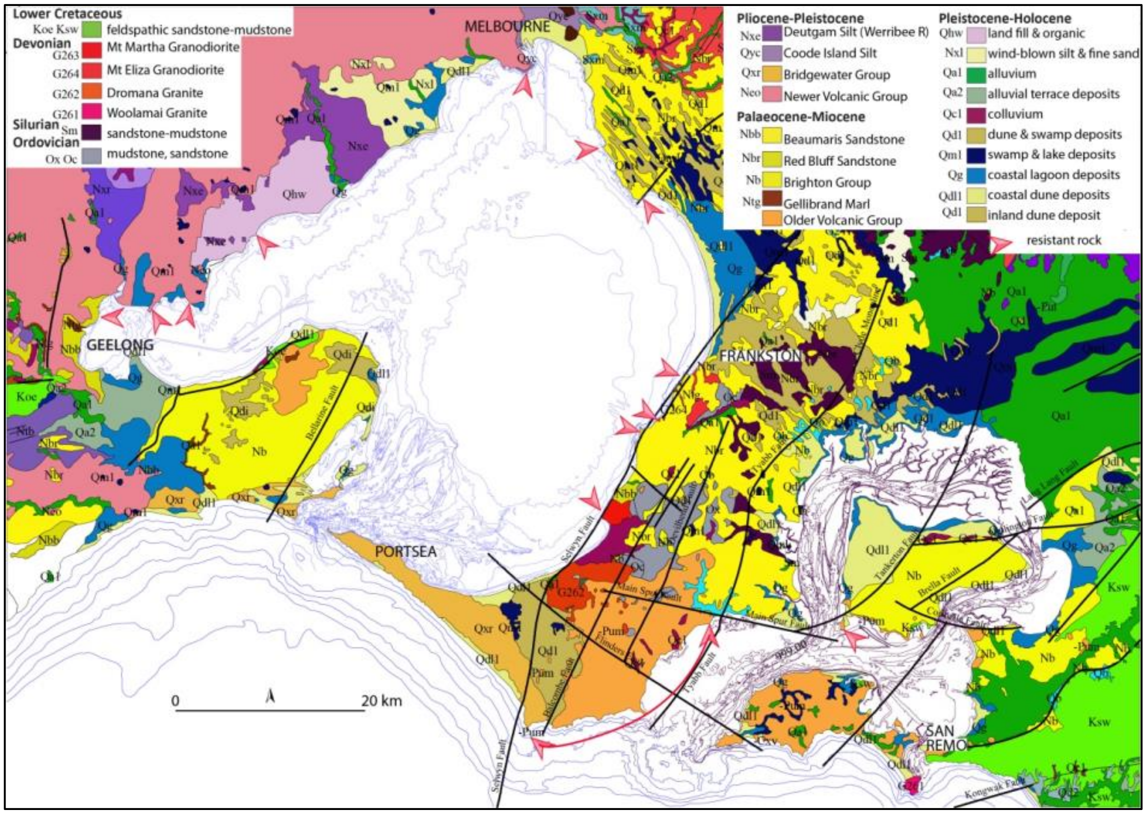

Figure 5. Coastal geology and structure, and sectors of resistant rock: Port Phillip and Western Port, (after Seamless Geology, Geoscience Victoria 2011).

Many sectors of the steep coast of the Bellarine and Mornington Peninsulas—including the granitic and Older Volcanic geologies—are fault-elevated and the rocks are closely fractured, sheared and often deeply weathered and susceptible to erosion. Poorly consolidated Brighton Group, Beaumaris Sandstone and Bridgewater Formation limestone not protected by sea walls also display steep and receding backshore.

Although marine Ordovician and Silurian sediments form the uplifted core of the Mornington Peninsula they have limited outcrop on the Western Port coast. The most extensive forms Sandstone Island and a small area of shore platform between Hastings and Crib Point. Devonian granitic rocks at Cape Woolamai and Pyramid Rock on the southern coast of Phillip Island is outside the present study. Limited outcrops of Lower Cretaceous arkose and mudstone occur along the eastern coast of Phillip Island, on the eastern San Remo Peninsula, the south coast of French Island and parts of Elizabeth Island. The most widespread hard rock materials around the Western Port coast are multiple flow units of Palaeocene to Oligocene age basalt and tuff. They form high cliffs and shore platforms from Cape Schanck to Flinders, more subdued bluffs and low cliffs to Somers, at Corinella, Cobb Bluff and the south coast of French Island.

Overlying the volcanic sequence is the Upper Miocene Brighton Group sandy fluviatile beds. The formation is widespread on French Island and the western side of Western Port from Heath Hill south to Corinella. The sediments that outcrop are generally strongly discoloured by ferruginous cementation although this does not persist at depth (Thompson, 1974). This cementation is very marked in coastal outcrops at Crib Point and Reef Island where pebbles eroded from the ferruginized beds accumulate as gravel beaches. Jenkin (1962) mapped a formation he termed the Warneet Beds that are exposed in Cannon Creek at Warneet and in bores to the north.

Most of the Western Port coast is composed of or fringed by unconsolidated Quaternary sediments of beach, aeolian, fluvial, colluvial, paludal and deltaic origin and include a range of active and palaeo fresh-water and saline environment organic deposits.

1.4 Configuration, High Water & Low Water Shorelines

Port Phillip has a single ocean connection defined by rocky headlands fringed by shore platforms at Point Nepean and Point Lonsdale. Western Port embayment has multiple entrances determined by Phillip Island and French Island. Shoreline length and type varies with the state of the tide (Figure 6). High water shoreline in an embayment should theoretically be longer than low tide but this only applies in a basin with smoothly sloping intertidal surfaces. In an embayment with estuaries or complex intertidal morphology such as tidal creeks and incised tidal channels, the shoreline length at low tide may be longer than at high tide as the banks of the channels are alternately exposed and flooded.

The high water shoreline length of Port Phillip including Swan Island, Duck Island and Mud Islands is approximately 310 km (Marine Bathymetry data set : Dept. of Sustainability and Environment 2014). Low Water shoreline length measured from the same data set is 332 km, the increase due largely to low tide exposure of channels and pools in Swan Bay. Western Port shoreline has complex configuration due to the large tide range and islands. Including French Island and the northern coast of Phillip Island, there are 342 km of high tide shoreline between Cape Schanck and San Remo, (Water Technology 2013). Adding estuarine and tidal channels increases this figure to 530 km (Arrowsmith *et al.* 2015). The low water shoreline length calculated by adding the segments of the marine bathymetry data set (Dept. of Sustainability and Environment 2012) is an extraordinary 672.731 km. The low tide shoreline has very different geomorphology from the high tide shore.

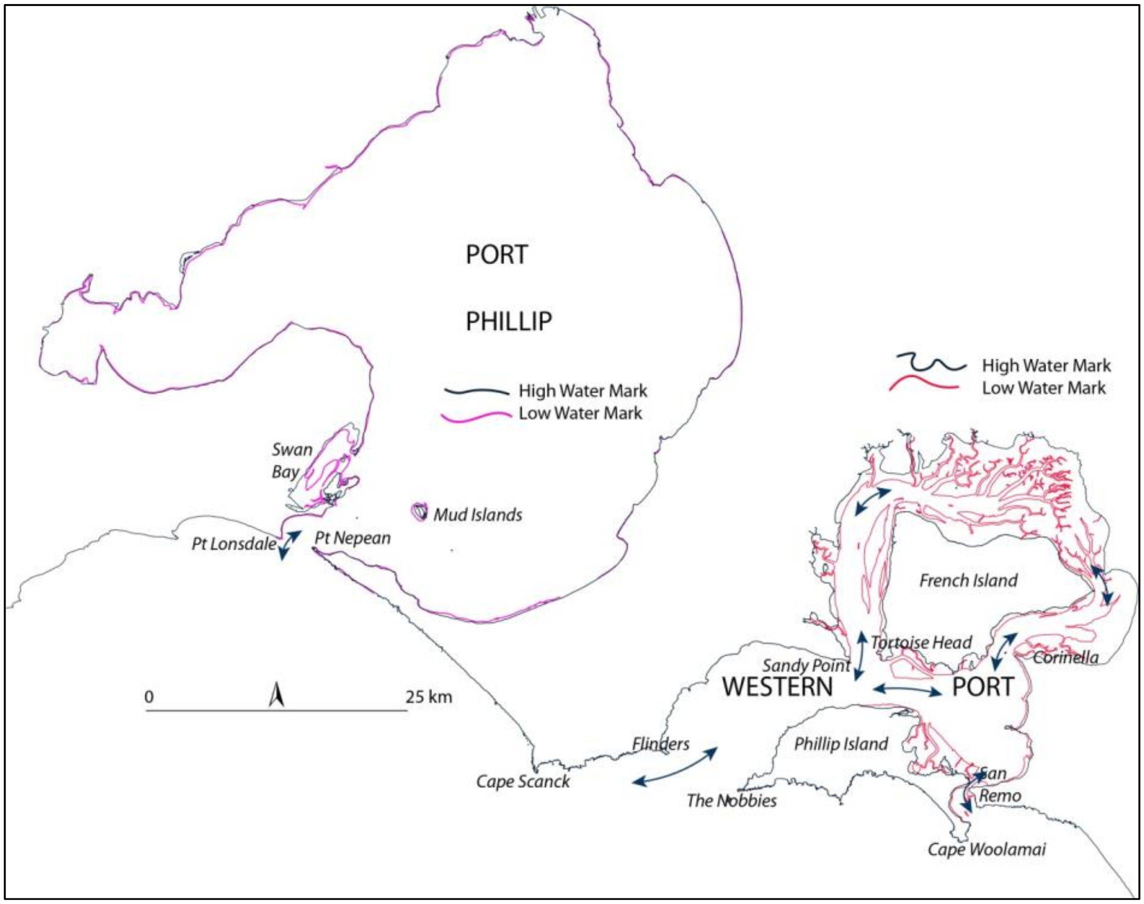

Figure 6. Entrances and High Water and Low Water shorelines Port Phillip and Western Port (Marine bathymetry data set: Dept. of Sustainability and Environment 2014). The multiple entrances and complex of tidal channels in Western Port greatly increases the Low Water shoreline length.

1.5 Shoreline and Coast

Shoreline (strand or limit of swash) is the instantaneous linear position of the water-land interface. Shorelines migrate vertically and horizontally landward and seaward on time scales ranging from the few seconds of swash-backwash exchange to the millennial and longer scale of absolute (eustatic) regional sea-level. In between these extremes strand line position is influenced by tides and wind and occasionally by exotic events such as slow to rapid tectonic uplift or subsidence, tsunamis and extreme fluvial inputs. Along with sea-level, the long-term overall control of the position of the strand is the coastal gradient.

The coast is a zone rather than a rigidly defined spatial entity and has offshore and onshore components where the interaction of terrestrial, marine and atmospheric components and processes produce a complex dynamic environment. The coast is a transitional area with vertical and horizontal boundaries, often indistinct but sometimes clearly defined and with very narrow limits. The coast is inherently a zone of change - human response must at least recognise, and ideally should be governed by, this inherent property.

1.6 Coastal Landforms

A geomorphic definition of the coastal zone takes account of features that present-day and past marine processes are the major factor defining the ongoing form and coastal character. Inside the coastal zone are a diversity of physical and biological properties, modes of evolution, and geographic occurrence. One purpose of classifying coastal landform systems is to provide a consistent framework to understand the controls on the temporal and spatial changes in position of the strand, as it is the core coastal landform. Such classifications must take account of the diversity of contemporary and inherited onshore and offshore factors determining coastal form and dynamics and therefore the rates change.

The components of a coastal landform classification are determined by purpose of the classification and the scale or resolution of representation (global to local). The purpose of present study is to assess shoreline response to potentially very small changes in water level, waves and currents in two semi-enclosed marine embayments with different tidal regimes. A generalised mapping scale of 1:25,000 has been adopted and the key components defining different coastal landform categories are: (1) elevation of backshore, (2) cross-shore profile from the supratidal zone to subtidal, (3) composition of shoreline materials, (4) shoreline dynamics (shoreline and backshore marine and terrestrial processes), (5) engineering or other direct human modifications to the backshore, foreshore and nearshore, (6) biological material as a shoreline process and form, (7) relict (palaeo) shorelines. The influence of the seven components on coastal geomorphology varies between Port Phillip and Western Port.

Coastal landforms of Port Phillip and Western Port are determined by local geology and structure, the occurrence of relict landforms, ongoing marine (tide range and wave regime) and terrestrial (runoff and streamflow) processes and biological features, particularly mangrove and saltmarsh. The two bays display substantial geomorphological and process differences. For this report, the coastlines are classified into landform categories based on composition, origin and dynamics of the landform. The categories are then grouped into coastal geomorphic units around each bay. Figure 7 is an example of four landform categories at Black Rock which are part of geomorphic unit 34 (Figure 10).

Details of the coastal landform categories and an assessment of their potential response to further channel deepening is provided in Sections 3 and 4 for Port Phillip and Section 5 for Western Port.

Figure 7. Examples of coastal landform categories in Port Phillip Bay at Black Rock Point: (A) *engineered coast*: sea wall, rock revetment, pier, filled former seafloor, covered former cliff, re-nourished beach; (B) *active cliff soft rock*; (C) *shore platform and active cliff hard rock*; (D) *high coastal bluff*. (Photo N. Rosengren June 2009).

1.7 Engineering Modifications

1.7.1 Port Phillip

Much of the pre-1840's shoreline of Port Phillip is now obscured or extensively modified by engineering works dating from the 1840's (Figure 8). Parts of Port Phillip Bay and the lower Yarra River channel have been artificially deepened since the 1850's to facilitate berthing and to accommodate larger vessels. Initial works focussed on the Yarra River and included steam dredging the river mouth, blasting basalt rock bars at Queen Street and Spencer Street, shortening the river by constructing the Coode Canal and excavations for Victoria Dock. Deepening the bay entrance by blasting limestone rock began in 1864 and continued until the 1950's. Subsequently, shipping channels in the south of the bay were established and maintained by regular dredging (South Channel, the Corio Bay and Yarra entrance channels) and dredge material grounds established (Figure 8).

The initial structures to service passenger and cargo trade were concentrated at Portsea, Port Melbourne and near Geelong, but to meet increasing requirements of recreational boating, mooring and launching facilities including large breakwater-defended marinas and canal estates are now widespread around Port Phillip. Sea walls, revetments, groynes and landfill have been constructed to prevent or reduce coastal recession and secure built assets. Since the mid 1970's beach re-nourishment using sand from land sources, nearshore dredging or low tide scraping has been applied to at least 30 sites around the bay. Extensive areas of the immediate backshore are now fundamentally reshaped by industrial and service facilities including the former salt works at Altona,

Western Treatment Plant at Werribee, aerodromes at Point Cook and Laverton, and widespread residential subdivisions including bay-linked canal estates at Point Cook, Paterson Lakes and Martha Cove.

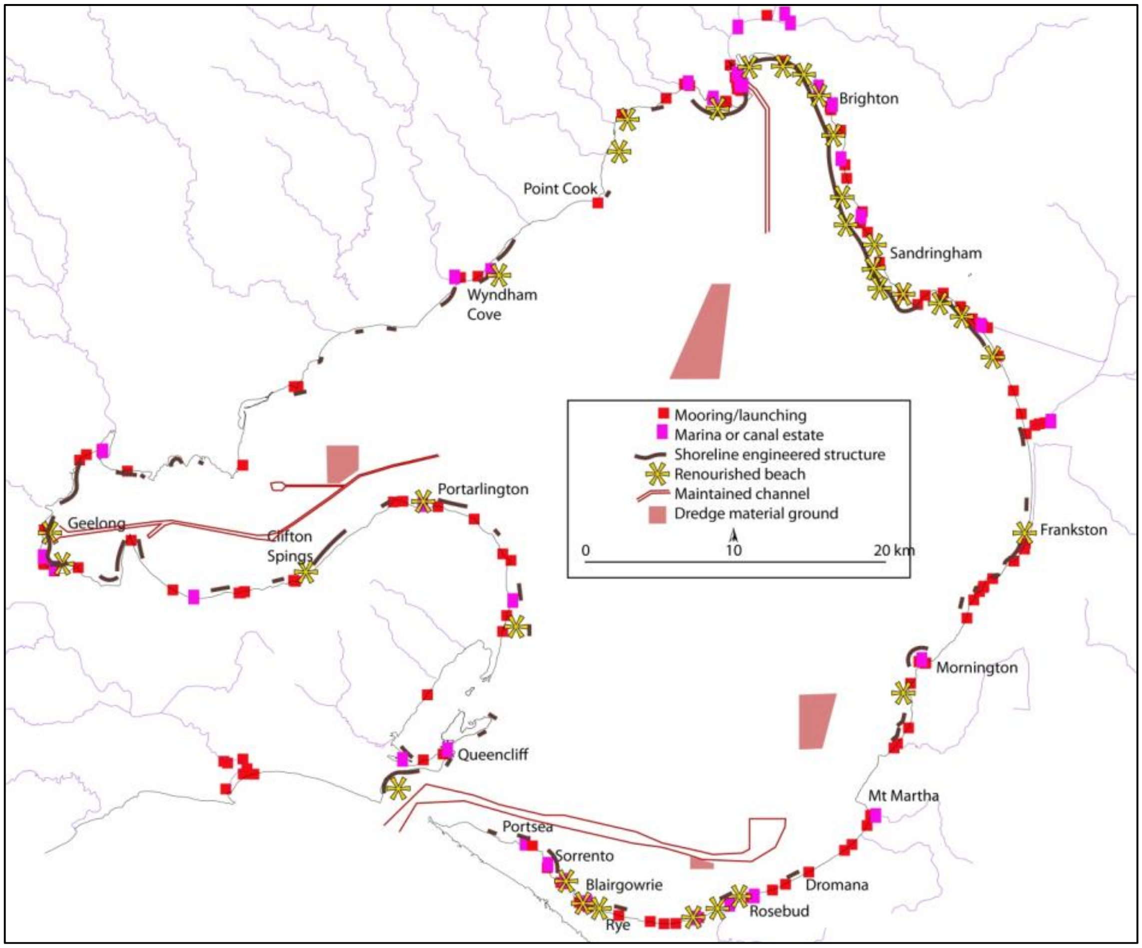

Figure 8. Shorelines of Port Phillip modified by port and harbour facilities, shore protection structures and beach nourishment (After Bird 2011, DELWP 2016 and interpretations NearMap aerial photographs 2015-16).

1.7.2 Western Port

Direct engineering modification of the Western Port shoreline is less than in Port Phillip and concentrated between Stony Point and Yaringa including the industrial port at Hastings (Figure 9). The largest recreational boat mooring and services facilities are the deepened and breakwater marinas at Hastings, Yaringa and Newhaven on Phillip Island. A substantial extension to the Yaringa Marina including excavating a basin and lock connected to the existing marina has been approved (Planning Panels Victoria, 2015). Authorized foreshore protection structures have been built at Somers, Lang Lang, Jam Jerrup (Red Bluff), San Remo and Cowes and an earthen backshore levee extends east of Tooradin to Lang Lang. North of Grantville and at the Lang Lang Foreshore Reserve are a number of private informal structures, some derelict. A maintained deep water channel leads to Crib

Point and Long Island Point via the Western Passage (Figure 8). Other excavations below high water include deepening of the existing marinas at Hastings and Newhaven and cutting and maintaining the entrance to the excavated marina at Yaringa.

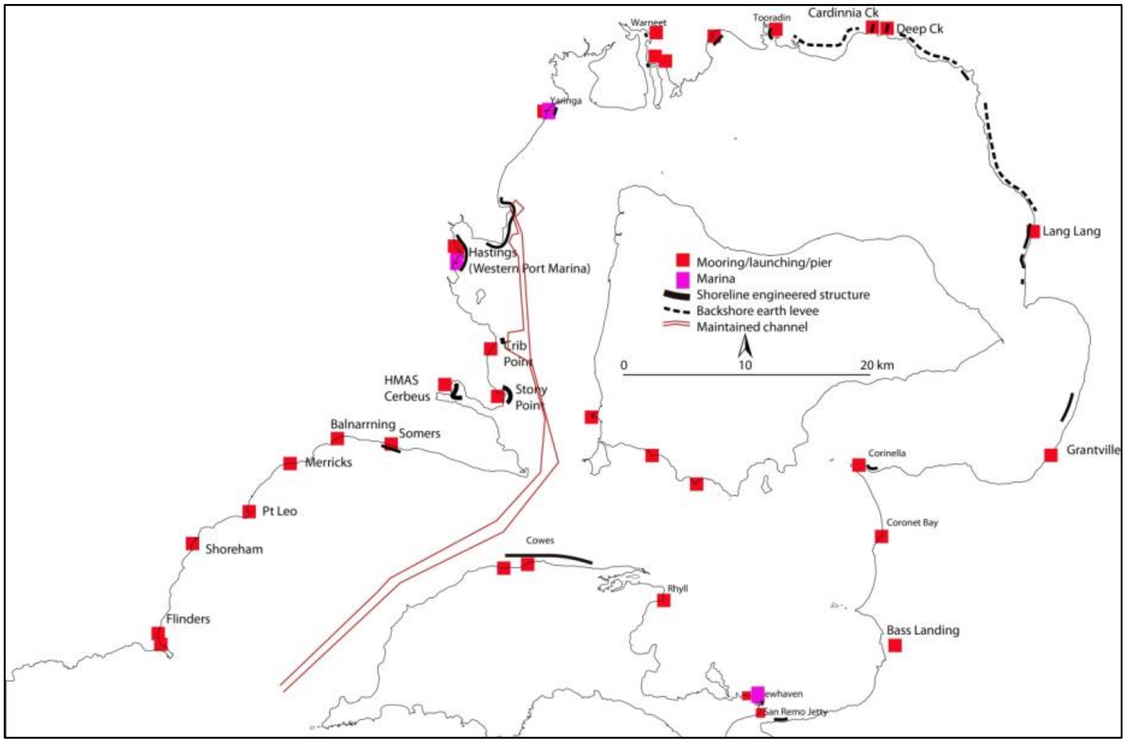

Figure 9. Shorelines of Western Port modified by port and harbour facilities and shore protection structures.

The most substantial change around Western Port has been the draining of the formerly extensive freshwater wetland fed by the Bunyip River, Lang Lang River, Yallock Creek and Cardinia Creek that extended from north of Koo-Wee-Rup west to Heath Hill and south to Lang Lang Beach (Hills 1942, Yugovic and Mitchell 2012). The swamps contained variable thickness of peat and clay exposed along the coast between the Bunyip River and Lang Lang Beach. The swamp deposits have been traced offshore (Miles, 1976) and underlie the tidal flats in the north-east of Westernport Bay where they are exposed in the tidal channels. Beginning in the 1880's the area is now entirely drained and claimed for agricultural land. Swamp drainage initiated major physiographic changes in the channels of the Bunyip River, Lang Lang River and Cardinia Creek. Deep incision of formerly swampy channels has exposed the underlying material and headward erosion has excavated sandy and gravelly prior stream and fan deposits and moved them down the drains to the coast and onto the floor of Western Port.

2 PORT PHILLIP COASTAL GEOMORPHOLOGY: BACKGROUND TO ASSESSING POTENTIAL IMPACTS OF CHANNEL UPGRADES

2.1 Physical Characteristics of Port Phillip

The principal physical and process characteristics of Port Phillip are:

- Single narrow entrance-opening to Bass Strait with high wave energy and strong tidal currents.
- Extensive accumulation of mobile sand shoals (Great Sands) inside the entrance underlain by Bridgewater Formation.
- Limited transmission of swell waves across Great Sands into the bay.
- Fetch-limited.
- Dominance of local wind in wave and current generation and sediment transport.
- East coast subject to storm wave conditions with locally very high impact on beaches.
- Negligible sources of beach sands from cliffs and streams.
- Asymmetric bathymetry - deeper and steeper on the eastern side and a shallow seafloor gradient on the west.
- Diverse geology as a result of the uplifted fault/monoclinal blocks forming the Bellarine Peninsula and Mornington Peninsula.
- Fractured and sheared bedrock along Selwyn Fault Mornington Peninsula coast.
- Uniformly low relief along the western coastline from Williamstown to Geelong.
- Deltaic fill of the Yarra valley.
- Long, low coastal barrier and dune enclosing former wetland (Carrum Swamp).
- Intermittent sectors of cliffs-bluffs with or without beach and narrow shore platforms on the northeast (Brighton to Beaumaris) and central east (Frankston to Mt Martha).
- Long sector of Bridgewater Formation cliffs and shore platform south of Sorrento.
- Wide and variable cover of seagrass/macroalgae along western coast.
- Limited area of coastal wetland (mangrove and saltmarsh).

2.2 Coastal Geomorphic Categories

Fourteen coastal geomorphic *categories* (including two anthropogenic) are recognised in Port Phillip (Figure 11). Within each category is a limited range of characteristics, chiefly the elevation, composition and dynamics of the landform. A key difference between each category is their response to coastal processes and in particular how they respond to changed water levels and wave energy. Most points along a coastline are comprised of two or more landform categories, for example a sandy beach in front of a low coastal bluff or a shore platform at the base of a hard rock active cliff. As the focus of this document is to define shoreline response to small water level changes, the categories that are shown on the map (Figure 11) are those most relevant to the potential long term impact of this rise. in the following sections, each category is briefly described and illustrated by maps, profiles and photographs.

Using the *landform category* as the basis, the bay shoreline has been divided into 48 *coastal geomorphic units*, each unit being a discrete distance along which single or limited multiple categories occur or re-occur (Table 1 and Figure 11). For example, *unit 13* represents the high bluffs at Clifton Springs, much of which has backshore engineered structures.

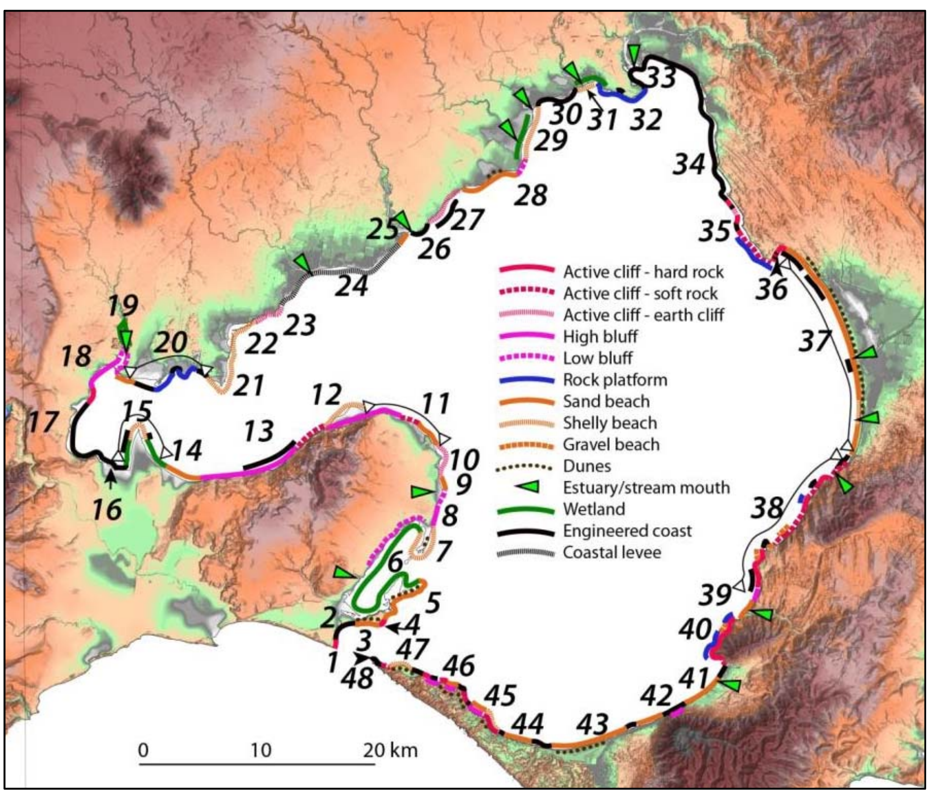

Figure 10. Coastal landform categories and coastal geomorphic units, Port Phillip. (Source: 10 metre DEM, field and aerial inspections, NearMap images).

TABLE 1: Port Phillip Coastal Geomorphic Units

No	Length km	Location	Geology	Geomorphology
1	0.7	*Pt Lonsdale*	Bridgewater Formation calcarenite	*Active cliff hard rock, shore platform*, minimal dry beach, and associated rubble and scree forming coastal bluffs.
2	3.4	*Pt Lonsdale Front Beach*	Bridgewater Formation & foredune	Fronted/covered by 3.42 kilometres of continuous *engineering structures* - 0.89 km of masonry sea wall and 2.53 km of rock revetment and paved promenade in front of low dune-covered bluffs extending from Point Lonsdale Township to Dog Beach. Three rock groynes.
3	2.1	*Point Lonsdale - Queenscliff (Dog Beach to Shortland Bluff)*	Quaternary-Holocene backshore high barrier ridges and dunes	*Dunes, sand beach.* Parallel dune ridges at a slight convergence angle to the shoreline alignment. Slip-face on high barrier dune at termination of revetment with Steep ramp of wind-blown sand with incipient foredune vegetation. Scarped established foredune in front of 10 metre high barrier ridge.
4	0.643	*Point Lonsdale (Shortland Bluff)*	Bridgewater Formation calcarenite	*Active cliff hard rock, shore platform* and minimal beach covered most high tides. *High bluffs* of Bridgewater Formation and fallen blocks of calcarenite.
5	1.0	*Queenscliff beach and harbour*	Pleistocene-Holocene beach and dune sand	*Dunes, sand beach*. Accreting, vegetated incipient foredune and 200 metre-wide zone of established foredunes, jetties, breakwaters and sea walls at Queenscliff Harbour.
6	12.1	*Swan Island*	Pleistocene-Holocene beach and dune sand	*Dunes, sand beach, wetland*. Sand beach and foredune ridges on Port Phillip shore (east), salt marsh behind narrow beach on Swan Bay sides (north and west).
7	18.6 (Swan Bay) 1.7 (Duck Island)	*Swan Bay*	Quaternary sediments - coastal, alluvial and colluvial overlying Brighton Group (not exposed)	*Low bluff, wetland.* Low energy shoreline. Degraded low gradient bluff 5 to 8 m high, cut into deeply weathered Brighton Group draped over by alluvial and colluvial sediments weakly incised. Coastal terrace comprising alluvial fan sediments, weathered slope deposits, broad low sand ridges, and salt marsh material in front of the degraded bluff.
8	8.8	*Edwards Point*	Quaternary sediments - sand, shell fragments and ironstone gravels	*Shell and gravel beach, wetland.* Prograding barrier/spit system, with the proximal end anchored against the bluff at the north of Swan Bay. There are three major ridge systems, separated by marshy swales with numerous smaller lagoons. The distal ends of the ridges recurve into Swan Bay with broad tidal flat extensions.
9	3.1	*St Leonards*	Quaternary beach deposits overlying Brighton Group	*High bluff, shell beach. B*each in front of bluff and short sector of intermittently active cliff. Backshore is low coastal plateau.

10	1.5	*Salt Lagoon*	Quaternary coastal, lagoon and beach deposits overlying Brighton Group	*Shell beach, low dunes, wetland.* Sand beach and barrier enclosing Salt Lagoon.
11	7.7	*Indented Head to Portarlington*	Quaternary beach and dune deposits overlying Brighton Group	*Shell beach, sand beach, low bluff, active cliff soft rock, engineered coast.* Bluff and short sector of intermittently active cliff. Variety of engineered structures and beach re-nourishment. Backshore is low coastal plateau.
12	4.8	*Point Richards*	Quaternary beach and dune deposits	*Shell beach, sand and gravel beach, low* dunes. Low converging and sub-parallel foredune with enclosed shallow lagoons. Complex shore-parallel and oblique offshore bars.
13	5.8	*Clifton Springs*	Mesozoic arkose overlain by Older Volcanics basalt and tuff, Gellibrand Marl, Brighton Group folded along Curlewis Monocline.	*Active cliffs soft rock, high bluffs, engineered coast*. Active landslide slopes, narrow beach, seasonal accumulation of seagrass wrack. Low tide shore platform. Complex shore-parallel and oblique offshore bars.
14	2.6	*Curlewis*	Older Volcanics basalt and tuff, Gellibrand Marl and Brighton Group folded along Curlewis Monocline.	*Low coastal bluffs, engineered coast.* Narrow beach backed by. Low tide shore platform.
15	8.1	*Point Henry*	Quaternary silty clay, shelly sand ridges	*Engineered coast, wetland*. Low promontory with variable shoreline. Saltmarsh on eastern side south of wharf, shelly sand ridges at distal end, clay bluffs and shore platform on west. Rock wall protection on northwest side.
16	3.5	*Stingaree Bay, East Geelong*	Coastal levees (previously - Quaternary silty clay, shelly sand ridges)	*Engineered coast, coastal levee.*Artificially constructed former salt evaporation lagoons.
17	12.2	*Corio Bay East Geelong to North Shore*	Black Rock Sandstone overlying Gellibrand Marl	*Engineered coast.* Sea wall, renourished beach, port facilities and wharves. Short sectors of coastal cliffs and bluffs.
18	0.8	*Corio Bay North*	Newer Volcanics basalt and Gellibrand Marl	*Active cliff soft rock, high bluffs.* Minimal beach
19	8.1	*Limeburners Bay*	Newer Volcanics basalt and Gellibrand Marl	*Estuary, low bluffs.* Estuary and lagoon of Hovells Creek.
20	11	*Avalon Beach to Point Wilson*	Newer Volcanics basalt, alluvium, coastal deposits. coastal levees	*Engineered coast, rock platform, gravel beach*. Low basalt plain margin previously with a crenulated shoreline of shallow bays and headlands basalt blocks and gravel, narrow sand beach fringe and low ±1.0 m sand ridge. Substantially modified by roadworks, buildings (fishing shacks along backbeach) and levees enclosing salt evaporation ponds.

21	4.8	*Point Wilson*	Newer Volcanics basalt, coastal deposits	*Rock platform, gravel beach, shell beach, wetland.* Low basalt plain margin with weakly crenulate shoreline. Embayments have an inner zone of saltmarsh behind multiple shelly ridges over 400 metres wise at Point Wilson.
22	3.6	*Sand Hummocks*	Holocene shell and sand	*Gravel beach, shell beach, wetland.* Barrier spits and islands of multiple low irregular gravelly-shelly sand ridges enclosing a shallow lagoon. Storms overwash the ridges and develop new entrances
23	2.7	*Kirk Point*	Newer Volcanics basalt, coastal deposits	*Rock platform, gravel beach, shell beach, wetland*. Low basalt plain margin with narrow shelly ridges. Basalt blocks and nearshore reefs.
24	11.4	*Western Treatment Plant*	Alluvium overlying Newer Volcanics basalt, coastal deposits	*Engineered coast, coastal levee.* Low coastal plain of alluvium overlying weathered basalt. Highly modified for over 100 years for use as sewage and waste-water treatment (now Western Treatment Plant). Backshore levee for entire length and sectors of basalt armour.
25	1.0	*Werribee River southern*	Quaternary sand	*Sand beach.* Remnant low ridged sand spit at southern side of Werribee river. Highly modified and surface re-shaped.
26	2.6	*Wyndham Cove*	Quaternary alluvium	*Active cliff earth cliff, shell beach, engineered coast*. Low coastal plain of alluvium overlying weathered basalt. Highly modified by sea walls and the Wyndham Cove marina breakwaters and nourished beach.
27	2.6	*Werribee South*	Quaternary alluvium overlying weathered Newer Volcanics basalt	*Active cliff earth cliff, shell beach, engineered coast.* Coastal plain of Werribee River alluvium overlying weathered basalt. Some basalt boulders on the shoreline. Highly modified by road and many fishing shacks and private slipways and various types of privately installed sea wall.
28	6.5	*Point Cook*	Quaternary alluvium and beach deposits overlying weathered Newer Volcanics basalt	*Shore platform, shell beach, dunes.* Point Cook is a low basalt promontory. Coastal plain of Werribee River alluvium overlying weathered basalt. Shoreline is a series of parallel sand ridges up to 2.5 metres high with a 200+ metre wide intertidal zone of sand bars.
29	4.9	*Skeleton Creek*	Quaternary beach and alluvial deposits	*Shell beach, wetland, estuary and engineered coast.* Multiple truncated low sand ridges and foredunes oblique to present shoreline. The elongate spit complex across the mouth of Skeleton Creek widened by 50 metres and extended northward by 450 metres between October 2009 and October 2016. The backshore and hinterland are highly disturbed by former salt evaporation ponds.
30	3.8	*Altona/Seaholme*	Quaternary beach deposits	*Wetland and engineered coast* Low coastal plain and narrow beach backed by continuous sea wall. Built structures include groynes, renourished beach, pier and launching ramp.

31	1.6	*Kororoit Creek*	Quaternary beach and estuarine deposits	*Wetland*. Very low (±1.0 m) ridged sand spit at mouth of Kororoit Creek. Crossed by tidal channel, saltmarsh and mangrove.
32	4.8	*Williamstown*	Newer Volcanics basalt	*Shore platform, engineered coast*. Low coastal plateau and irregular coastal bluff and platform. Short sector of sea wall and renourished beach.
33	6.7	*Yarra mouth, Port Melbourne*	Quaternary alluvium and dunes	*Engineered coast, estuary.* Deltaic deposits and sand dunes all now highly modified by port facilities.
34	14.3	*Melbourne NE coast*	Quaternary dunes overlying Brighton Group	*Engineered coast*, *low bluffs*. Plain and low plateau terminating in coastal bluffs and short sectors of active cliff. Highly modified shore and backshore - sea walls, groynes, landfill, and several beach re-nourishment sites.
35	3.5	*Black Rock*	Brighton Group	*Engineered coast, low bluffs, high bluffs, active cliff soft rock*. Plain and low plateau terminating in coastal bluffs with short sectors of active cliff at Red Bluff and Black Rock Point. Wide shore platforms. Some shore protection structures.
36	1.5	*Beaumaris*	Beaumaris Sandstone, Gellibrand Marl	*Active cliff hard rock, engineered coast*. Plain and plateau terminating in 10+ metre high coastal cliffs of resistant Beaumaris Sandstone and a narrow shore platform. Marina and some shore protection structures.
37	20.5	*Mentone to Frankston (Carrum Barrier)*	Quaternary beach sand and dunes	*Sand beach, dunes.* Longest beach in Port Phillip. Continuous sand barrier with multiple dune riges enclosing the formerly extensive and now mostly drained Carrum Wetlands. Maintained outlets of Mordialloc Creek, Paterson River and Kannanook Creek. Extensive sea wall between Mentone and Mordialloc.
38	17.5	*Olivers Hill to Balcombe Creek*	Red Bluff Sandstone overlying Gellibrand Marl and Older Volcanics basalt with inliers of weathered Mt Eliza Granodiorite	*Active cliffs soft rock, active cliffs hard rock, high bluffs, gravel beach, engineered coast.* Crenulated coast of high coastal bluffs with active landslide slopes and short sectors of cliff in ferruginous sandstone and basalt. Pocket beaches with coarse sand and some gravel beaches. Headlands with narrow shore platforms. Numerous boat-bathing sheds at back of beach and base of bluff north of Balcombe Creek.
39	1.5	*Balcombe Creek*	Red Bluff Sandstone and Mount Martha Granodiorite covered by Quaternary dune sand	*Low bluffs, dunes, sand beach, engineered coast, estuary. D*une-covered bluffs and sand beach. Intermittently closed estuary of Balcombe Creek. Numerous boat-bathing sheds at back of beach and base of bluff.
40	5.1	*Mount Martha*	Mount Martha Granodiorite	*Active cliffs hard rock, shore platform.* Steep coastal slopes and cliffs in variably weathered granodiorite. Broad shore platforms averaging 30 m wide slopes gently seaward at the cliff base. Rounded granite boulders on the platform and gravel beaches in some small embayments. In the less weathered rock to the south (towards Deakin Drive) there is no shore platform and the coast has an irregular and indented form.

41	5.3	*Safety Beach*	Quaternary beach and dune sand	*Sand beach, dunes, engineered coast.* Gently curving narrow barrier beach of coarse sand with low dune ridge crossed by outlets of small creeks and the engineered entrance canal to Martha Cove Waterway in the north (former estuary of Brokil Creek). Formerly broad, low ridged sand plain; it is now heavily modified by paths, parking areas, numerous boatsheds, boat ramps and sectors of sea wall. Beach profile shaped by mechanical beach cleaning operations.
42	1.5	*Dromana - Anthony's Nose*	Dromana Granite and colluvium	*High bluff, engineered coast*. Narrow beach in front of the western slopes of broad ridge of Dromana Granite. Heavily modified by paths, parking areas, boat ramps and sea wall that is awash at most high tides.
43	9.1	*Rosebud-Tootgarook*	Quaternary beach and dune sand and swamp deposits	*Sand beach, dunes, engineered coast*. Long continuous barrier beach backed by wide foreshore reserve. Rhythmic beach topography fronted by a wide inner bar and offshore shallow sand flats up to one km wide. Very responsive to wind wave direction and storm waves. Mechanical reshaping of beach and intertidal bars has taken place, both for beach re-nourishment and subsequently for seagrass control.
44	4.8	*Rye*	Quaternary beach and dune sand overlying Bridgewater Formation	*Sand beach, dunes.*Continuous barrier beach backed by wide foreshore reserve with remnant elongate transverse ridges.
45	3.9	*Blairgowrie - Sorrento*	Quaternary beach and dune sand overlying Bridgewater Formation	*Low bluff, cliff-top dunes, sand beach.* Low calcarenite bluff capped by dunes that have migrated from the ocean coast. Intensive beach use but minor engineering structures on beach.
46	5.4	*Sorrento-Portsea*	Bridgewater Formation	*Engineered coast, active cliffs soft rock & hard rock, shore platform.* Alternating pocket beaches and short headlands of calcarenite. Continuous engineering structures including masonry, rock and sandbag sea walls, private jetties, ferry tgerminal.
47	3.1	*Observatory Point*	Bridgewater Formation	*Sand beach, shell beach, dunes*. Wide accretionary foreland of multiple, low sand ridges. Continuous sand beaches.
48	1.9	*Point Nepean*	Bridgewater Formation	*Engineered coast, active cliffs soft rock, shore platform*. Cliffs and platforms. Parabolic cliff-top dunes extending from south-west across peninsula.

Three broad groups of Port Phillip coastal landforms are described below:

A: Backshore: Cliffs (Section 3);

B: Backshore: Bluffs (Section 4);

C: Beach Ridges and Dunes (Section 5).

2.3 BACKSHORE: CLIFFS

Coastal cliffs occur on a wide range of geological materials and terrain. Some cliffs are the seaward-facing inclines formed by marine truncation of the hinterland terrain. The slope base is subject to frequent or continuous wave swash, turbulence or currents that preclude extensive or long-term accumulation of clastic materials by alluvial-colluvial or beach depositional processes. Rock material is episodically detached from the slope and removed by wave action, but the slopes are comprised of geological materials of sufficient cohesion, volume and backshore elevation to form a persistent steep profile. Slope material ranges from strongly coherent to weakly consolidated or disaggregated.

Steep coasts can be divided into classes according to the persistence of wave action effecting the cliff foot and face. Emery and Kuhn (1982), proposed three main types of coastal cliffs: active cliffs, inactive cliffs and former cliffs, the latter correspond to the coastal bluff described by Bird (1977). In this present report, three categories of cliffs are mapped and described: active cliffs (hard rock); active cliffs (soft rock); active cliffs (regolith cliff). The "inactive" and "former" types of Emery and Kuhn are grouped as bluffs and separated according to elevation as high bluff and low bluff (Figure 11).

Figure 11 (A) Active cliffs. high bluff and engineered slope at Red Bluff, Sandringham, (B) regolith (silt) cliff Werribee South, (C) regolith (gravel) cliff St Leonards, (D) regolith (sand) cliff, Dog Beach Queenscliff (Photos N. Rosengren 2015).

Former bluffs e.g. at Clifton Springs and Daveys Bay, Mount Elisa have become re-activated (as active cliffs) due to changes in wave conditions and/or removal of slope-foot material such as by beach erosion or landslides causing lower slope extension. Many formerly active cliffs have been converted to engineered bluffs by fill, sea wall, and beach re-nourishment.

2.3.1 Active Cliffs

Active cliffs have continuous exposure to direct wave action and are continuously receding due to the combined effects of marine and subaerial processes. Rock fall, slides, rotational slumps, rills and sheet wash deliver material to the slope base where it is removed by wave action and provides tools for marine abrasion. Coasts exposed to strong wave action and with deeper water nearshore develop and maintain active cliffs more so than sheltered or shallow nearshore water shorelines.

Active cliffs are not defined by height - the key element is they are subject to frequent wave swash of sufficient energy to dislodge or remove rock-regolith material. In soft rock, basal removal of material developing a notch or overhang may precipitate upper slope failure by sliding or toppling—the mechanism determined by cohesion and structure of the slope material.

Cliffed coasts are retrograding coastal landforms, meaning the cliff profile and ultimately the shoreline (high water mark) retreats landward. Cliff crest or slope face regression are typically at uneven rates, and in some instances bulk failure of an upper slope may over the short-term cause the cliff base to prograde i.e. advance seaward. Examples at Clifton Springs and Mt Elisa have been cited above (Section 2.3).

Profile form, mobility and rate of recession of active cliffs is largely determined by the inherent properties of substrate—lithology, orientation and spacing of planar discontinuities such as bedding, unconformities, joint and fault fractures and weathering style and penetration of the parent rock. Active cliffs occur along the Port Phillip coast in rocks of varied lithology and resistance to marine erosion and display a range of slope form and dynamics (Figure 12). Examples of the range of active cliffs around Port Phillip are described in Sections 3.2 to 3.4 below.

The longest cliffs in Port Phillip are a result of tectonics and igneous activity. Uplift along Selwyn Fault has exposed hard and soft rocks from Olivers Hill to Dromana, including the resistant Mount Martha Granodiorites. Fault stress has imposed close-spaced fractures and shearing in the Mount Elisa Granodiorite and the overlying Older Volcanic basalts and Brighton Group sediments resulting in rocks prone to slope failure and of low resistance to wave action (see Section 3.1.2). The active cliffs and mass movement bluff slopes on the Bellarine Peninsula at and north-east of Clifton Springs are developed on uplifted and tilted sedimentary beds along the Curlewis Monocline.

2.3.2 Active Cliffs - Hard Rock

Hard rocks are subjectively defined as exposures that resist weathering and undergo only irregular detachment of fragments and larger blocks by waves and currents. Hard rocks around Port Phillip are limited to the Mount Martha Granodiorite, short sectors of Mount Eliza Granodiorite, ferruginous beds of Beaumaris Sandstone, Older Volcanics basalt and Bridgewater Formation calcarenite.

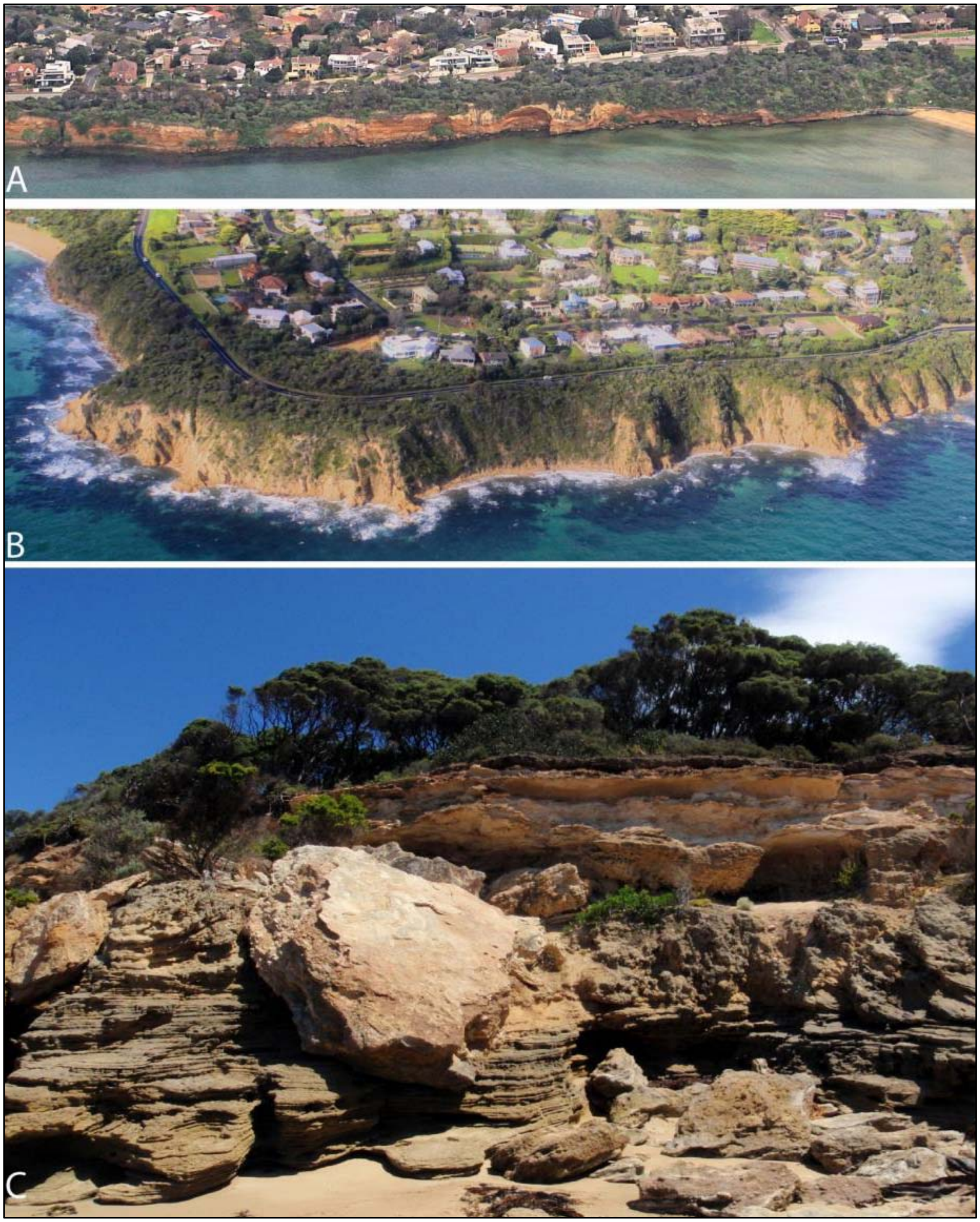

Figure 12. Cliffs in hard rock: (A) near-vertical with local overhang, Beaumaris Sandstone, Beaumaris; (B) slope-over-wall in Mount Martha Granodiorite; (D) overhangs in Bridgewater Group, Point Lonsdale. (Photos: N. Rosengren 2016)

Comparison of shoreline and cliff crest positions from maps and aerial photographs show the five kilometres of high cliffs and bluffs formed on Mount Martha Granodiorite south of Balcombe Creek is the most stable cliff coast in Port Phillip. Regression of hard rock cliffs takes place by detachment of large blocks and toppling failure of overhangs and ledges. Figure 13 shows the cliff base of the three sites in Figure 12. At Mount Martha (13B) there are no detached blocks at the slope base. At Beaumaris (13A) detachment of the large blocks has occurred by a combination of removal of basal support and impact of storm waves, whereas at Pont Lonsdale stress failure on an overhang may have been triggered by groundwater loading above the slab.

Figure 13. Cliff base in hard rock: (A) large detached blocks separated along bedding and joints, Beaumaris Sandstone, Beaumaris; (B) no loose rock, Mount Martha Granodiorite; (D) fallen slabs and blocks of Bridgewater Group, Point Lonsdale. (Images: NearMap Aug 14, 204).

Although wave action in Port Phillip is fetch-limited, storms produce short period steep waves to 3.0 metres high (Short 1996) and wave runup during storm surge frequently overtops (Figure 14) and damages masonry sea walls (Bird 2010), therefore wave quarrying of blocks as in Figure 13A is possible.

Figure 14. (Left) storm wave breaks across sea wall at Point Lonsdale May 2016. (Right) sea wall at South Brighton damaged by storm waves in June 2003. (N. Rosengren).

2.3.3 Active Cliffs - Soft Rock

On long sectors of Port Phillip cliffs are developed in “soft rocks” i.e. poorly consolidated and/or deeply weathered sedimentary, volcanic and granitic formations prone

to rapid slope failure and particle and block detachment. The four principal areas are: Bellarine Peninsula northeast of Clifton Springs (geomorphic unit 13), the northeast coast from Green Point to Beaumaris (geomorphic units 34 and 35), Frankston to Balcombe Creek (geomorphic unit 38), and intermittent sites between Rye and Point Nepean (geomorphic units 45 to 48). Short sectors of hard rock active cliff and coastal bluffs occur inside and adjacent to these localities.

The majority of shoreline engineering structures around Port Phillip have been constructed in front of soft rock active cliffs to reduce the nature and frequency of slope movement to protect property and infrastructure, for user safety or (in the case of beach nourishment) to increase amenity value of the shoreline (Figure 15).

Figure 15. Cliffed coast in soft rock and engineering structures at Edgewater Drive Clifton Springs: (A) active cliff with rills; (B) rock wall and fence; (C) groyne; (D) active mass movement; (E) renourished beach with retaining groynes; (F) gullied mass movement slope. (Photos: oblique N. Rosengren Dec. 2016; verticals from NearMap Oct. 2016).

In coastal cliffs developed in permeable or weakly consolidated rocks and regolith rarely directly impacted by waves, subaerial processes—notably ground water seepage and runoff producing rills and gullies —may be the main processes in cliff dynamics and provide sediment at the slope foot for beach nourishment (Figure 16). As shown in Figure 16, active cliffs in soft rock may be subject to wave action only at times of extreme storm waves.

A factor contributing to beach depletion between Brighton and Beaumaris since the 1950's has been the construction of revetments and sea walls excluding backshore slopes as a source of beach sand (Bird 2010). As a result, extensive beach re-nourishment programmes have been necessary here and at 30 other sites around Port Phillip since the 1970's (Figure 17).

Figure 16. Rills and gullies at Black Rock Point - awash at the base in storm in 1998 (A) and with a wide beach in 2007 (B). X on 16A shows the photo point in 16B. (Photos N. Rosengren).

Figure 17. Picnic Point Sandringham in 1972 showing sea wall isolating former active cliffs and in 2012 after construction of groynes and beach re-nourishment. (Photos N. Rosengren).

Tectonics is a factor in the location of active soft rock cliffs around Port Phillip. On the Mornington Peninsula coast the highest and most active cliffs are along the trace of Selwyn Fault in fractured bedrock and displaced rock masses and debris flows from older large-scale landslides (Figure 18, Figure 19).

Figure 18. Newly developed cliff in landslide basal debris, Daveys Bay, Mt Elisa. (N. Rosengren May 2016).

Figure 19. Soft rock active cliffs developed along fault trace (red line) and landslide debris. Insets show sheared weathered granodiorite (left) and Brighton Group beds back-tilted at the toe of a landslip. (Photos: N. Rosengren Dec 2016 (aerial), May 2016 (ground)).

Landslides are common in the cliffs that extend along the north side of the Bellarine Peninsula, between Curlewis in the west and Portarlington in the east. The landslides near Curlewis in the west have developed within the Gellibrand Marl and tuffaceous soils of the Older Volcanics, both of which are characterized by fissured clays of high plasticity and low residual angles of friction. As such these slides tend to be translational or shallow rotational and are capable of undergoing large displacements (Wilson and Miner 2006). Extensive rills and close-spaced gullies are a major mechanism for slope retreat in addition to basal marine erosion (Figure 20).

Figure 20. Multiple rotational slides and slope-face gullies, MacAdams Lane, Portarlington. (N. Rosengren, 2013).

Most soft rock active cliffs in Port Phillip have narrow shore platforms and although fronted by relatively shallow water and in places by a wide zone of multiple sand bars, the small tide range allows strong onshore winds to maintain wave action at the cliff base for

much of the tidal cycle. Slopes around Port Phillip classified here as active cliffs (and some coastal bluffs as discussed below) will become increasingly mobile as water level rises, including temporary elevation as storm surge, or longer-term on-going rise due to eustatic or tectonic causes.

Figure 21. Active cliffs in Bridgewater Group dominated by weakly consolidated calcarenite dune beds with widely-spaced resistant calcrete units. (Photo: N. Rosengren May 2014).

2.3.4 Active Cliffs - Regolith Cliffs

Regolith cliffs are designated as a separate class of active cliffs in Port Phillip although could be incorporated into soft rock cliffs. The distinguishing feature selected is they are comprised of *transported*—as distinct from *in* situ— regolith of unconsolidated Late Pleistocene to Holocene sedimentary and partially organic alluvial, colluvial and coastal deposits (Figure 11, page 22). They may include a large or predominant fraction of coarse sediment. Parts of soft rock landslip cliffs (Figure 18) and scarps developed in coastal dunes (Figure 24) are regolith cliffs. The materials have sufficient cohesion, packing or clast size to maintain a steep face when exposed to wave action, but are susceptible to disaggregation and dispersal under some wave regimes.

The distinctive delta-shaped sedimentary body, with the apex several kilometres upstream from Werribee and the distal ends on the coastline from south of Point Cook to the mouth of Little River, is the floodplain of the Werribee River (Figure 22). It is not a true sub-aqueous delta as it consists dominantly of a reddish-brown, poorly-bedded silty and sandy clay with minor sand and gravel and lacks marine fossils. It is most likely to have originated as a floodplain crossed by distributary streams, traces of which can be seen at other localities. It has formal recognition as the Deutgam Silt (VandenBerg 2009). Outcrops along the coast are therefore classed as regolith cliffs. Most are now covered by a range of

engineered structures or sand trapped by groynes protecting the Western Treatment Plant (Figures 22, 23).

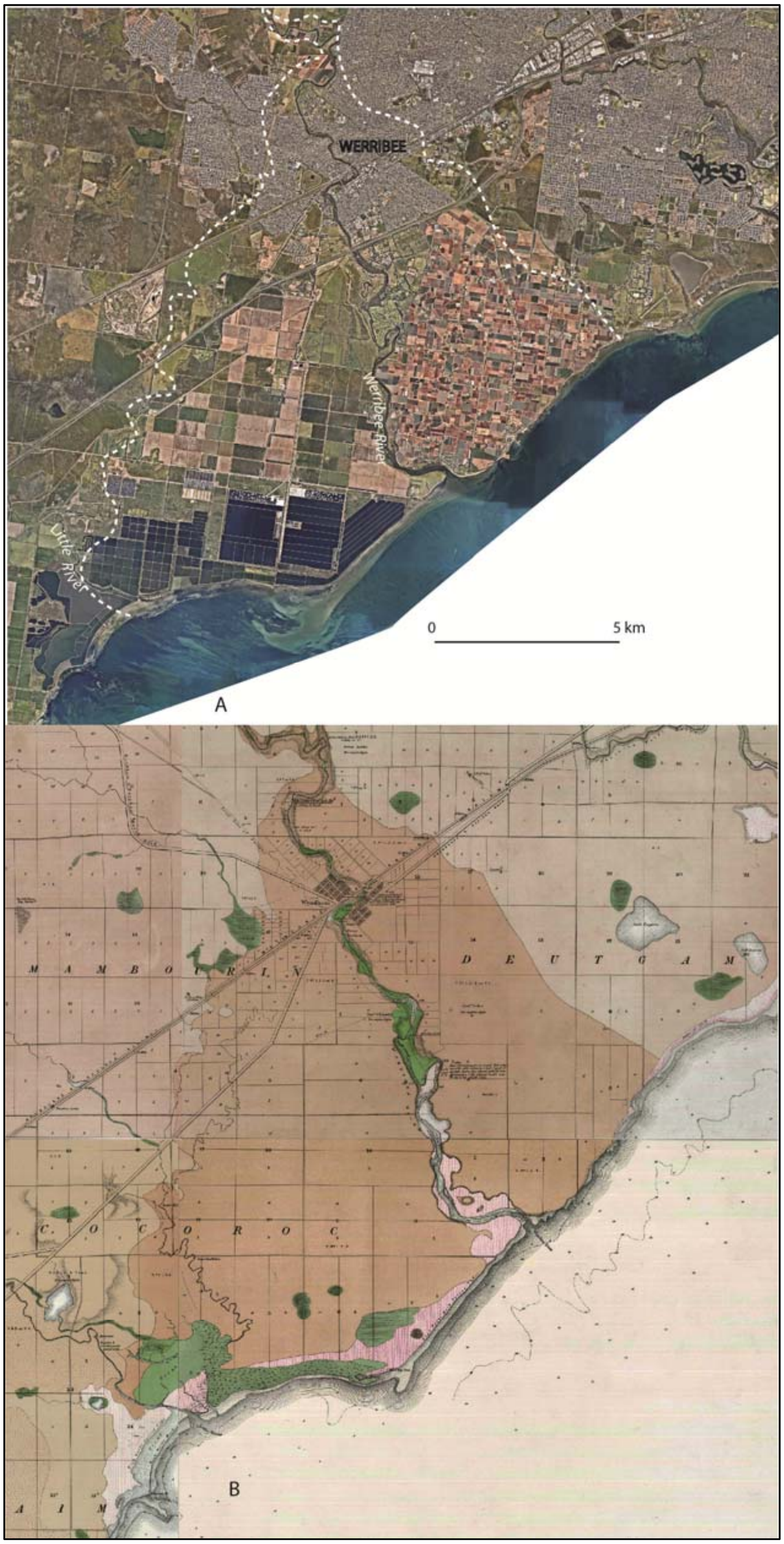

Figure 22. Lower Werribee River ("Werribee delta"). (A) Floodplain (broken line on NearMap image 2016), plotted from: (B) Geological Quarter Sheet 20 (Geological Survey Office, Melbourne 1863).

Figure 23 Regolith cliffs of the Werribee River floodplain largely obscured by engineered structures and beach sand caught behind groynes. (N. Rosengren Dec 2016).

Coastal dunes in Port Phillip are dominantly low, narrow shore-parallel ridges or established foredunes developed as barriers, spits and forelands. Transgressive dunes and high dunes are of limited extent but locally form a distinctive class of class of regolith cliffs and bluffs. Cliffs develop in beaches and foredunes in direct response to storm waves, but rapidly degrade or backfill to lower angle stable slopes. On vegetated established dunes, beach depletion allows wave removal of basal support causing slumping and sliding of sand higher up the slope. This may be washed away, but if of sufficient volume and if the vegetation cover survives, will persist as a protective apron at the slope foot restricting further erosion. With further vegetation recovery, the slope will become quasi-stable as a grassy to scrubby bluff (Figure 24).

Figure 24. Sandy cliff and grassy bluff developed from slump deposits, Dog Beach Point Lonsdale (N. Rosengren Jan 2016).

2.4 BACKSHORE BLUFFS

Coastal bluffs are slopes with variable or continuous cover of regolith, soil and vegetation and limited exposure of basement or resistant rock. Some bluffs are former (stranded) or inactive sea cliffs relict from higher sea-level, or more recently isolated from wave action due to tectonic uplift, by accumulation of slope debris, beach deposits, growth of organic materials (vegetation or reef), or by shoreline or offshore engineering structures that diminish the effectiveness of wave and current action. As with coastal cliffs, most bluffs are a continuation of the slopes and geomorphology of the hinterland topography, intersected as the shoreline recedes. The distinction between an active cliff and a coastal bluff may be temporal, as sectors of bluff may be or initiated as cliffs or reactivated due to changed marine or onshore conditions.

A qualitative but relevant distinction in Port Phillip is between high bluffs and low bluffs (Figure 23). Low bluffs can be overtopped in a storm surge resulting in backshore inundation as well as creating or activating a cliff. High bluffs may be subject to major landslides that extend the toe seaward and initiate cliff development (Figure 24). This process is occurring along a number of cliff sectors on the tectonic coast of the Mornington Peninsula and northern Bellarine Peninsula.

Figure 25. Bluffs at Portarlington. The high bluff is a former active cliff at higher sea-level. The low bluff is cut into slope deposits and beach gravels. (Photo N. Rosengren May 2013).

Figure 26. Landslide on high coastal bluff at Edgewater Drive, Clifton Springs causing active coastal cliff, (A) vertical (NearMap Oct 2016), (B) oblique (N. Rosengren Dec. 2016).

Bluffs form the backshore terrain of much of the Bellarine Peninsula where they alternate with sectors of active soft rock cliff. A five kilometre long bluff behind the cuspate foreland complex of Point Richards links the two sectors of active cliff at Portarlington and Spray Farm Lane (Figure 27 Figure 28).

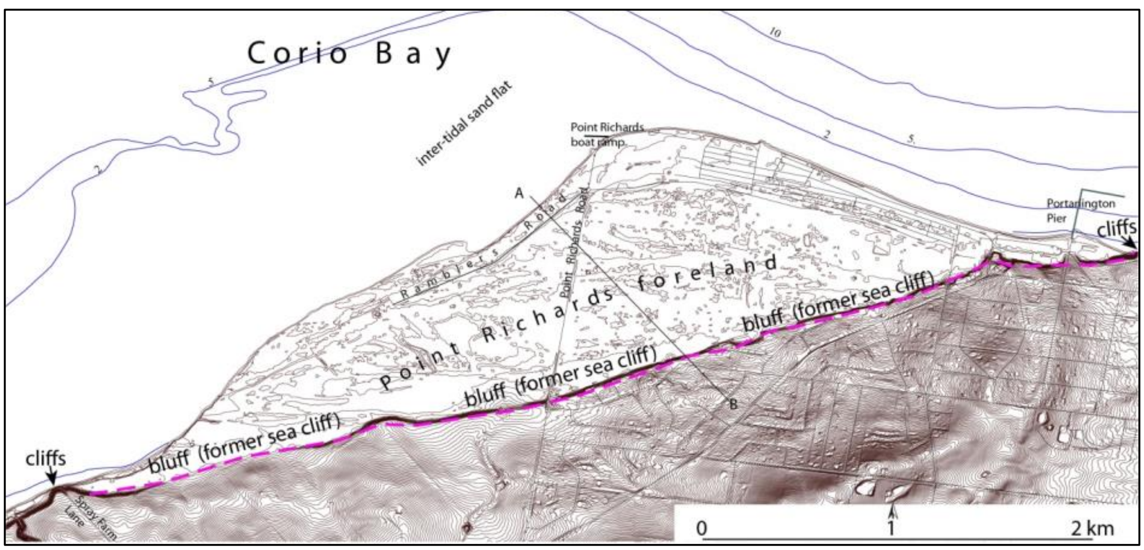

Figure 27. Bluff between Portarlington and Spray Farm Lane, Portarlington. (Rosengren 2015).

2.5 BEACH RIDGES & COASTAL DUNES

Backshore sand ridges around Port Phillip are developed by wave and wind (aeolian) processes. Although a distinction is made between beach ridges—produced by wave swash—and ridges and mounds built up by wind, they are not mutually exclusive and many ridges are or composite origin. Narrow zones of backshore ridges are widely distributed but persistent and multiple wide wave-built beach ridges are a feature of the Bellarine Peninsula, western coast from Altona to Point Wilson and at Observatory Point at the western end of Nepean Peninsula. Aeolian ridges (foredunes) are significant features of the eastern and southern shores of Port Phillip, although they are most likely composite features building on an initial wave deposit. Transgressive dunes—sand bodies that have

moved across the backshore region and overlie older terrain—are of very limited extent in Port Phillip.

2.5.1 BEACH RIDGES

A beach ridge is an accumulation of sediment or organic material such as seagrass, deposited, shaped and aligned initially by wave swash. Beach ridges may build on berms and subsequently be isolated from the shoreline by newer berms and ridges developing in front. The critical process of beach ridge emplacement is storm wave action forming berms and delivering sediment to the berm crest building above calm weather level (Figure 28)

Figure 28. Prograding swash-aligned beach ridge of coarse sand and shell at Ramblers Road, Point Richards, Portarlington. (Photo: N. Rosengren May 2016)

Ridges are separated by swales – the preferred term for the shallow, elongate depressions between a ridge pair. Multiple beach ridges indicate a foreshore is (or has been) accreting or they may be relict or stranded features from higher sea-levels. The slope of beach ridges is determined largely by grain size with the steepest ridges composed of shell and coarse sand and gravel. Beach ridges may act as a nucleus for aeolian accretion and can also be breached or re-arranged by wind. Some beach ridges are clearly composite features with initial deposition and alignment determined by swash deposition and subsequent modification and accretion by the combined effects of vegetation growth and wind

deposition. The beach ridge complex forming the Point Richards foreland at Portarlington is composed of coarse sand, shell and minor gravel and has no aeolian component (Figure 29).

Figure 29. Point Richards cuspate foreland beach ridges in front of the long bluff at Portarlington. (N. Rosengren Nov 2013).

Beach ridges become coastal barriers when they develop and extend in front of a low coast or impound a lagoon by defeating or diverting streams. Sand and salt tolerant vegetation is a key factor in building multiple beach and dune ridges.

A prominent feature of the Bellarine Peninsula and west coast Port Phillip is steep, close-spaced ridges with a high and sometimes almost exclusive composition of shell, coarse sand and gravel that are built entirely by wave deposition. There are multiple shell-dominated ridges in a 200 metre-wide zone at Point Wilson Jetty (Figure 30) and forming the recurving spits at Sand Hummocks lagoon (Figure 31). Other prominent multiple beach ridges are: the Edwards Point recurving spits south of St Leonards (Figure 32); the lobate foreland accumulated on the central eastern coast of Swan Island over the past 30 to 40 years of sand bypassing dredging and pumping to maintain the entrance to Queenscliff Harbour (Figure 33); the complex of mobile, elongated, recurving sand spits extending northwards from the mouth of Skeleton Creek and a zone of parallel near shore sand bars (Figure 34). The spits are one of the major coastal sand bodies of Port Phillip Bay and are an

outstanding example of a recurving sand spit system. They comprise a major prograding sector of Port Phillip Bay and one of the few on the Victorian coast.

Figure 30. Multiple shell-rich beach ridges at Point Wilson. (Photo N. Rosengren Dec. 2016).

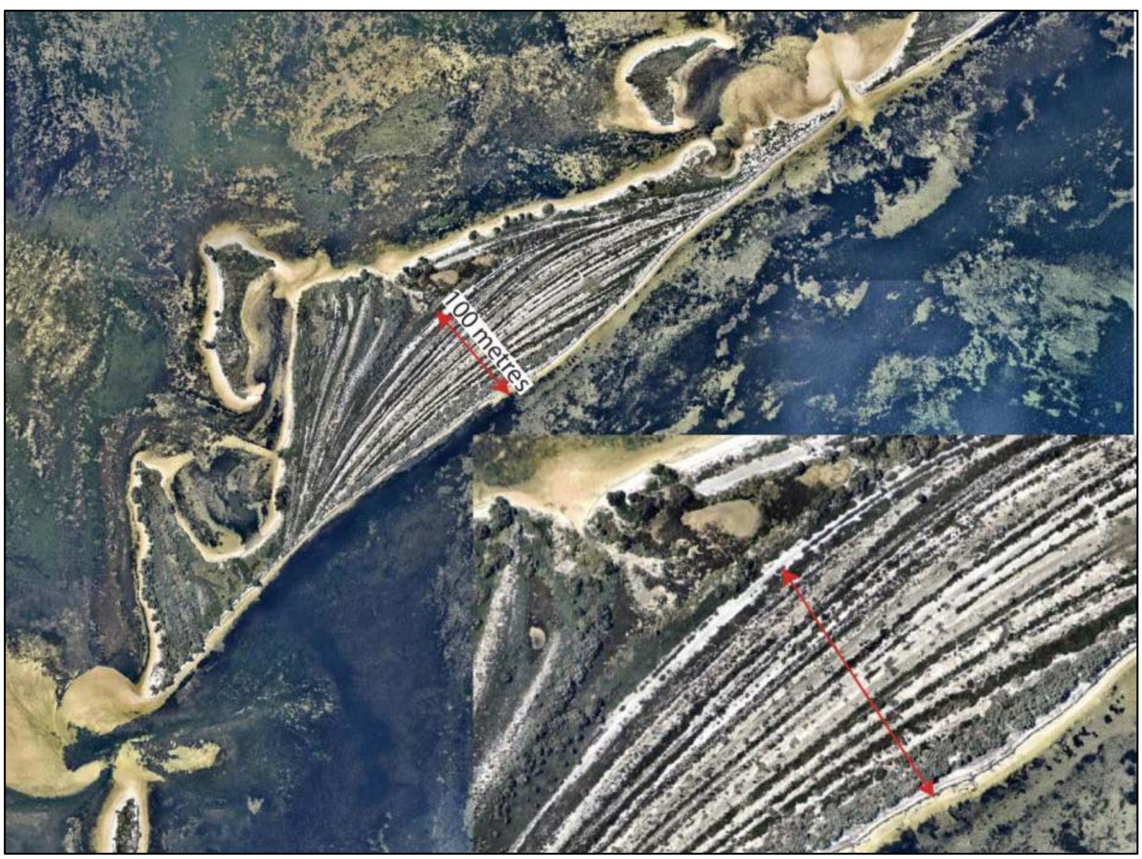

Figure 31. Shell ridges forming the barrier spits at Sand Hummocks (Image: NearMap Oct. 2016).

Figure 32. Multiple recurving sand, shell and gravel ridges of Edwards Point. (Photo: N. Rosengren Nov 2013).

Figure 33. Lobate foreland of multiple recurving sand ridges, Swan Island. (Photo: N. Rosengren Dec 2016).

Although they are artificially nourished by pumped dredge spoil, the ridges at Swan Island are a clear indication of the rate at which coastal accretion can occur given sufficient supply of sand and without a fall in sea-level. As some ridges are up to 1.8 metres high there must be a component of aeolian accretion.

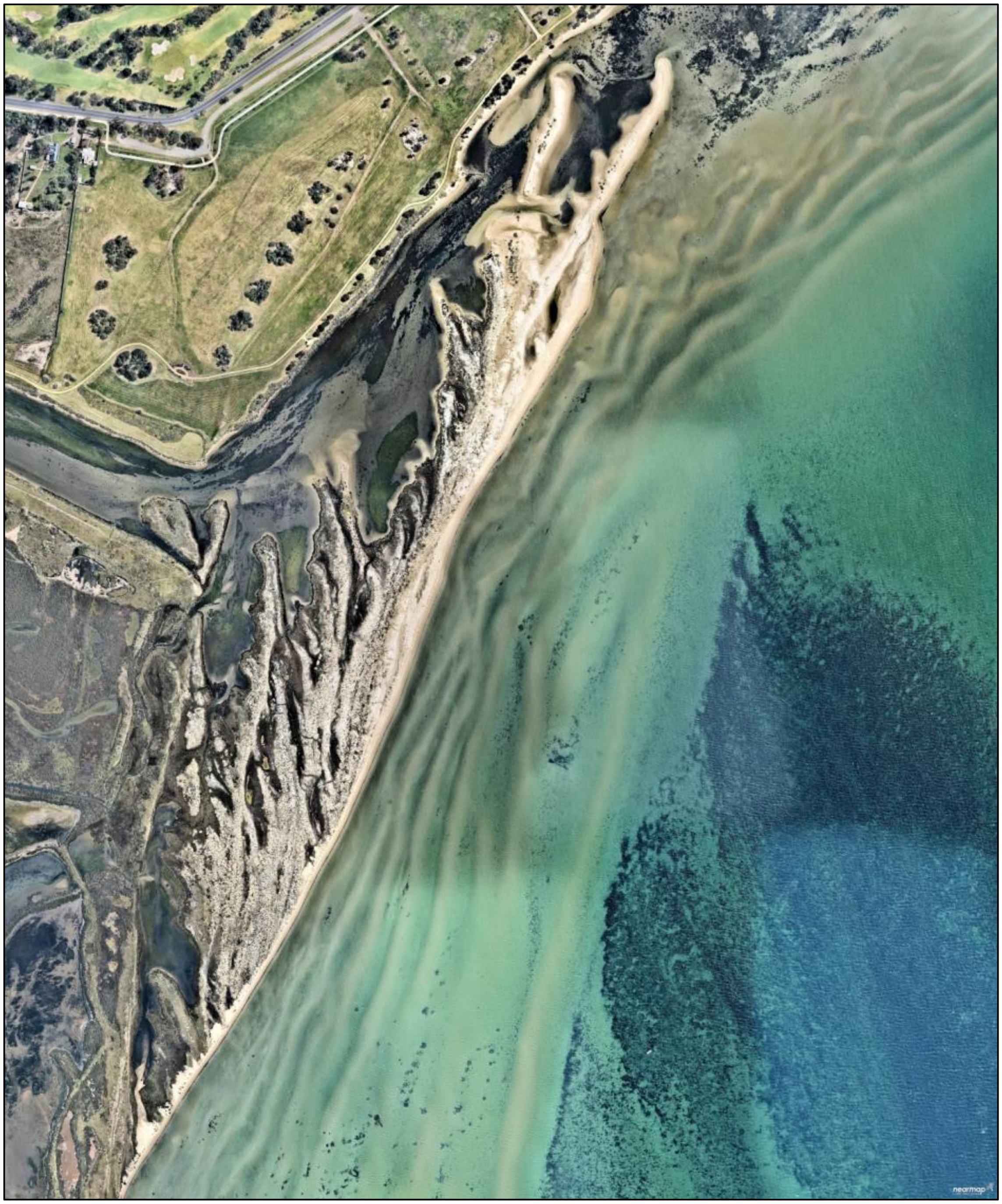

Figure 34. Multiple recurving and branching spits, Altona. (Image: NearMap October 2016).

2.5.2 COASTAL DUNES AND COMPOSITE RIDGES

A foredune is a wind-blown (aeolian) deposit often accumulating around an existing obstacle such as driftwood, vegetation or a stranded beach ridge and now beyond the reach of normal wave swash. The initial dune deposits are termed incipient foredunes, and with further upward and lateral accumulation and growth of vegetation become established foredunes. Beach ridges and foredunes commonly occur in multiple parallel or curving sets forming a ridged backshore plain or coastal barrier fringed by a barrier beach. Shore-parallel

ridges indicate a consistent direction of shoreline progradation. Truncated and oblique ridges indicate a stage of shoreline recession and/or re-orientation has occurred, or is taking place as at Dog Beach, Point Lonsdale (Figure 35).

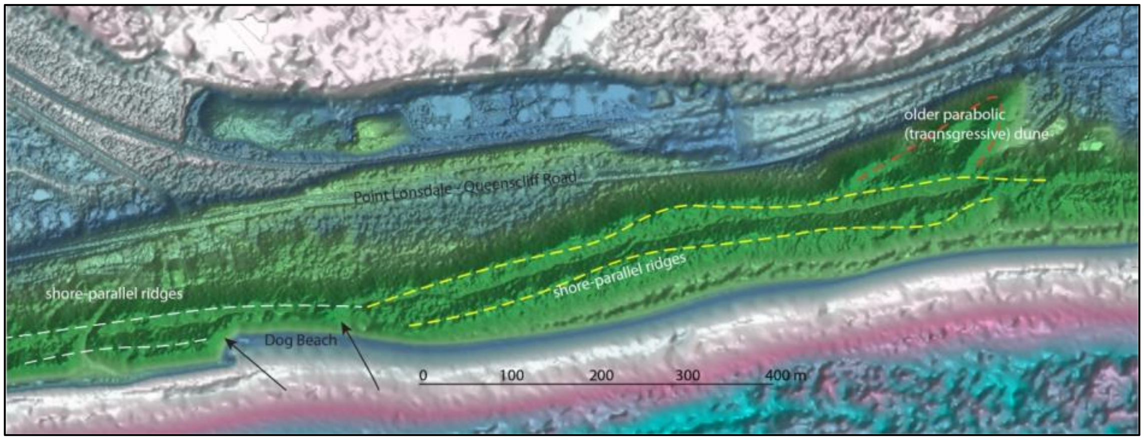

Figure 35. LiDAR DEM at Dog Beach, Pt Lonsdale. Established fordune ridges are being truncated (arrows) by the terminal scour at eastern end of sea wall.

The long barrier beaches on eastern Port Phillip (Mordialloc to Frankston), Safety Beach, Dromana to Rye Beach) are backed by sandy terrain of variable width, origin and preservation. They are now substantially modified by backshore built structures and facilities, the impact of high number of beach users and beach management including mechanical cleaning and sand scraping. The 17 km continuous beach between Mordialloc Creek and Frankston was originally backed by elongate narrow ridges of stranded established foredunes that enclosed the former Carrum Swamp. Although fetch-limited, the beach experiences occasional high-energy wind and wave conditions. North of Paterson River backshore dunes are now largely covered by urban and recreational structure. The Seaford Foreshore Reserve has a dune zone averaging 100 metres wide with two to four parallel ridges generally less than two metres high and an outermost ridge three to six metres high. This dune ridge develops a high scarp during storms but appears to recover over a six to 12 month period (Figure 36).

Figure 36. Seaford Foreshore Reserve dunes development and recovery of dune scarp between 2009 and 2016. The entire dune has an outer fence and fenced paths cross the dunes provide beach access. Red line is fence. (Image: NearMap)

The parallel, linear, continuous and uninterrupted form of the ridge crests and small variations in height indicate the absence of transgressive dune formation and that the ridges must have maintained continuous vegetation cover. However as shown at Swan Island, there must be a component of wind-blown sand.

With the exception of the intriguing ridge sequence at Observatory Point at Point Nepean, no other Port Phillip coasts have such a continuously wide dune zone relatively free of built structures. Safety Beach between Martha Cove and Anthonys Nose, Dromana was the broad valley of Brokil and Tassels Creeks (Figure 38) with a veneer of sand over alluvial silts and clays rather than a series of dune ridges. By the 1960's beach recession was evident as backshore sand had been removed or the surface degraded (Figure 37).

Figure 37. Sand veneer over silty clay alluvium is the backshore of Safety Beach, exposed after storm in 1964. (Photo: State Library of Victoria).

The successive alienation of backshore terrain and potential beach replenishment sand sources is illustrated Beaches between Dromana and Rye is also developed on coastal barrier systems but with less backshore sand (Figure 40). Although locally the dune zone is over 100 metres wide, it is substantially modified by a wide range of public and private facilities and infrastructure including private bathing boxes located on the remnant dunes. The coast experiences episodes of coastal recession and timber groynes and sectors of sea wall remain.

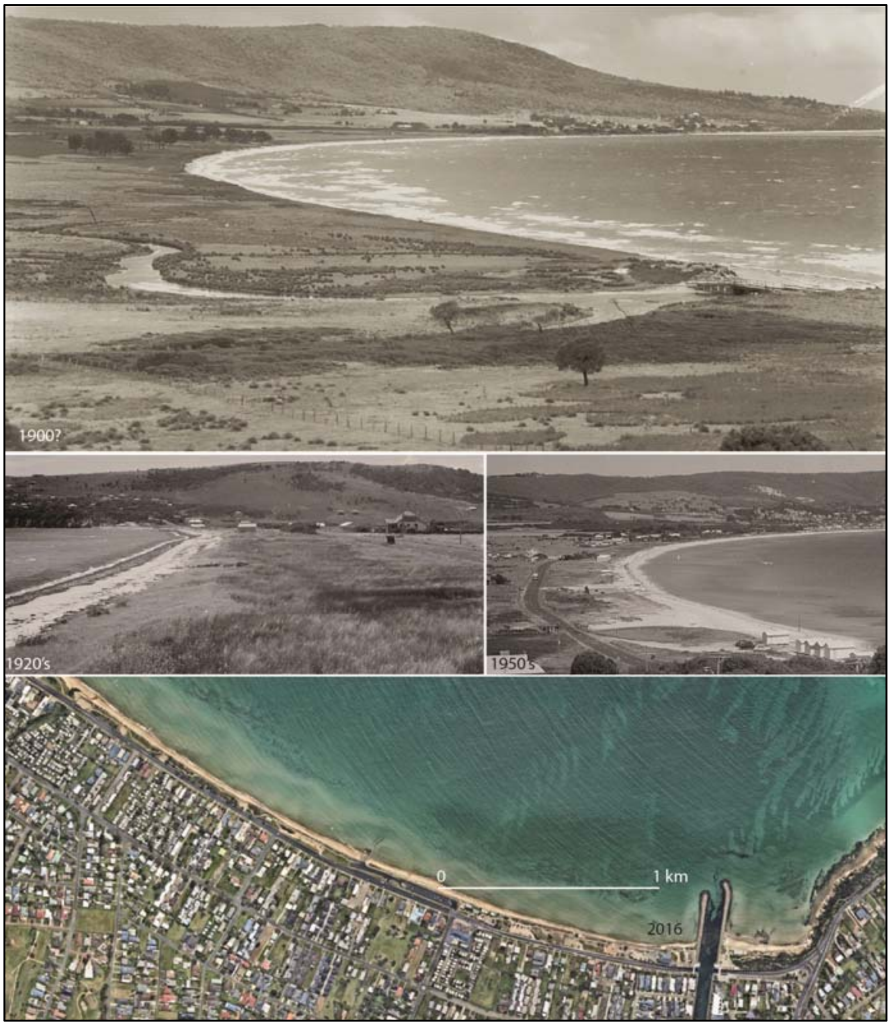

Figure 38. Photographs of Safety Beach from late 1800-early-mid 1900 (State Library of Victoria 1900?, 1920's, 1950's) to present-day (NearMap, Dec 2016).

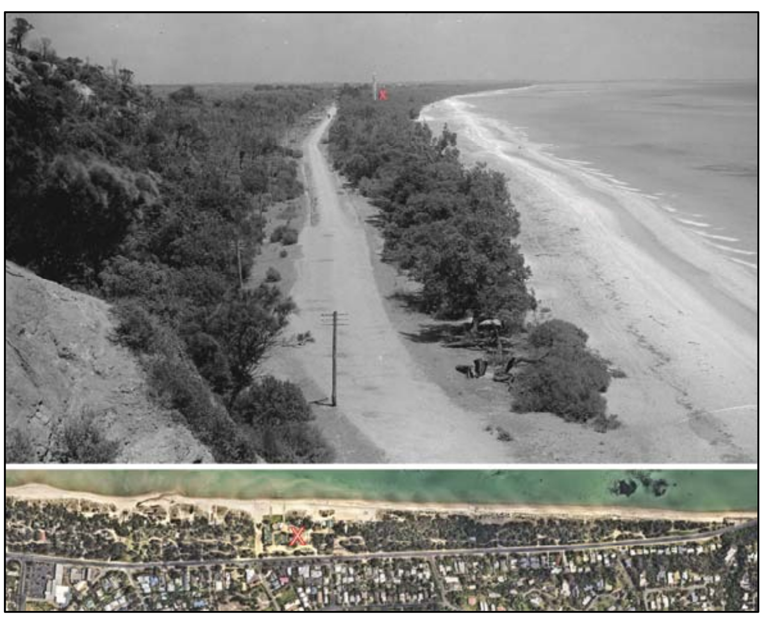

Figure 39. (A) Dromana and McCrae Beach *circa* 1900 (State Library of Victoria). Note the broad foredune narrows to the south at Tootgarook. (B) 2016 (NearMap). The **X** is the Eastern Light (no longer in use).

2.5.3 Observatory Point Ridges

Observatory Point is the outer edge of a broad rounded foreland 2.5 km east of Point Nepean. The foreland is built of a succession of linear and curving parallel sandy ridges extending seaward several hundred metres in front of a former low cliffed shoreline cut into Pleistocene dune calcarenite (Figure 40, Figure 41).

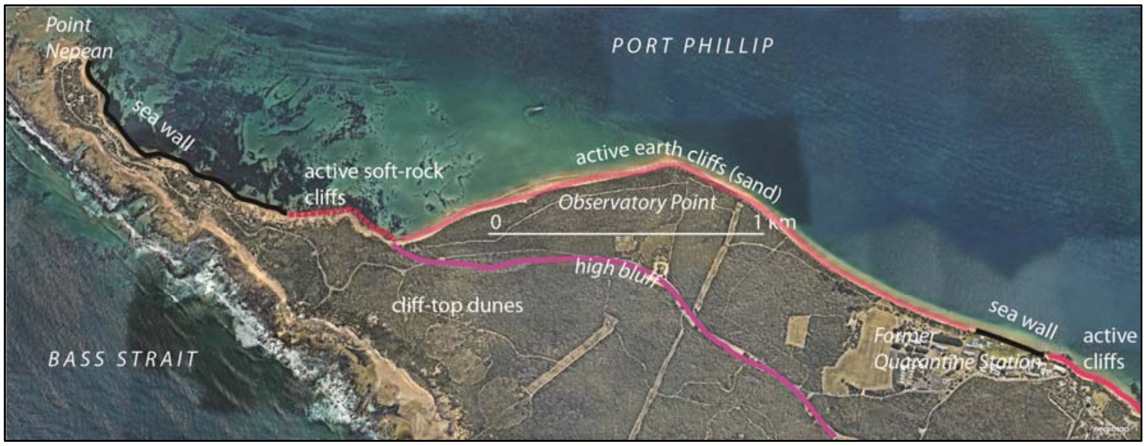

Figure 40. Observatory Point foreland east of Point Nepean. (Image: NearMap Oct 2016).

A long and complex history of alternating episodes of progradation and erosion is evident in the form, orientation and spacing of the ridges (Figure 40).

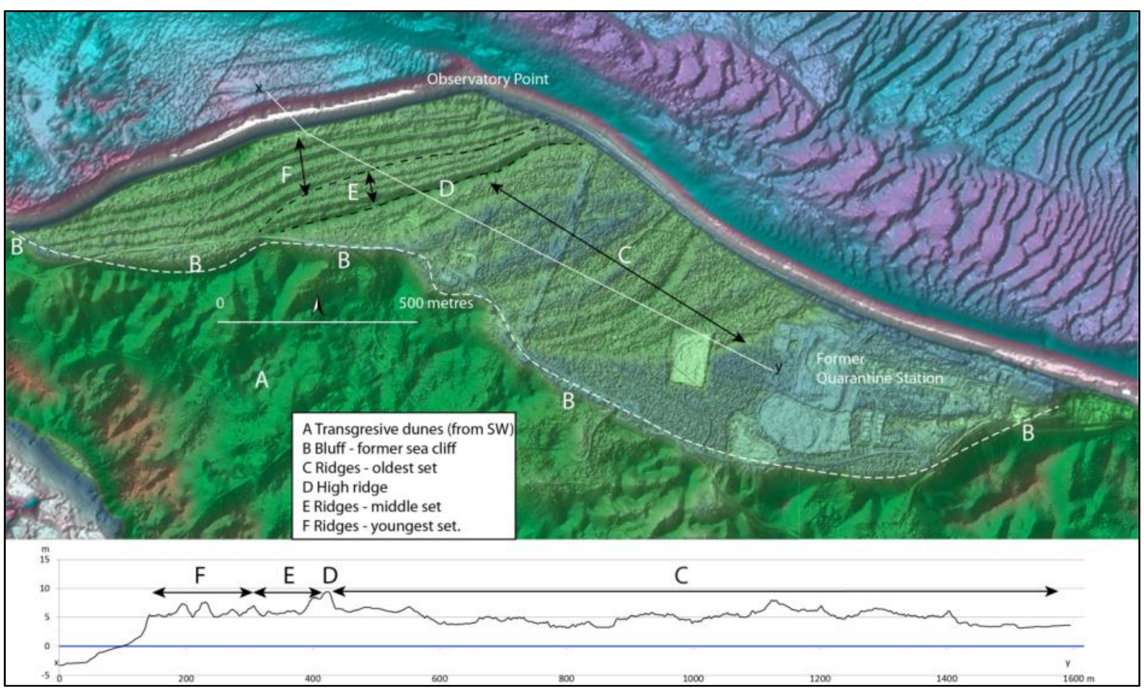

Figure 41. LiDAR DEM of Observatory Point and profile across ridge sequence.

Ridge set C (Figure 41), the oldest preserved, was built on a shallow nearshore sand shelf (now the site of the former Quarantine Station). At that time the coastal cliffs immediately east of the Station extended 100 metres north (into the bay) providing a larger

embayment in which the ridges accumulated. Three scenarios can account for the truncation of ridge set C and the realignment of the shoreline:

- falling and then rising sea-levels;
- (b) tectonic subsidence;
- (c) migration of the deeper tidal channel to the south as an adjustment to accumulation patterns of the Great Sands.

The geometry of the younger ridge sets is also discordant with the present shoreline orientations, as ridge sets E and F are both truncated just east of the foreland apex.

Based on NearMap imagery (2010 to Nov 2016), ground and aerial inspections (Nov 12 2016 and Dec 16 2016) the apex and western shorelines of Observatory Point are experiencing sustained recession, indicated by a continuous sand scarp and toppled vegetation (Figure 42A, 42B). The eastern shoreline is in varied condition with some sand cliffs (Figure 42A) but also short sectors with an incipient foredune ridge with colonising grass (Figure 43B).

Figure 42. Observatory Point eroding shoreline western side. (Photo: N. Rosengren, Dec 15 2016).

Figure 43. Observatory Point. (A) Palaeosols in ridge set C. (B) incipient foredune.

2.6 ESTUARIES & STREAM MOUTHS

Estuaries are the lower reaches of a stream where sea water is measurably diluted by fresh and a salinity gradient extends some distance steam. The constant determinants of tidal penetration distance are tide range and stream floor slope, but river discharge and onshore wind are also factors at times. A large number of streams drain into Port Phillip (Figure 44) but those from the west and north have catchments of low elevation, restricted area and of relatively low rainfall. The low tide range is partly offset by the very low gradient of the lower reaches allowing tidal penetration for several kilometres in the Werribee River.

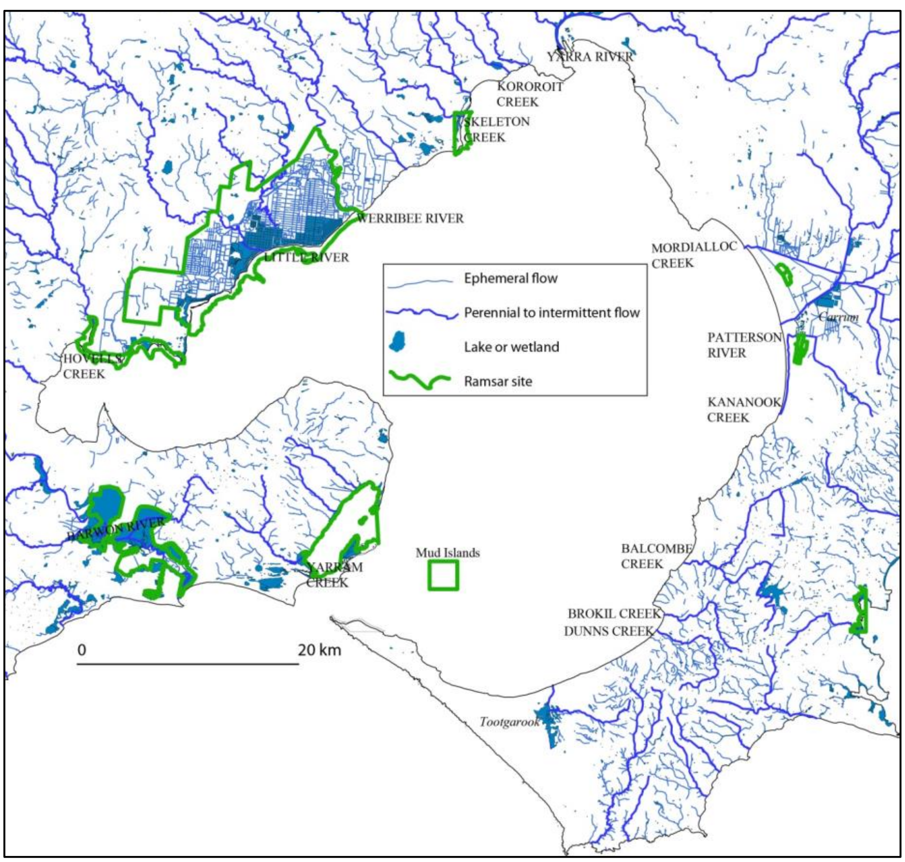

Figure 44. Streams, wetlands and Ramsar sites, Port Phillip.

Apart from the Yarra River and Werribee River, most streams are intermittent to ephemeral. Most waterways are modified and highly regulated by flow diversions, adjacent land use and channel engineering including dredging tom maintain a marine connection for boat access. These works have substantially changed the natural estuarine character and processes of Mordialloc Creek, Patterson River (former Dandenong Creek), Little River and Brokil Creek (Martha Cove Marina) (Figure 45). The least modified lower waterways are Balcombe Creek (Figure 45) and the funnel-shaped estuary of Limeburners Bay at the mouth of Hovells Creek. Despite its industrial surroundings, Kororoit Creek maintains a reasonable estuarine character—including a limited mangrove community—compared with the much modified lower Laverton and Skeleton Creeks nearby.

Figure 45. Balcombe Creek estuary with fringing and in-channel wetlands, compared with the former lower waterways of Tassils Creek and Brokil Creek obliterated by the Martha Cove marina. (Photo N. Rosengren Dec 15 2016).

2.7 COASTAL WETLANDS

Given the constraints outlined in 2.6 above, wetlands associated with estuaries and streams are non-existent, vestigial or at best remnant around much of Port Phillip. Coastal wetland extent and diversity is limited by ambient factors such as backshore and intertidal slope, substrate type, water quality and turbulence as well as by past and ongoing disturbances. Limeburners Bay (Hovells Creek) retains fresh to brackish-saline flora and fauna communities including a substantial stand of mangroves along both shorelines in the upper estuary. The tidal entrance to Limeburners Bay, although restricted by a curving spit on the east, is always open. Balcombe Creek estuary is intermittently closed by a sand bar.

Compared with the limited extent of estuarine wetlands there are large areas of other coastal wetland types including Ramsar sites at Mud Islands and four large sites along the western coast of Port Phillip (Figure 44): Section 1: Skeleton Creek to Point Cook; Section 2: Block from Werribee River to Avalon Airfield ; Section 3: Northern coastline of Corio Bay from Point Wilson to Limeburners Bay; Section 4: Swan Bay. Much of Sections 1 to

3 are derived wetlands utilising abandoned salt ponds or other excavations and the or constructed Western Treatment Plant area.

Mud Islands (Figure 46), Swan Bay (Figure 47) and The Inlets (Figure 48) retain the greatest array of natural landform wetlands as they are partially or substantially enclosed by spits and coastal barriers and include varied landforms with different degrees of tidal ventilation. Mud Islands is a group of elongate sandy islets and shoals overlying an outcrop of calcarenite on the Great Sands six kilometres north of the Nepean Peninsula. The ridges rise less than 3 m above high spring tide and are arranged roughly in a circle enclosing a large, shallow, central lagoon. The highest parts are beach ridges of shelly sand, capped by finer wind-blown sands on the western margin of the group. The lagoon and salt marsh areas are of fine sandy mud. The configuration of the group changes rapidly and markedly (Bird 1993), due to opening and closing tidal entrances by storms, beach and dune sand movement and the growth of salt marsh (Figure 46).

Figure 46. Mud Islands (NearMap image 2010) and changes 1836-1984 (Bird 1993).

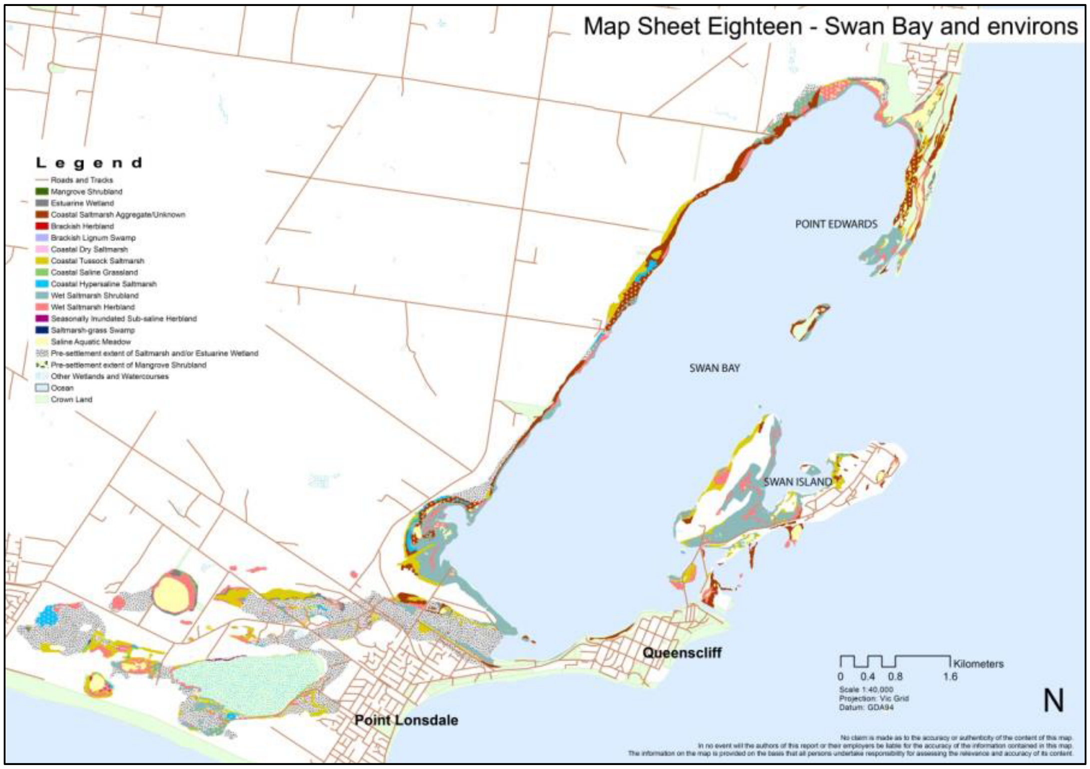

Figure 47. Swan Bay coastal saltmarsh vegetation. (From Boon *et al.* 2011).

The shallow tidal lagoons at The Inlets lies behind elongate barrier spits that parallel the trend of the coastline and extend 300 to 500 m offshore. The spits are built of sand, shells and basalt pebbles, are of variable width and surmounted by vegetated beach ridges to 1.5 m high. There are three main spits, with several tidal crossings and a number of low washover sectors. Flood tide deltas and distributary channels extend from these points into the lagoon.

Figure 48. The Inlets (N. Rosengren Dec 15, 2016).

2.8 THE SHORE ZONE

The shore zone is a practical method of summarising the physical and related biological nature of alongshore units based on their cross section components. Importantly, this is one method of assessing the response of a coast to water level changes including potential impacts associated with channel dredging and larger vessel traffic. The visible component of the shore zone is the intertidal zone, but effectively it is the area between wave base and the limit of wave impact. The shore zone is related to the backshore zones described in Sections 2.2 to 2.5 above, however not all backshore zones will necessarily have similar shore zones. For example, rock platform shore zones can occur in front of a range of backshore types including active cliffs or coastal wetlands. The impact of changed coastal processes, e.g. changes in wave dynamics and water level, is initially displayed in the shore zone before it is translated to the backshore.

The Port Phillip shore zone is dominated by sediments. Rock and nearshore reef are restricted to the northeast coast (Brighton to Beaumaris) and part of Mornington Peninsula (Figure 49). Seagrass and macroalgae cover occupies a wide zone on the west coast and Bellarine Peninsula but is sparse or absent along much of the east coast (Figure 50).

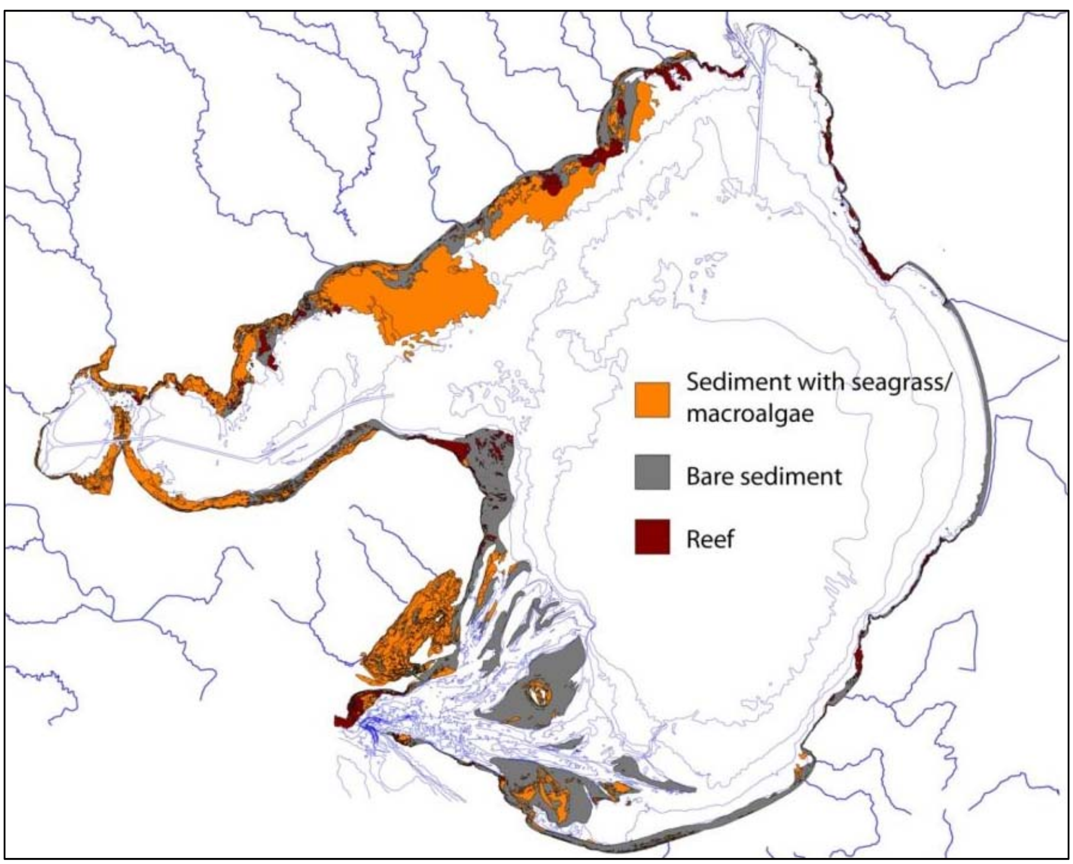

Figure 49. Peripheral substrate around Port Phillip. (DPI Port 2000).

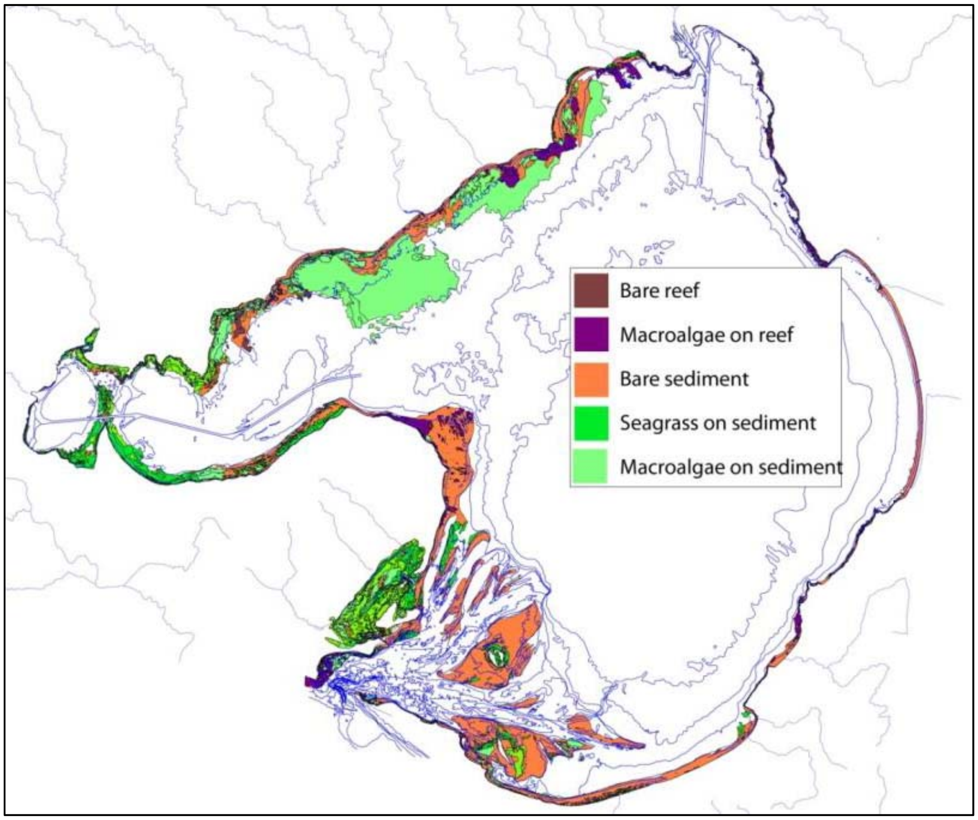

Figure 50. Seagrass and macroalgae cover compared with bare sediment and reef.

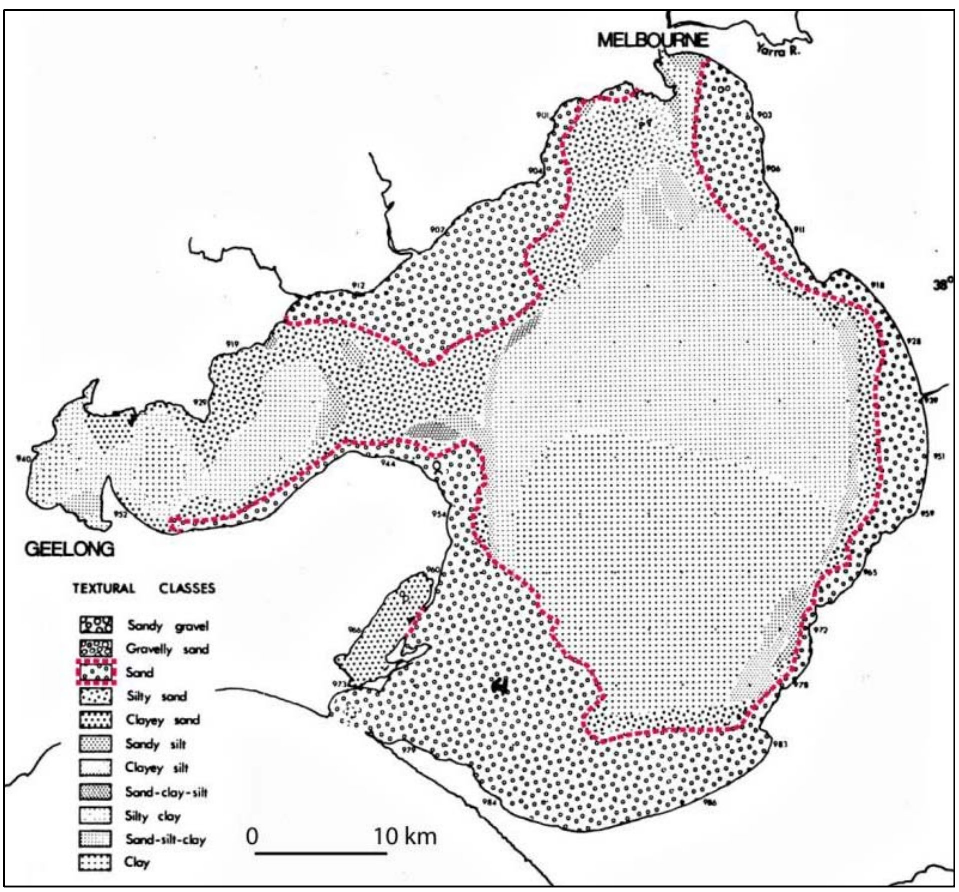

Figure 51. Sediment distribution, Port Phillip, showing the widespread peripheral sand. (After Beasley 1966).

Offshore sediments also show distinct zonation (Beasley 1966, Holdgate *et al* 2001). Nearshore muddy sediment is confined to Hobsons Bay and Corio Bay. The nearshore and coastal sediments to depths of 2 to 5 metres are predominantly sandy along the whole of the eastern coast south of Hobsons Bay and on the west coast south of Altona to Point Wilson. Peripheral sands occur around most of the coast as shown by Beasley (1966) (Figure 51), including areas on southern Corio Bay. This coast is surprisingly shown as mud by Holdgate *et al,* (2001) (Figure 52) although the shoreline and nearshore surface is clearly a sandy zone for over one km offshore Figure 53).

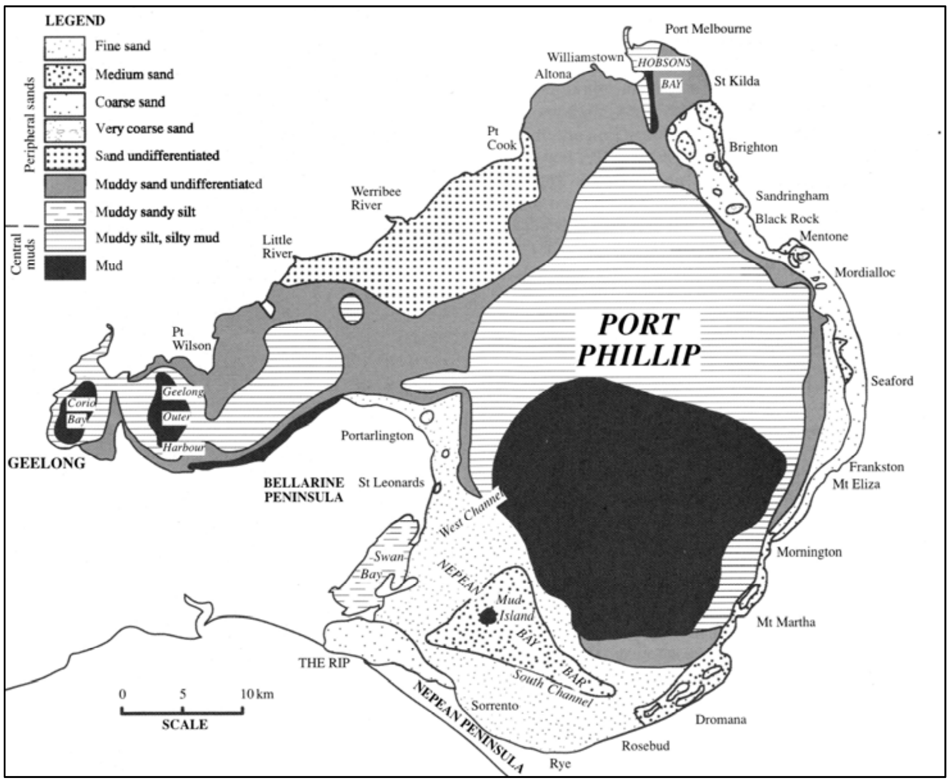

Figure 52. Seabed sediment distribution, Port Phillip (From Holdgate *et al.* 2001).

Figure 53. Sandy shore zone and nearshore Pt Richards to Clifton Springs. (N. Rosengren Dec. 15 2016).

Around Port Phillip, the two main determinants of shore zone class and coastal landforms are substrate and exposure to wave energy. Steep shorelines are typically associated with hard substrate types but also with dynamic soft rock substrates where exposed to storm waves or experiencing slope mass movement. Coastal sediment supply also differentiates coastal classes as shore zones with sand show a range of erosion and accretion landforms and linked sediment transport cells.

A typology for the shore and intertidal area (shore zone) modified from Dethire and Harper (2011) is applied to Port Phillip. Using a combination of substrate composition (5 types), sediment texture (4 types), width (2 types) and slope of intertidal zone (2 types [combining inclined and flat]), 27 intertidal shoreline zonal classes are recognised (Table 2), (Inclined and Flat slope types are combined). The distinctions between classes (slope and width) are to a degree arbitrary and overlap with fine scale variations along-shore.

In column 6 of Table 2, CLASS CODE is the identification number of the Coastal Class. *The **RATING/10** is a subjective rating on 1 - 10 scale of the **sensitivity of the shore zone to change**. The rating includes the potential for erosion and submergence due to low elevation of the backshore. A rating of 10 = highest sensitivity and a rating of 1 = lowest sensitivity to change. The rating is an overall rating and is not specific to potential impacts of channel deepening.*

Potential impacts of channel deepening impact is assessed in table 3.

TABLE 2. SHORE ZONE TYPES (INTERTIDAL)

SUBSTRATE	SEDIMENT	WIDTH Wide (>30 m) Narrow (<30 m)	SLOPE Steep (>20^0) [Inclined (5^0-20^0) Flat (<5^0)]	COASTAL CLASS Cliff Ramp Platform	CLASS CODE & RATING/ (1 - 10)
Hard Rock	n/a	**Wide**	**Inclined - Flat**	**Ramp-Platform: wide**	**1 (1)**
		Narrow	**Steep**	Cliff-Bluff	2 (1)
				Ramp-Platform: narrow	**3 (2)**
Soft Rock	n/a	**Wide**	**Inclined - Flat**	**Ramp-Platform: wide**	4 (8)
		Narrow	**Steep**	Cliff-Bluff	5 (10)
				Ramp-Platform: narrow	**6 (8)**
Rock with sediment overlay	Gravel	Wide	Inclined - Flat	Ramp-platform & gravel beach: wide	7 (5)
		Narrow	Steep	Platform & ridge - gravel	8 (5)
			Inclined - Flat	Ramp-platform & gravel: narrow	9 (7)
	Sand & gravel	**Wide**	**Inclined - Flat**	**Ramp-platform & gravel-sand beach: wide**	10 (6)
		Narrow	Steep	Platform & gravel-sand ridge	11 (8)
			Inclined - Flat	**Ramp-platform & gravel-sand beach: narrow**	**12 (8)**
	Sand	**Wide**	**Inclined - Flat**	**Ramp-platform sand beach: wide**	**13 (6)**
		Narrow	**Inclined - Flat**	**Ramp-platform & sand beach: narrow**	**14 (8)**
	Mud	Wide	Inclined - Flat	Ramp-platform mud flat: wide	15 (6)
		Narrow	Inclined - Flat	Ramp-platform mud flat: narrow	16 (8)

Sediment	Gravel	Wide Narrow	Inclined - Flat Steep Inclined - Flat	Gravel flat: wide Gravel ridge Gravel flat: narrow	17 18 19	(6) (6) (8)
	Sand	**Wide** **Narrow**	**Inclined - Flat** **Inclined - Flat**	**Sand flat** **Sand beach**	**20** **21**	**(7)** **(10)**
	Mud	Wide Narrow	Inclined - Flat Inclined - Flat	Mudflat: wide Mud flat: narrow	22 23	(7) (8)
Organics	n/a	Wide Narrow	Flat Flat	Fringe: wide Fringe: narrow	24 25	(7) (9)
Anthropo-genic	n/a	n/a	n/a	Permeable **Impermeable**	**26** **27**	**(3)** **(1)**

The most frequent classes are shown in **bold (1, 3, 6, 12, 13, 14, 20, 21. 26, 27)**.

Mapping all shore zone classes in detail around Port Phillip is beyond the scope of the present study. For the purposes of this assessment, generalised zones of resistance/sensitivity are shown on Figure 54. Illustration of all classes is in Section 2 of this report (Figures 11 to 34).

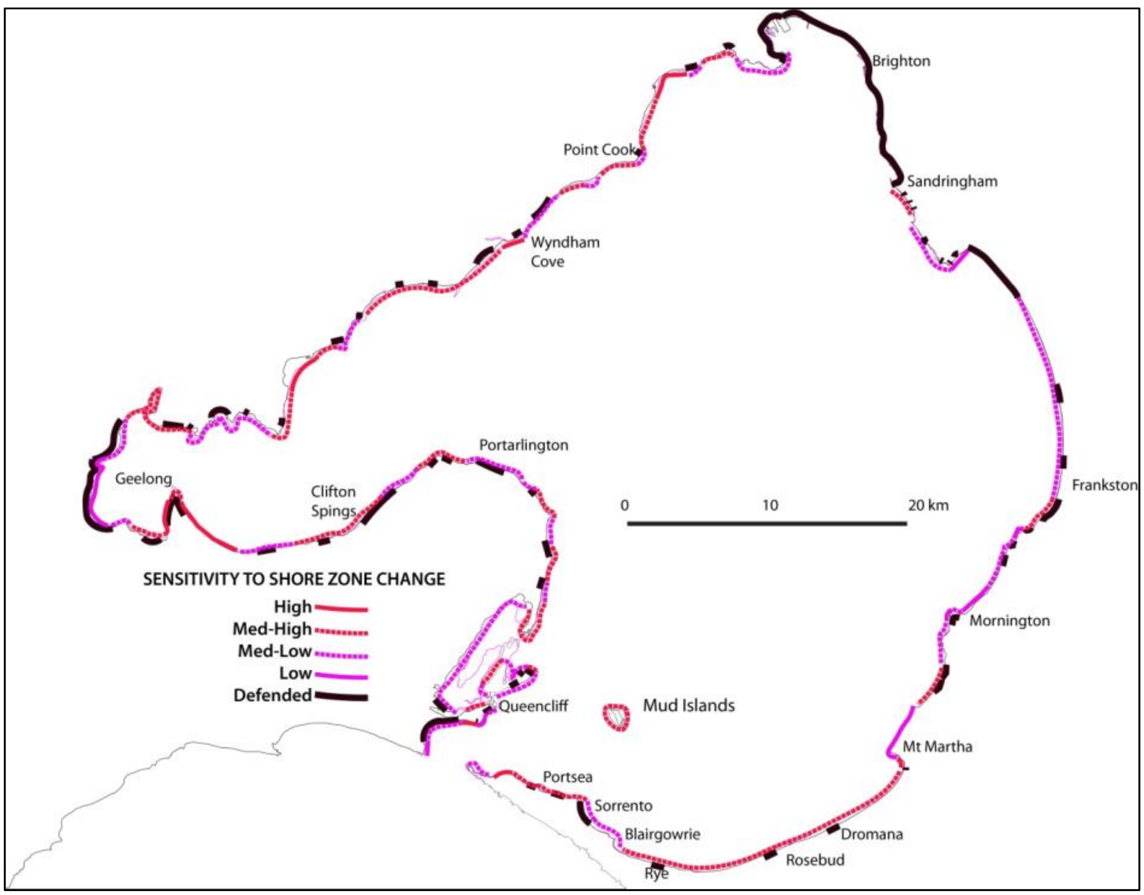

Figure 54. Generalised shore zones based on sensitivity to change (Table 2).

The shore zones of Port Phillip show the following characteristics:

- generally a wide shore zone despite the limited tidal range
- shore zone gradients are low angle slope

- sub-tidal slope often steeper than inter-tidal
- low tide often marked by a break of slope
- hard rock cliffed shore zones limited extent
- limited areas of inclined-ramp slopes (5^0—20^0)
- predominantly flat slopes (<5^0) on both rock and sediment substrate
- most ramp-platform rock substrates have sand or gravel beaches
- limited extent of gravel substrate
- limited extent of mud and organic substrate
- extensive anthropogenic substrate (including re-nourished beaches).

Shore zone resistance/sensitivity rating in Port Phillip is based on the following assumptions:

- The rate of down- and back-wearing on all hard rock coasts is too slow to be altered by potential changes in waves, currents and sea-level.
- Back-wearing on soft-rock coasts is occasioned often by slope failure rather than wave-derived processes.
- Sediment cover on ramps and platforms is not an agent of attrition or downwearing of the underlying surfaces.
- Apart from areas near the Entrance, beach sediment is derived from adjacent beaches, nearshore waters, only locally from cliff erosion and negligible fluvial contribution.
- Over seasonal and longer terms, episodes of natural beach re-nourishment alternate with phases of depletion (Bird 2011).
- Sediment arriving through the Entrance is incorporated into the Great Sands and adjacent beaches to the west but is not distributed further into the bay and in limited quantities to the southern beaches.
- Engineering structures, including beach nourishment are effective in defining the shore position and will be maintained.

2.8.1 Shore Zone Changes

Resistance to shore zone change is determined by the inherent-static properties of the coastal materials—rock, sediment and organics and the backshore and offshore slope. Over a given period, changes occur in response to differing marine and subaerial energy

inputs governed by regular e.g. seasonal and cyclic processes, and irregular-infrequent high energy events such as storms or landslides. On rock coasts, changes in profile are not reversible whereas local sediment accumulation and depletion occurs within predicted and modelled limits.

The review of backshore and shore zone geomorphology in sections 1 and 2 of this report has shown a wide range of shorelines occur around Port Phillip. A number of factors: backshore elevation, slope and lithology along long stretches of coast result in shore zones of low resistance to change (Table 2 and Figure 54). Even though fetch-limited, Port Phillip is a strong-wind bay and seasonal directional change is a key process driving beach plan-position on embayed sectors of the coast such as Sandringham. Beach state also changes seasonally e.g. from low tide terrace to transverse bar and rip in response to storms that generate waves up to 3 metres high (Goodfellow and Stephenson (2005). Many studies of Port Phillip over the past 80 years have established that beach changes on various time scales are an on-going characteristic (Hills 1940, Baker 1964, Bowler, 1966, Beasley 1969; Bird 1988, 1993, 2011; Black and Rosenberg 1992, Foreshore Erosion Board 1936; Jones 1988, Vantree 2001).

Bird (2011) in a comprehensive review of beach changes identified 18 potential causes of beach changes that have occurred to varying degrees around Port Phillip. The causes range from global (eustatic sea-level rise), regional (tectonic uplift or subsidence), to very local (vegetation stabilisation of a dune that formerly provided beach nourishment), and include human intervention deliberate and inadvertent.

The principal driver of shore zone change across all Port Phillip over the long term is sea-level. Although tidal currents in the Great Sands region are the agent of sediment movement, in the microtidal environment of Port Phillip, the primary driver of sediment transport at beaches is current generated by local wind. Rising sea level increases the height of the tidal prism and the period of tidal inundation, causing landward advance of the average positions of breaking waves at low-tide and high-tide shoreline. Climate-driven sea-level rise may be accompanied by changes in storm frequency and increased strength of local winds, and in relation to extreme events, sea-level rise raises the baseline elevation that is then added to by a storm surge. Hence, the return interval of given extreme water levels is reduced (Plater and Kirkby 2011). Shore dynamics in the short-term will therefore be more responsive to wind-driven wave changes rather than to an increase in water level—

due either to eustatic sea-level rise or changes associated with channel widening or deepening. As the potential changes in currents, waves and sea-level associated with the channel upgrades will be minimal (Cardno 2016), it is concluded that changes to shore zone geomorphology will be minimal and within the range to be expected from those produced by background ocean and atmospheric conditions.

Around much of Port Phillip, the shore zone landward and in places the seaward boundary is fixed by engineered structures, including beach re-nourishment. As these play a major role in asset and facility protection and are part of the recreational fabric of Port Phillip, it is assumed that with few exceptions, they will be retained, maintained, extended and strengthened as necessary—this action will accommodate any slight impacts that may accrue from channel upgrades.

3 POTENTIAL IMPACT OF PROPOSED CHANNEL UPGRADES AND CONSTRUCTION OF BAY WEST CONTAINER TERMINAL

3.1 Previous Channel Deepening

The Channel Deepening Project (CDP) at Port Phillip between 2008 and 2009-10 was the subject of extensive pre-dredging and post-dredging environmental studies e.g. Cardno Lawson Treloar (2007) Cardno (2010). The studies provided detailed air and seaborne imagery of the seafloor and bordering beaches, seafloor sediment sampling and coring and hydrodynamic field and modelling. The direct physical impact of channel dredging on Port Phillip is initially submarine i.e. deepening/widening of channels and dumping of dredge spoil in the bay. Sediment dispersal plumes from both these activities can drift onto beaches but this is time-limited to the dredging/dumping operations. By altering the seafloor configuration, and therefore the volumetric capacity of Port Phillip, a number of permanent changes in dynamic process can occur that may translate to the processes that shape the shore zone (Cardno Lawson Treloar 2007). These include changes that potentially could alter coastal processes and shore zone geomorphology:

- the tidal prism (absolute height of high and low water)
- sea-level and storm surge heights
- tidal currents
- wind-driven circulation
- wave direction, wave height, wave period
- sediment transport and deposition
- flushing time

Bird and Provis (2011) reviewed the evidence for and potential causes of beach changes in Port Phillip following completion of the CDP. The review evaluated changes in bathymetry, water levels (sea-level, tidal), waves and currents that may have affected coasts bordering the dredging sites. The analysis, in summary from that study (page 90) was:

> *The pattern and rate of change on beaches in the southern part of Port Phillip Bay during the past 2 years* [2009-2011] *(during and post CDP) is consistent with that documented over the past 150 years*.

3.2 Present Proposal

The proposal being considered by Infrastructure Victoria is for is an island terminal off the west coast of the bay, south of the mouth of the Werribee River. A shipping channel would be dredged to the south east to reach the deeper central section of the bay. Berth

pockets and swing basin would be dredged adjacent to the seaward side of the island. As these new channels are in areas of the bay not influenced by ocean swell, refraction effects on wave and sediment patterns would be minor. The Great Ship Channel would be widened, but not deepened beyond the existing 17.3 m CD, South Channel deepened to 17.3 m CD and the turning area around Hovell Pile deepened to 17.8 m CD. These are within the range of changes assessed in the initial CDP and potential minimal impacts on shore zone are similar to those considered for the previous CDP listed in Section 3.1 above.

3.2.1 Potential Impacts of New Proposal

The analysis of coastal geomorphology (Figure 10, Table 1) and shore zone sensitivity (Figure 54 and Table 2) shows three relevant characteristics of central and southern Port Phillip relevant to assessing potential impacts of channel upgrades of Great Ship Channel, South Channel and Hovell Pile.

- high incidence of sandy shorelines and soft-rock backshore
- extensive shore of medium-low to medium-high sensitivity
- occurrence of short sectors of high sensitivity, notably Bellarine Peninsula low sandy shorelines:
- Lonsdale Bight (Dog Beach east of the breakwater),
- Queenscliff to Swan Island
- Edwards Point recurving spits and Duck Island (Figure 55)

Figure 55. Sensitive shore zones eastern Bellarine Peninsula: (A) Lonsdale Bight, (B) Queenscliff-wan Island; (C) Duck Island - Swan Bay; (D) Edwards Point spit. (Photos: N. Rosengren Nov 2013).

- Nepean Peninsula alternating pocket beaches and headlands of sandy calcarenite:
- Cameron Bight to Portsea (Figure 56)
- Observatory Point west (Figure 58)

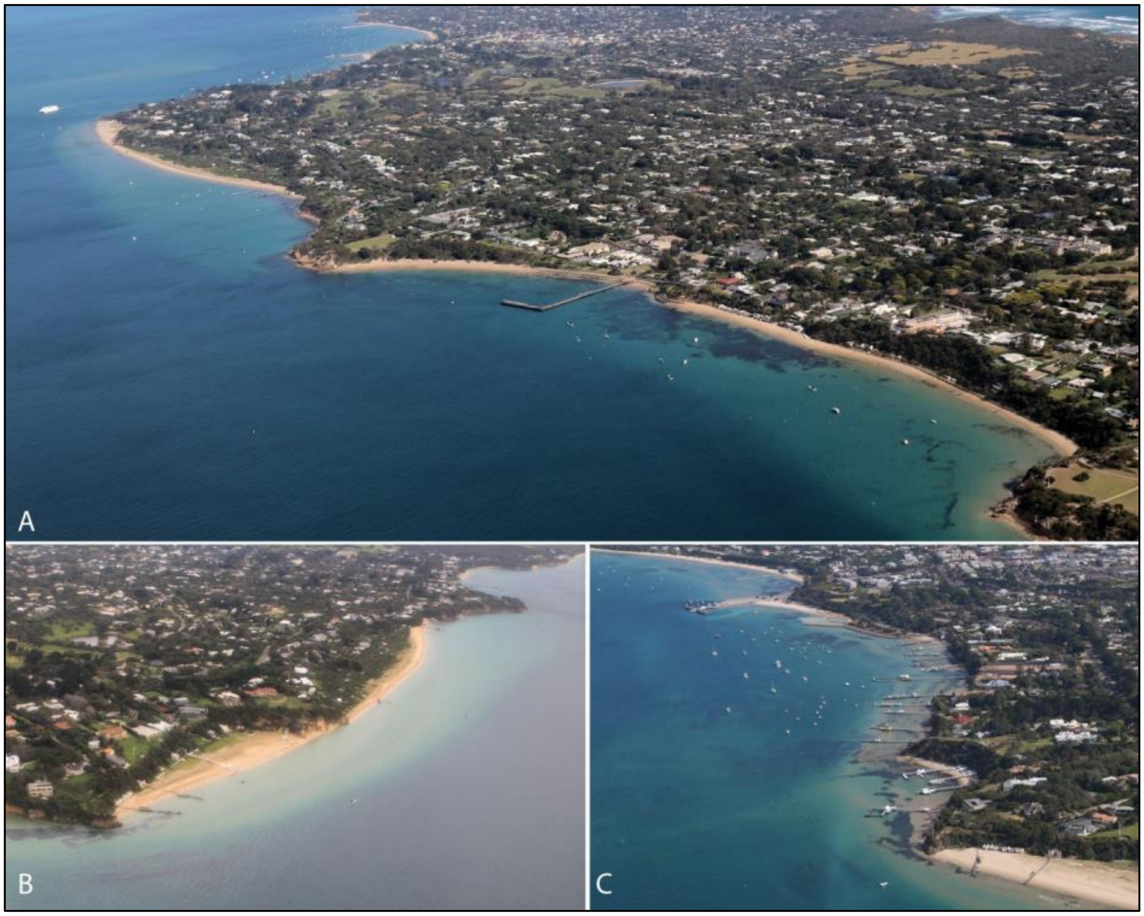

Figure 56. (A) Pocket beaches and sandy calcarenite headlands between Blairgowrie and Portsea are dynamic shore zones and subject to beach loss and cliff failure. (B) Shelly (or Shelley) Beach and (C) numerous private jetties and boat sheds. (Photo N. Rosengren Dec. 15 2016).

Figure 57. Observatory Point: eroding shore zones west (right) and some foredune accretion (left). (Photo N. Rosengren Dec. 15 2016).

Historical analysis presented by Bird (2011), showed that the range of changes experienced in the post-dredging years was within the range recorded over the historical (since 1930's-50's) period. It is expected that shore zone —particularly beach width and

thickness—changes at least of the magnitude shown—and if eustatic sea-level rise and an increase in climate-change driven storm frequency and magnitude occurs—possibly of greater magnitude are to be expected.

Modelled preliminary data of changes in sea-level, current speed/direction and wave conditions (Cardno in prep.) show them to be of similar magnitude to those modelled for the previous CDP or to have no significant change. Given the range of water-level, wave and current conditions that are produced by ambient and expected future processes, additional impacts produced by changes introduced by the proposed channel deepening are beyond the threshold of measurement or isolation.

The potential impact of larger bow waves and propeller swash from increased vessel displacement may be a factor on some beaches. The relationship between these waves and beaches and the direction and speed of vessel travel needs more detailed analysis, such as comparison of bow wave form and frequency with wind-waves (Figure 58).

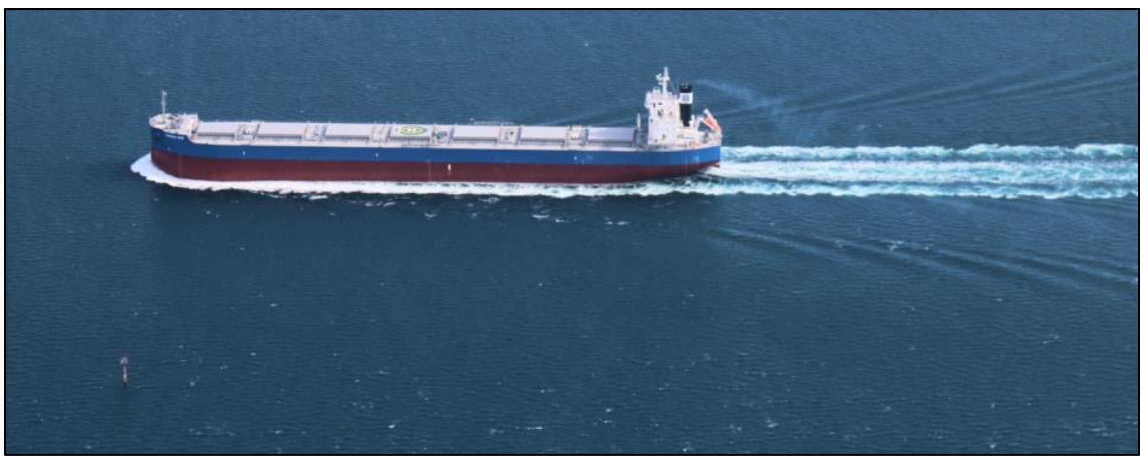

Figure 58. Bow waves and propeller swash from departing vessel South Channel. (Photo N. Rosengren Dec. 15 2016).

3.3 BAY WEST - PROPOSED CONTAINER TERMINAL

3.3.1 Port Infrastructure

The container port development considered for Port Phillip requires (Figure 59):

- a constructed island terminal approximately 5.3 km long and 0.5 km wide located 1.5 km offshore south of the mouth of the Werribee River to Wedge Point
- bridge link between terminal and coast with landfall 700 metres south of Werribee River mouth
- a dredged shipping channel to -17.5 m and approximately 10 km long and 200 metres wide linking the terminal to the deeper (-20 m) central section of the bay

- berthing pockets and swing basin dredged adjacent to the seaward side of the island.

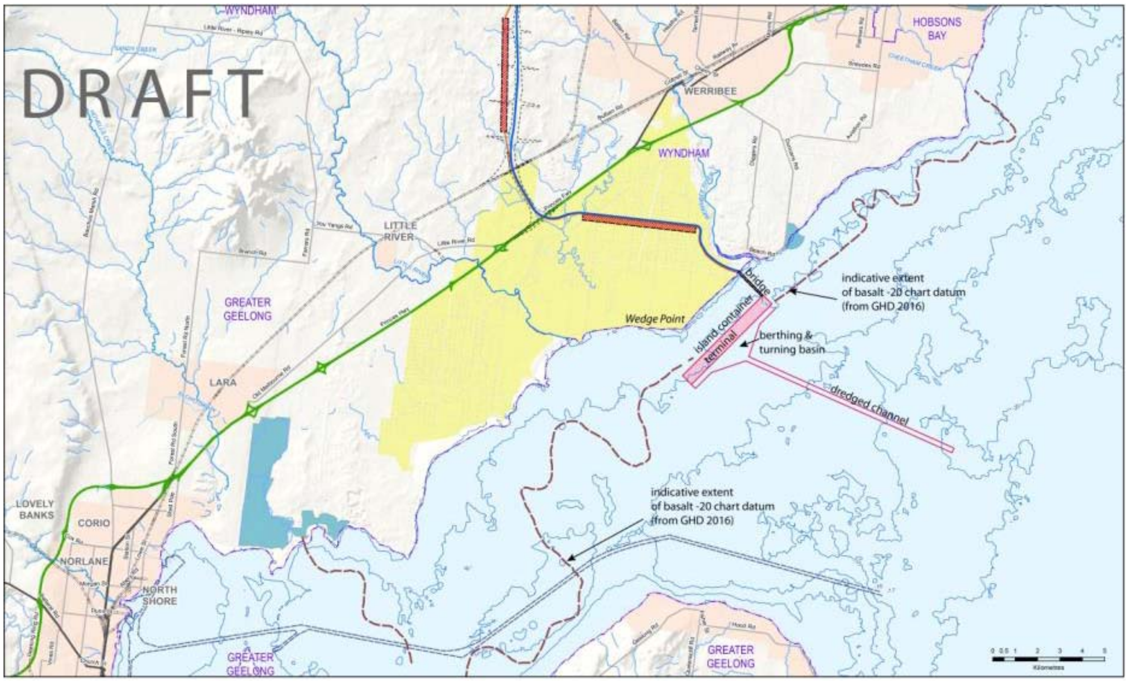

Figure 59. Proposed container terminal, western Port Phillip. (Infrastructure Victoria).

3.3.2 Geology and Geomorphology - Western Port Phillip

The site lies offshore from Wedge Point, a low promontory mid-way between the Werribee River and Little River estuaries (Figure 60). Apart from the corridor parallel to the right bank of Werribee River (Figure 60 C), the onshore surficial geology and geomorphology is almost completely masked by the regraded surfaces, lagoons and levees of the Western Treatment Plant.

Bathymetry and seafloor and subsurface geology are known from a recent marine geophysical field survey by GHD (2016). The survey used a combination of Sub Bottom Profiling (SBF), Side Scan Sonar (SSC) and Marine Magnetometer (MM) techniques to determine offshore occurrence of hard rock—specifically basalt lava of the Werribee Plains Newer Volcanics lava field—as outcrop and beneath sedimentary and weathered cover. The interpreted data show basalt to crop out at variable distance offshore but across much of the project area to be under a cover of 20 m+ of “soil” (sediment and/or weathered mantle).

The sedimentary cover is a superficial deposit of sand, silt, and clay derived from erosion of earth cliffs adjacent to the Werribee River and from contemporary fluvial deposits. These overlie poorly-bedded silty and sandy clay with minor sand and gravel sediments that are the extension of the onshore Werribee River floodplain and Deutgam

Silt. The sediments include basalt gravels. The basalt surface is variously defined in the geophysical signal returns that indicate a palaeovalley with relief of 20 metres (Figure 61).

Figure 60. Wedge Point and lagoons and levees of WTP: from south (A) and north (B). Mouth and lower estuary of Werribee River (C). Onshore terminal corridor is parallel to the road along the right bank of the Werribee River. (Photo N. Rosengren Dec. 15 2016).

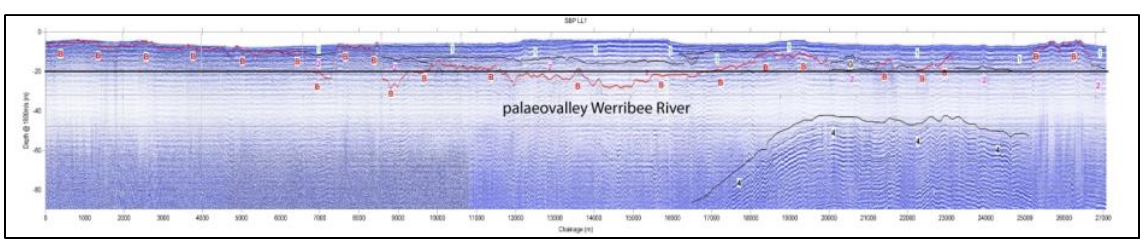

Figure 61. Example of interpreted seismic cross section parallel shoreline at proposed container terminal showing top of basalt and palaeovalley. (From Figure A6, GHD 2916). (My interpretation of Werribee palaeovalley).

Borehole information referred to in Figure A11 of GHD (2016) i.e. Geological Survey of Victoria core sites, was not available for this report. The nearest comparable locality was

from the core record supplied from investigation by Coffey Geotechnics (2014) for the Wyndham Cove harbour installation. Two boreholes penetrated between 10 and 15 metres below sea-bed and are used as a guide to the texture of offshore sediments. For the two boreholes, similar texture classes have been combined and stated as a percentage of the total borehole distance.

<u>Bore Hole 34</u> (15 metres). Silty *clay* 82%; Sandy *clay* 17%; Silty sand 1%.

<u>Bore Hole 73</u> (13 metres). Silty *Clay* 42%; Silty Sand 31%; Sandy gravel 15%; Sandy *Clay* 12%.

Clayey sediment comprised 99% of BH 34 and 54% of BH73. It is expected that stratigraphy and sediment composition across the project area. Although the two bay-wide sediment assessments Figure 51 (Beasley 1966) and Figure 52 (Holdgate *et al.* 2001) show sandy sediment offshore between Point Cook and Kirk Point, these are seabed-sample based and do not necessarily represent the thicker sedimentary column. No boreholes with lithological logs across the Western Treatment Plant site west and south of the Werribee River are listed on the GSV Boreholes database. In 10 borehole logs east of the river clayey sediment is dominant in the upper 10 to 20 metres with thinner layers of sand and occasional gravel. Basalt is not present above 15 metres in any of the 10 records examined.

3.3.3 Shore Zone: Werribee River to Kirk Point

The coast has not been ground traversed and interpretation is based on aerial inspection (15 Dec. 2016), NearMap images (Figure 60) and comparison with 1863 geological maps, Figure 62, Figure 63). This coastline and backshore is the margin of an alluvial floodplain with traces of ancestral streams and shallow depressions formerly with wetlands, now mostly drained or obscured. LiDAR shows the terrain and coastal edge on the northern side of the river is one to two metres higher than the surface to the south, although reshaping of the surface south of Werribee River for the WTP makes direct comparison difficult. The coast from WTP 160S Road (900 metres south of Werribee River) for 12 km south to Beach Road boat ramp is effectively an engineered or defended coast with earthen levee/embankments that contain the lagoons of the WTP. Narrow sectors are reinforced by basalt blocks at the back of the beach (Figure 63). Long sectors of the shore have a narrow reflective sand and shelly beach in front of a low earth cliff with a salt marsh cover and nearshore multiple parallel sand bars in a zone up to 200 metres wide.

Geological Quarter Sheets 20ne & 20se (Geological Survey Office Melbourne, 1863 at a scale of two inches to one mile) do not specifically identify beaches but the legends show

"*Raised beaches Estuary beds & blown sand*" at "*High Water Spring Tide*" at the coast (Figure 62).

Volcanics overlain by "*Marine and freshwater beds"* without a *Raised beaches* zone are mapped as extending to the coast in two sectors: (a) extending for 2.8 km from immediately north of the Werribee River, (north of this the *Raised beaches* zone is narrow until near Point Cook); (b) from 1300 metres south of the Werribee river along 800 metres of coast (Figure 62).

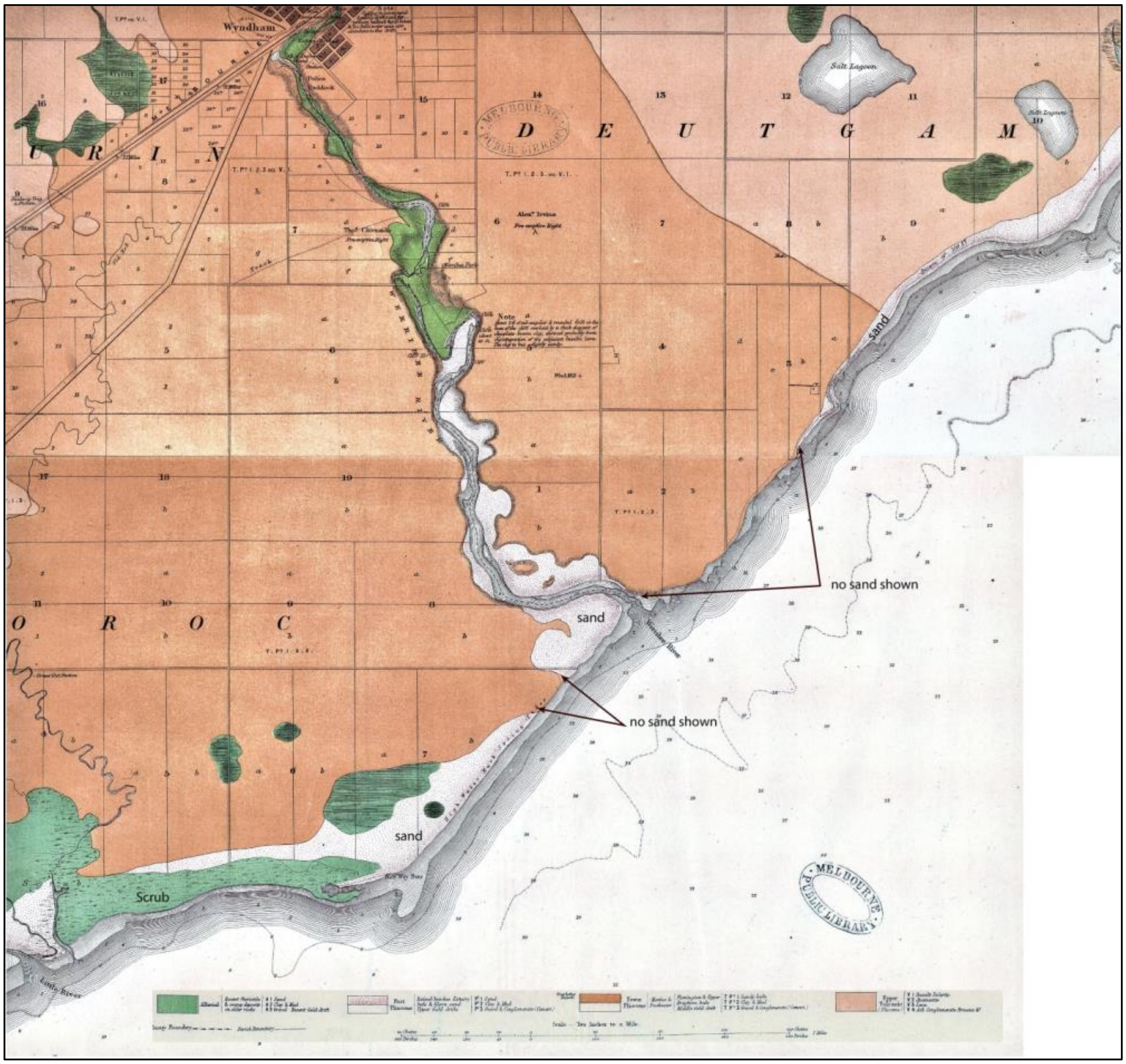

Figure 62. Extracts from Quarter Sheets 20ne & 20se, (Geological Survey Melbourne 1863) showing shoreline between Little River and near Point Cook. Sand and scrub (my labels) and sectors without sand (my arrows).

The *Raised* beaches are over 600 metres wide at Wedge Point (identified as *Half Way Trees* on the 1863 map). West of *Half Way Trees* to Little River estuary the map

identifies the backshore as alluvial with a cover of scrub (Figure 62). This surface is now obscured and parts of the former sandy coast are defended by a basalt seawall (Figure 63).

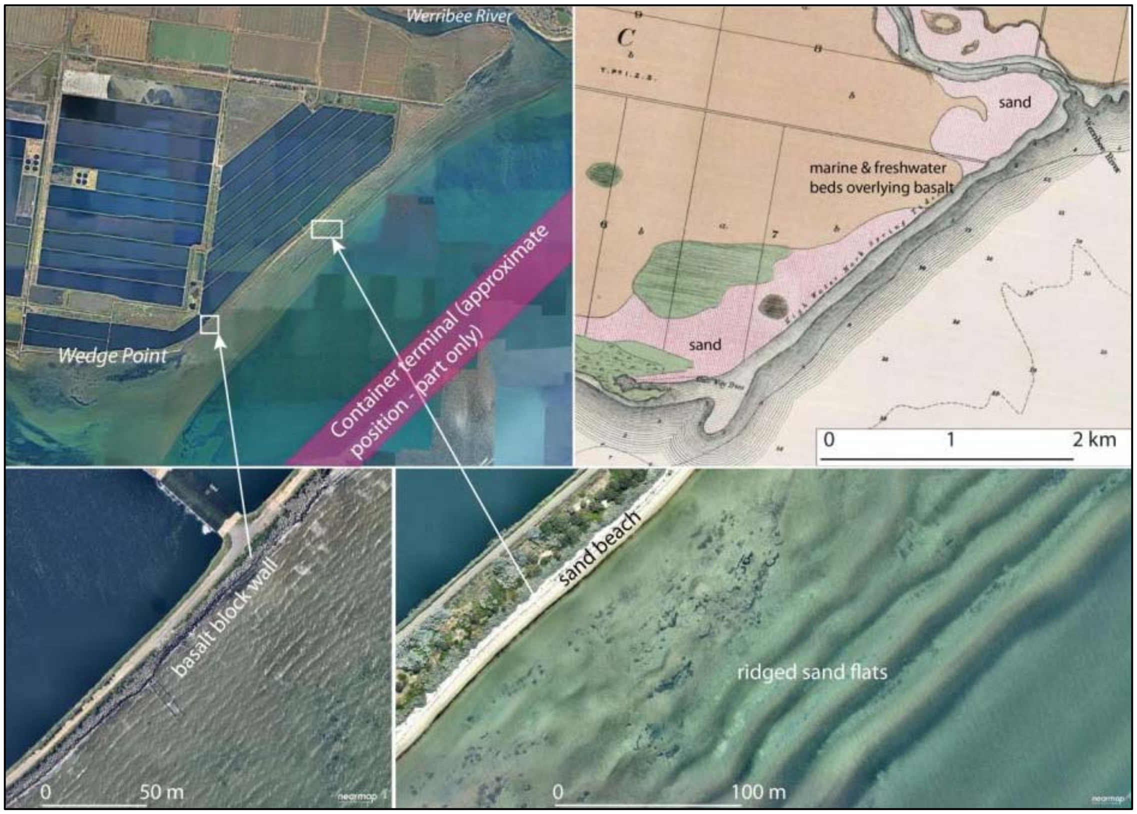

Figure 63. Levee banks and lagoons of the Western Treatment Plant, sector of basalt wall, sand beach and ridged parallel sand bars between Wedge Point and Werribee River. (Near Map 2015, Geological Survey, Melbourne 1863).

The Foreshore Erosion Board (1936) report (p. 49) describes “Werribee Foreshore Erosion” at the “Mouth of the Werribee River”, referring to measured recession of earth cliffs along the northern estuary edge and the shoreline east of the Werribee River. No reference is made to the area south of the River, implying it was not experiencing rapid erosion.

Condon (1951) described the coast as:

“Along the tidal stretch above the mouth of the [Werribee] river and along parts of the foreshore (east of Little River), there are very recent deposits of sand, peat and clay with marine shells. The deposits nearest the foreshore consist of a beach ridge, some 4 feet above normal high tide level, consisting of quartz sand and broken shells and on the shoreward side a salt-water swamp with a floor of peaty clay. The beach ridge probably began as a submarine sandbank which was raised above sea level in a storm. The raised sandbank cut off the area behind it except during storms, when large quantities of seaweed were deposited in the flat area behind the sand ridge, producing peat on decomposition. Offshore, sandbanks are forming and their shape in plan and section would appear to conform with the plan and section of the sand ridges at Altona”.

Condon's (1951) description is consistent with a less eroded partly sand-covered shoreline south of the Werribee as shown in the 1863 Geological Quarter Sheets (Figures 62 & 63). Bowler (1966) recorded the coast from Altona to south of Little River as an almost continuous narrow, thin beach of poorly sorted sand and shell with large quantities of accumulated drift material, including decomposing seaweed overlying basalt. There are now only patches of beach from Wyndham Harbour to Point Cook. At Campbells Cove the beach is covered or replaced by basalt seawalls and a number of shore defences and launching ramps constructed by the owners of the beach shacks.

3.3.4 Nearshore Bars and Sand Movement

In the shallow waters from Altona to Point Wilson is a wide shoaling zone with multiple sand ridges and a variable cover of seagrass. This is a mobile zone and the spacing and position of bars changes over short times (Figure 64).

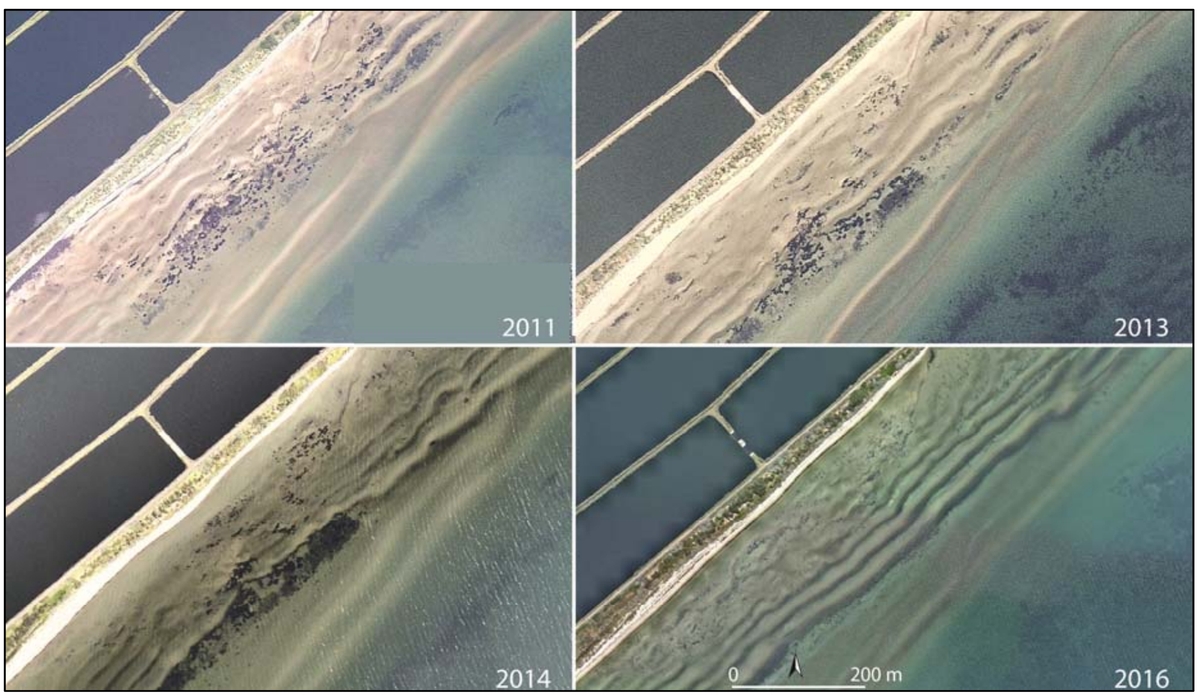

Figure 64. Shoaling zone 250 metres wide between Wedge Point and Werribee River mouth. (NearMap Images).

Indicators of net long-term northerly sand drift north of Kirk Point include the orientation and deflection of spits at the mouth of Werribee River and Little River and accumulation of sand on the southern side of groynes at Wedge Point (Figure 60 A). Water Technology (2004) for Wyndham Cove (marina) EES, reviewed dredging records at the Werribee River and using wind data from Laverton developed a wave and sediment model applicable to the central west coast (Figure 65). The wave climate is highly seasonal with waves from the SSE predominant during summer including waves in excess of one metre. In

winter ENE and NE directions are most frequent and waves above 1 m are less frequent. As a result there is a net northerly sediment movement of 8,000 to 10,000 m^3 per year, much smaller than the modelled capacity for sediment transport. Despite the dynamics of the sand zone offshore, there appears to be limited and only intermittent movement onshore.

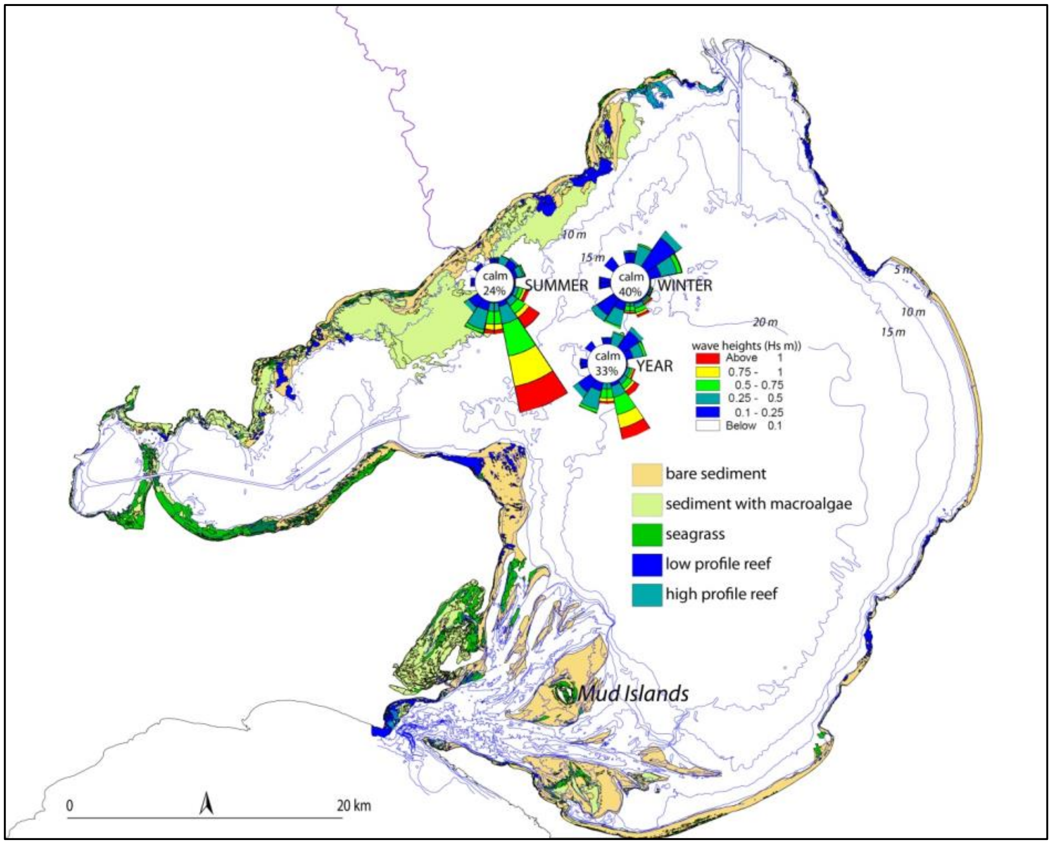

Figure 65. Wave rose model for Wyndham Cove applicable to central west coast of Port Phillip (Water Technology 2004). Sediment, reef, seagrass and macroalgae from DELWP (2002).

Localised accumulations of beach sand develop but are not persistent and short-term accretion is succeeded by an episode of beach erosion. The nearshore sand zone and ridged sands are accumulating on a shelf with a defined break of slope at -2.0 to -2.5 metres below Low Water Mark in a zone 150 to 250 metres wide north of Werribee River. South of the Werribee River the zone is 350 to 400 metres wide and at Wedge Point the sand forms a subaqueous foreland of several broad, curving dynamic sand bars over 1200 metres wide with a variable cover of seagrass (Figure 66).

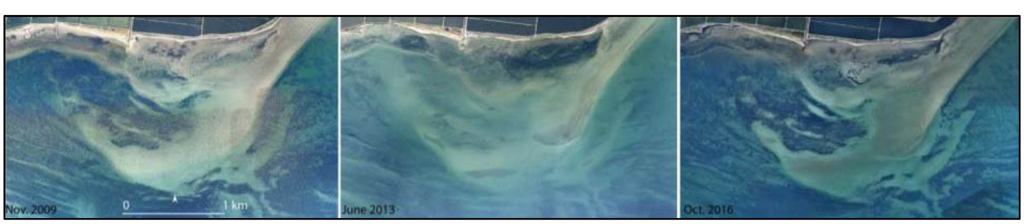

Figure 66. Wedge Point 2009, 2013, 2016 - mobile sand bars and variable seagrass cover. (NearMap).

3.4 Potential Impact of Proposed New Container Port

The proposed new container port and associated infrastructure would be a substantial and rapid physical change in the nearshore configuration of western Port Phillip, including dredging a narrow deep channel exposing banks of clay-rich sediments below a surficial sand cover. As a new island it would function as a very large offshore breakwater. Changes in waves, currents, sediment movement and subaqueous and shoreline geomorphology would result. As shown in Section 4.3.1 and Figure 65 above, effective wave action is from the south generating modest sediment movement northward. Three shore zones could be impacted by the changed regimes:

(a) shore immediately landward of the breakwater i.e. Little River to Werribee River;

(b) estuarine entrance to the Werribee River;

(c) shore and infrastructure north of Werribee River mouth.

The potential changes are summarised as (Figure 67):

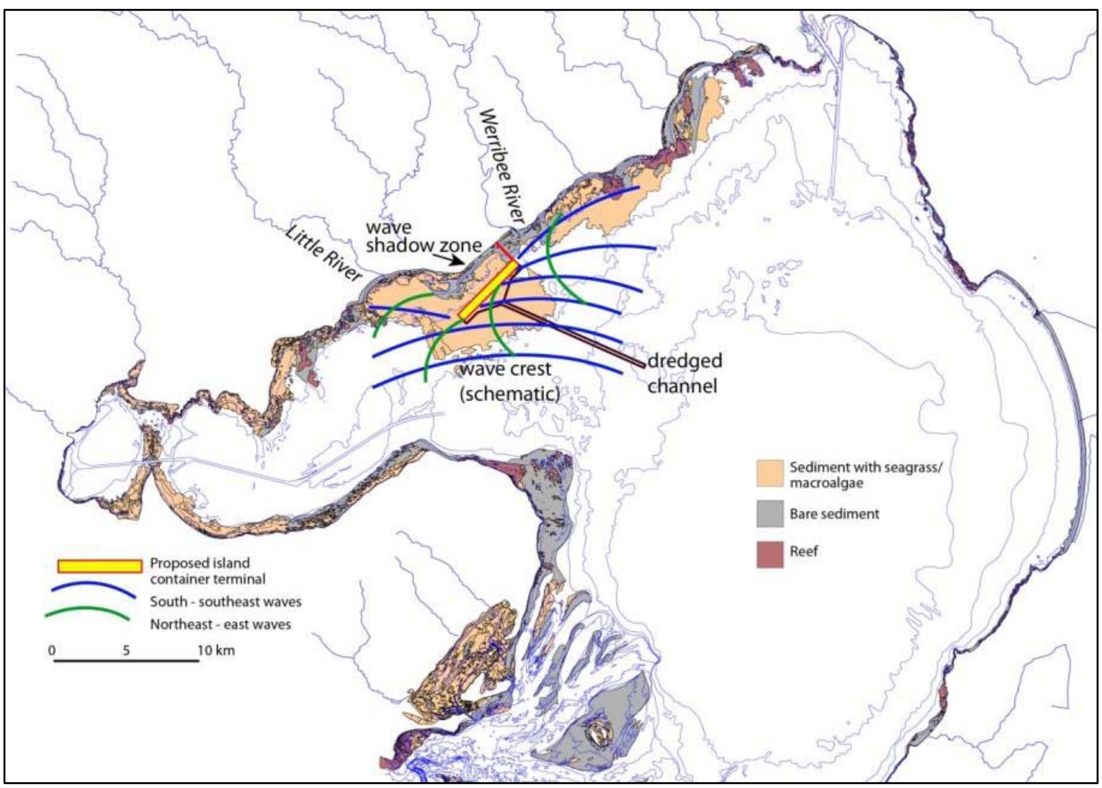

Figure 67. Schematic wave crest changes at proposed container terminal.

- wave diffraction and refraction around the impermeable island structure will result in a change in wave crest direction at the shoreline, north, south and landward of the terminal
- much of the six km of shore zone landward of the terminal will have reduced to minimal wave action

- interruption to onshore and alongshore sediment movement along the entire landward shore of the breakwater
- creation of a shadow/depositional zone in the landward (lee) of the terminal
- increase in deposition at the subaqueous Wedge Point subaqueous foreland
- cuspate foreland development projecting towards the terminal north of Wedge Point
- substantial reduction of sediment transport alongshore and onshore north of Wedge Point
- change in seagrass wrack dynamics in the lee of the terminal, possibly leading to substantial accumulation
- changed angle of wave approach at and north of Werribee River
- interception of currents and bottom sediment by the deepened dredged channel and berth and swing basin seaward of the terminal resulting in sediment starvation of the shallow (<-10 m) sea floor on the northern side of the channel
- reduction in sediment supply to the north of Wyndham Cove leading to narrowing of remnant beaches
- alternate accumulation and scour at ends of terminal determined by seasonal wave direction.

3.5 Summary of Impacts

The substantial changes to the nearshore configuration—deepened channels and large offshore structure—will change wave energy and onshore-alongshore sediment transport across a broad area south of Werribee River mouth, with implications for shoreline configuration and processes along at least six kilometres of coast. Due to the long-term northerly drift sediment will accumulate as a lobate foreland in the wave shadow zone landward of the terminal at and immediately north of Wedge Point as the longshore transport capacity is substantially reduced. North of the terminal beaches will receive less sediment but will also be subject to much reduced southerly wave action and less potential erosion. The mouth of the Werribee River will receive minimal sediment from the south and the ebb tide jet may extend further seaward as the dominant agent of sediment movement and deposition. North of Wyndham Cove breakwaters and the groynes anchoring the artificial beach, shoreline erosion at Crawfords Road and Campbells Cove Road may increase as a result of loss of sediment transported from the south.

Circulation cells will develop at each end of the terminal resulting in local and seasonally variable deposition and erosion. Strong wave action may generate terminal scour at the ends of the container terminal, similar to that experienced at downdrift end of sea walls. This will be more likely on the northern (downdrift) end of the terminal. The quantity of material involved will be small and could be addressed as necessary by nourtishment.

4 WESTERN PORT: COASTAL GEOMORPHOLOGY

4.1 Coastal Geomorphology

The broad physical characteristics of Western Port and comparisons with Port Phillip have been outlined in Sections 1.3 to 1.7 above. Recent coastal studies include a bay-wide classification of shorelines (Rosengren 2013), detailed studies of bank (shore) erosion at Lang Lang (Tomkins *et al.* 2014) and Haskoning Australia (2015) collated existing information of the geology, geomorphology and dynamics of Western Port coast and water.

Western Port has long sectors of low muddy intertidal shoreline with variable cover of mangrove and salt marsh. Hard rock high coasts are restricted to 14 km of Older Volcanic basalt cliffs between Cape Schanck and Flinders. Elsewhere hard rock sectors are short and discontinuous and include Silurian sedimentary rocks at Stony Point and Sandstone Island and ferruginous Brighton Group at Red Bluff (Lang Lang) and Elizabeth Island. Older Volcanics outcrops of basalt and tuff between Flinders and Point Leo and at Corinella, San Remo, French Island and the northwest of Phillip Island are variously weathered and appear as bluffs and steep regolith slopes.

The principal physical and process characteristics of Western Port are:

- Fault aligned embayment
- Physiography and water movements dominated by configuration of Phillip Island and French Island
- Limited coastal bedrock outcrop
- Two entrances and relatively large connectivity to Bass Strait
- Limited transmission of ocean swell
- Fetch-limited
- Large tide range that increases towards head of bay
- Extensive shallow and intertidal area
- Tidal currents are significant around most of the bay as geomorphic agents and transporting fine-grained sediment
- Frequent wind-driven storm waves in shallow water with locally very high impact on soft rock and earth cliffs
- Earth cliffs a significant contributor to bay sediment
- Inheritance of past delivery of coarse sediment from drained and realigned streams

- Wide and variable cover of seagrass/macroalgae
- Extensive area of coastal wetland (mangrove and saltmarsh).

4.2 Geological and Landform Evolution

4.2.1 Context

The complex of marine embayments, islands and adjacent low lying terrain south of the Dividing Range between the Mornington Peninsula and the South Gippsland Hills is referred to as the Westernport (or Western Port) Sunkland (Keble 1950, Hills 1960, Jenkin 1962, Spencer-Jones *et al.* (1975).

It is a region where block faulting, active over the duration of the Cainozoic, clearly defines the broad geological and landform units. Faulting has continued into the Quaternary and the area is seismically active although the seismic risk is low (Gibson and Brown, 2003). The major faults are long, curving lineaments with NNE/SSW alignment intersected by shorter but well-defined E/W faults (Figure 1). The Tyabb Fault extending from east of Flinders to north of Hastings defines the western margin of the Sunkland (Keble 1950), while to the east are the pronounced escarpments of the Heath Hill Fault and Bass-Almurta Faults.

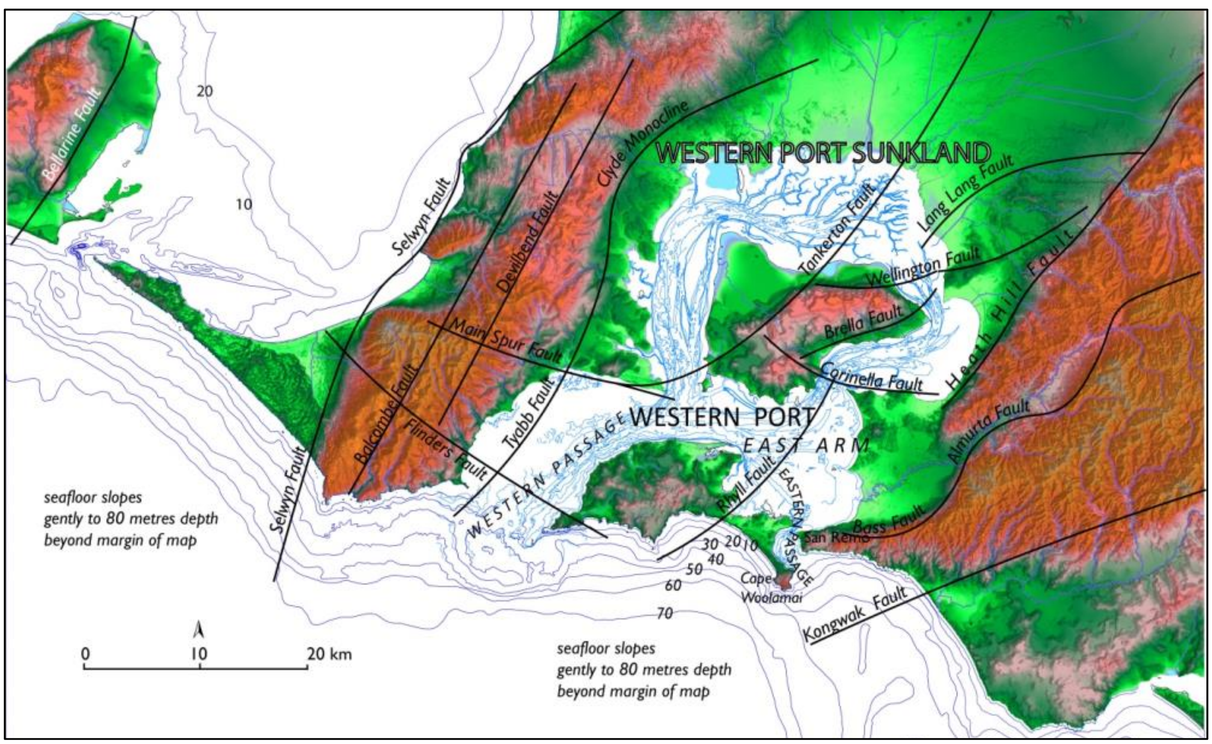

Figure 68. Terrain and structure Western Port Sunkland.

Intersection of the Tankerton, Wellington, Brella and Corinella Faults produces the higher central ridge of French Island. A major impact of faulting has been to produce the

lowlands around the north of the bay and the elongate tidal embayments around French Island (Figure 2).

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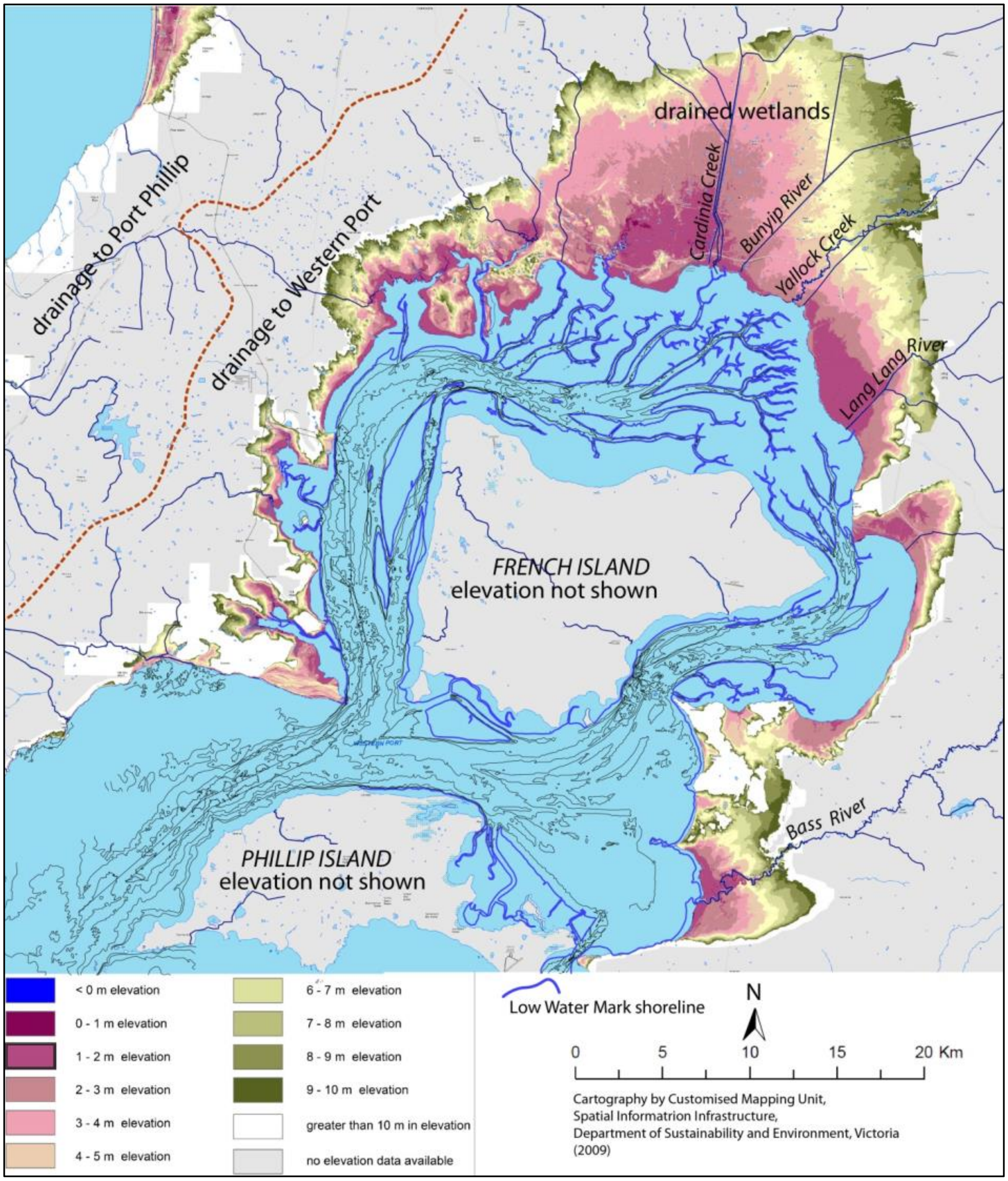

Figure 69. LiDAR map of areas below 10 metres around Western Port, streams and drains, Low Water Mark shoreline (DSE, Victoria 2009).

Although the tidal embayments partly reflect the direction of now submerged and betrunked river systems (Lang River, Bunyip River, Yallock Creek and Cardinia Creek), they are essentially fault and bedrock geology determined features modified by tidal scour and deposition rather than being relict drowned river valleys.

4.3 Distribution and Lithology of Geological Formations

4.3.1 Palaeozoic

Western Port is underlain by Palaeozoic sedimentary and granitic rocks but outcrop is restricted (Figure 2).

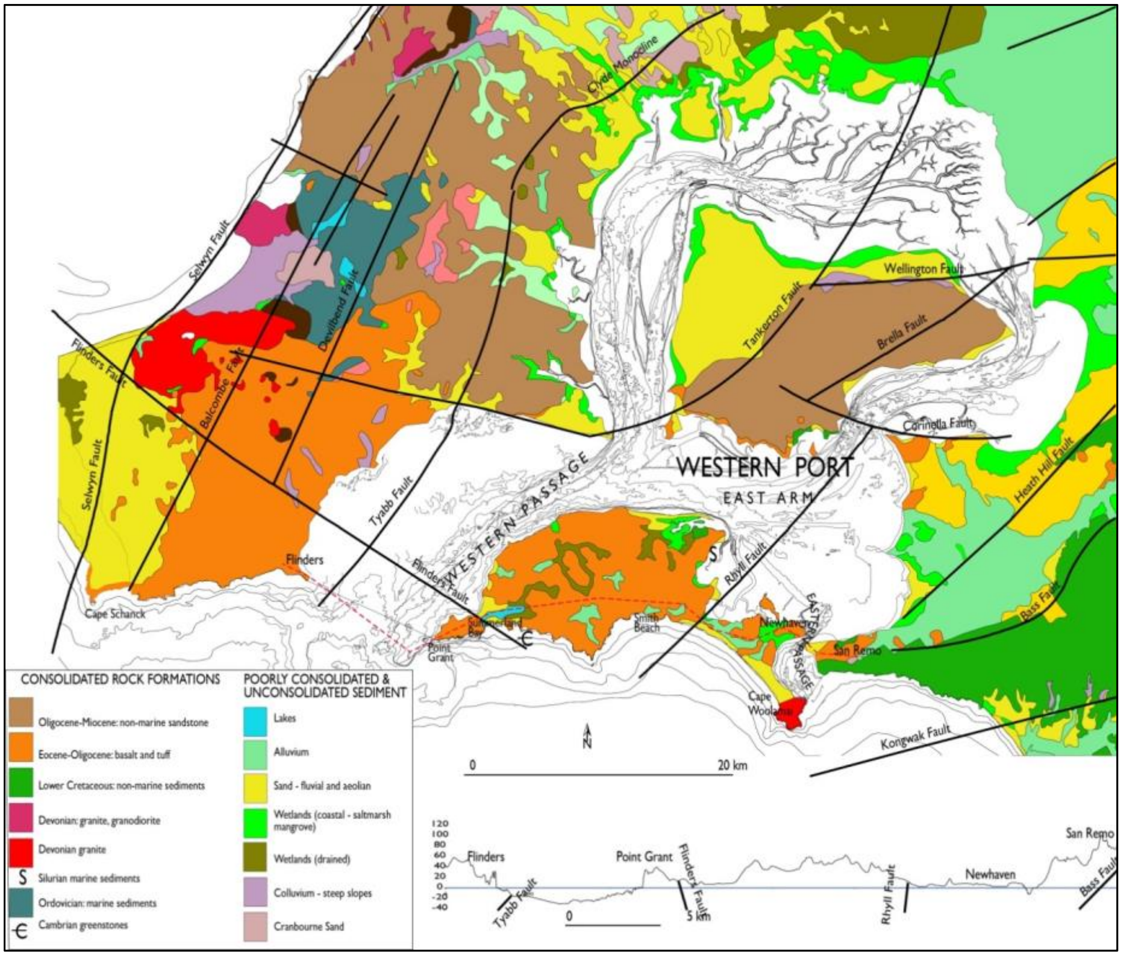

Figure 70. Geology of Western Port ranked in terms of rock resistance (Rosengren 2013 after Seamless Geology Project: Geoscience Victoria 2011).

Silurian marine sedimentary strata crop out at Sandstone Island and on the shoreline of Hastings Bight north of Crib Point between Woolleys Beach and Jacks Beach. The beds strike NNE and are steeply dipping, an anticlinal fold axis evident along the centre of Sandstone Island and a southerly plunging syncline at Woolleys Beach. Although deeply weathered, the structure and composition of the Silurian beds can be determined to be fine to medium grained mudstones, siltstones and occasional shales. Sandstone and siltstone with traces of quartz veins encountered from RL−43 metres in boreholes drilled offshore north of Long Island Point are interpreted to be of Silurian age (Maunsell AECOM unpublished data).

Devonian granitic rocks are a significant geology in the catchment of the Bunyip River. Subsequent to the channelizing of the original rivers as part of the Koo-wee-rup

swamp drainage, incision and flood discharge contributed substantial coarse sediment to northern Western Port. Granites crop out around the shoreline of Western Port only on the south coast of Phillip Island at Cape Woolamai and Pyramid Rock.

4.3.2 Mesozoic

Non-marine sediments of Lower Cretaceous age comprise the catchment of the Bass River but outcrop is confined to the southeast of Western Port (San Remo, south coast of French Island and near Rhyll on Phillip Island). They are not known surface or sub-surface on the western side of Western Port.

4.3.3 Eocene: Older Volcanics

An extensive suite of volcanic rocks of Eocene age occurs around Western Port and extends into the South Gippsland Hills (Jenkin, 1962). The major outcrops are in cliffs and coastal bluffs on the southern Mornington Peninsula, Phillip Island and French Island and from Corinella to Cobb Bluff. They are predominantly basalt lava flows with some thick interbedded tuffs and non-volcanic sediments. All are extensively weathered and much of the original basaltic cover has been stripped off. Basalt underlies the floor of the bay beneath a sedimentary cover that is often thin (Spencer-Jones *et al.* 1975). However, volcanics are absent along the north western part of Western Port, including Hastings Bight and the coast north of Long Island Point. No material of volcanic origin was recovered from the deep boreholes drilled in the offshore proposed dredge area north of Long Island Point.

4.3.4 Miocene: Sherwod Formation

A marine transgression in the Miocene resulted in widespread deposition of sandy marls and limestone either overlying the volcanic rocks or directly onto the Palaeozoic sediments in areas where basalt had already been eroded. The formation was designated Sherwood Formation by Jenkin (1962) who regarded it as almost entirely sub-surface. Spencer-Jones *et al.* (1975) showed the distribution to be more widespread in the east and southeast of Western Port.

4.3.5 Upper Miocene – Pliocene: Brighton Group (Baxter Formation)

A distinctive and widespread surface geological unit of Western Port are non-marine clays, sands and gravels, often carbonaceous and with occasional thin seams of brown coal. The unit was described on the Mornington Peninsula as the Baxter Sandstone (Keble, 1950) and renamed Baxter Formation by Thompson (1974) because of the wide range of sediment sizes. The sandy beds are often ferruginous near the surface but this characteristic does not

persist at depth (Thompson 1974). The variable grain size and cross-bedding indicate a fluvial origin for these beds. The Baxter Formation is now regarded as equivalent of the widespread Brighton Group and is the major pre-Quaternary surface and shallow sub-surface geological formation around the western side of Western Port.

4.3.6 Pleistocene: Cranbourne Sand

A broad belt of unconsolidated, wind-blown quartzose sands occurs across the northern Mornington Peninsula, the northwest and north of Western Port, French Island, and to the south of Lang Lang. The sands are in the form of north-west to south-east trending dune ridges, derived from weathered Palaeozoic rocks and Baxter Formation sandstones and developed during more arid glacial low sea level times. These dunes were in part responsible for disrupting and blocking streams draining from the north and developing the extensive wetlands of the Koo-Wee-Rup, Dalmore and Tobin Yallock Swamps.

4.3.7 Pleistocene and Holocene: Terrestrial Swamp Deposits, Alluvium and Colluvium

Western port is fringed by an extensive zone of unconsolidated sediments of alluvial, swamp, coastal and aeolian origin. They range from coarse sands to peaty clays and form low-angle alluvial fans, floodplains, terraces, low ridges and wetlands. North of Stony Point and extending from onshore at Hastings to offshore in the North Arm to Watsons Inlet is a widespread sheet of grey clay up to 6 metres thick, possibly representing a former lake deposit (Spencer-Jones *et al.*, 1975). Around the north and east of the bay from Cardinia to Lang Lang is a wide zone of now drained wetlands–the former Dalmore, Koo-Wee-Rup and Tobin Yallock Swamps. These freshwater and terrestrial fluvial and colluvial deposits are distinguished from the continuous and extensive zone of coastal and intertidal wetlands and related sediments that fringe Western Port.

4.3.8 Pleistocene and Holocene: Coastal, Intertidal and Subtidal

The mainland and island shorelines of the North Arm and East Arm of Western Port are buffered from ocean swell waves due to the shelter afforded by Phillip Island and French Island. Higher energy shorelines with active rock cliffs and shore platforms are restricted in extent and the greater part of the bay shoreline north of Sandy Point and San Remo consists of salt marshes with a seaward fringe of mangroves and extensive intertidal flats (Bird 1993). There are short sectors of sand beaches and spits, often related to areas where there has been some disturbance to the mangrove zone and/or the coastal stream systems.

A combination of low angle coastal slopes, large tidal range and abundant fine-grained sediments has allowed the development of a broad tidal flat coastline. The intertidal and submarine morphology is shaped by ebb and flood tidal flow and the movement and deposition of sediment. Evidence of higher Holocene sea level in the form of stranded cliffs, beaches and foredunes is found in areas such as the Bass River delta, Corinella, Pioneer Bay and north of Yaringa (Marsden and Mallet 1975; Bird 2003).

Marsden and Mallett (1975) recognised six major coastal and offshore zones in Western Port, each with a number of subzones (Figure 4).

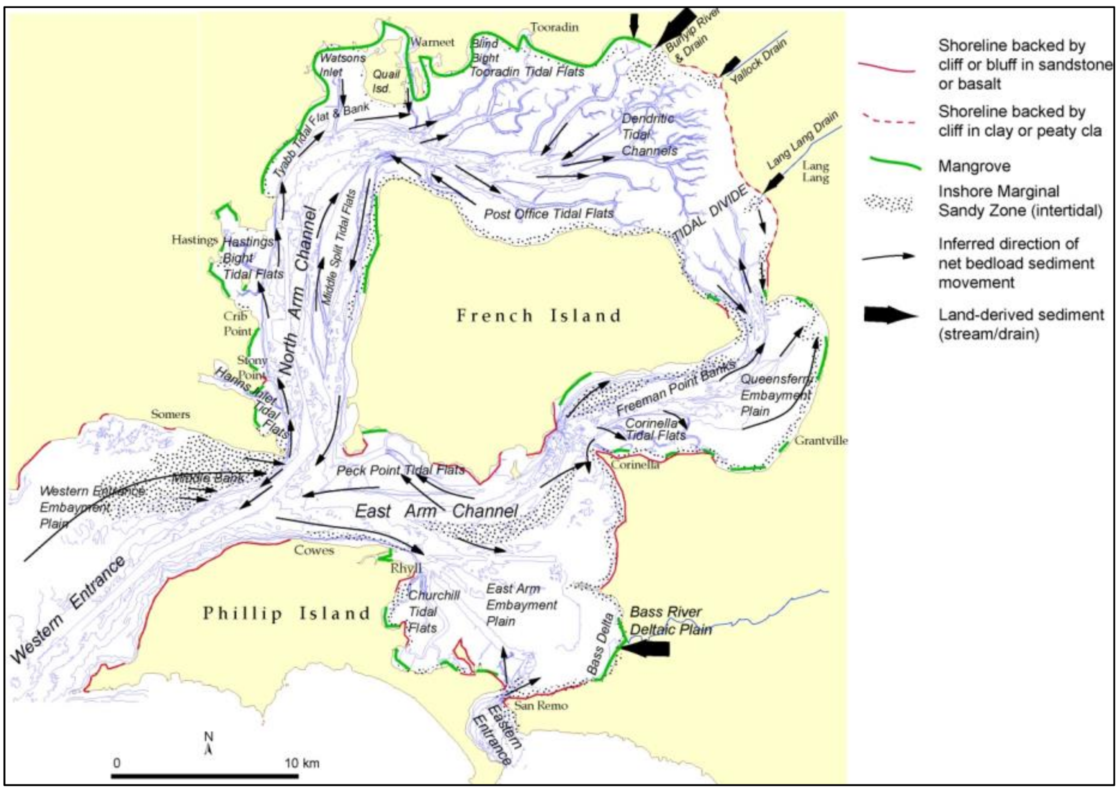

Figure 71. Generalised shoreline types and the major zones of Western Port (after Marsden and Mallett, 1975).

These are summarized here as:

- Coastal Zone: from the highest tide mark to the outer edge of the mangrove zone.
- Inshore Marginal Sandy Zone: the middle to higher intertidal zone usually narrow and linear, sand with variable fraction of mud and mainly seagrass-free.
- Intertidal Flats and Banks: largely but not entirely exposed at low tide. Generally muddy sediment with local concentrations of shell.
- Offshore Banks and Shoals: subtidal mud and sand bodies.

- Embayment Plains: three broad, submerged gently sloping plains of variable sand, silt and clay composition.
- Tidal Channel System: two entrance channels, three trunk channels and numerous tributary channels and creeks.

4.4 Tidal Processes and Sedimentation

Compared with the size of the embayment, the catchment area of Western Port is relatively small (3,721 square kilometres compared with 9,790 square kilometres for Port Phillip) and much is of low relief. Freshwater discharge is also relatively low compared with the volume of tidal movement and as the influence of ocean swell is greatly attenuated by the narrow entrances, water and sediment movement in Western Port is determined by currents generated by flood and ebb tides and by wave action developed from local winds. The intertidal volume of the bay of 0.95 x 10^{12} Ml compared with the average daily stream discharge of 1.1 x 10^{3} Ml (Sternberg and Marsden 1979) emphasises the dominance of tidal processes.

The detailed studies of hydrology and sediment movement carried out in the 1970's (Marsden and Mallett 1975, Hinwood and O'Brien 1975, Marsden *et al.* 1979, and Sternberg and Marsden 1979), and more recently (Hancock *et al.* 2001, 2003, EPA 2011, Cardno 2013, showed that; (a) the major water movement was dominantly in a clockwise direction around French Island, (b) there is distinct set of tidal ebb-flow and flood-flow channels and these determine the rate and direction of sediment movement, (c) there was limited new sediment supply to the bay but considerable internal sediment movement, (d) net landward transport and deposition of clay-rich suspended sediments, aided by biological and mechanical processes, has resulted in wide mud-dominant tidal flats, (e) there are wide variations in sediment type with local concentrations of fine to gravelly sand and broken shell.

More recent studies of sediment source and distribution in Western port are summarised by Wallbrink *et al.* (2003) and Haskoning Australia (2015). They concluded that persistent high turbidity arises from the daily reworking and resuspension of fine sediment by tidal, wind and wave action. Data from sediment cores indicates a net loss of mud from the Upper North Arm over the last 25 years and a relocation of fine-grained (silt/clay) in a clockwise southerly direction. Upper North Arm cores show a transition to higher sand and lower silt/clay composition over the last 40-60 years. This could be due an increase in the

rate of sand supply to the Upper North Arm from the Westernport catchment over the last few decades, or an increase in the rate of removal (resuspension and transport) of mud, or a combination of both processes (Hancock *et al.* 2001). Consequently, sediment delivered to or derived from the northern region has the ability to affect water quality and seagrass habitat of eastern and southern regions by the creation of a zone of turbid water during transport, and by increasing the extent of mud deposition in the Corinella and Rhyll segments (Figure 5).

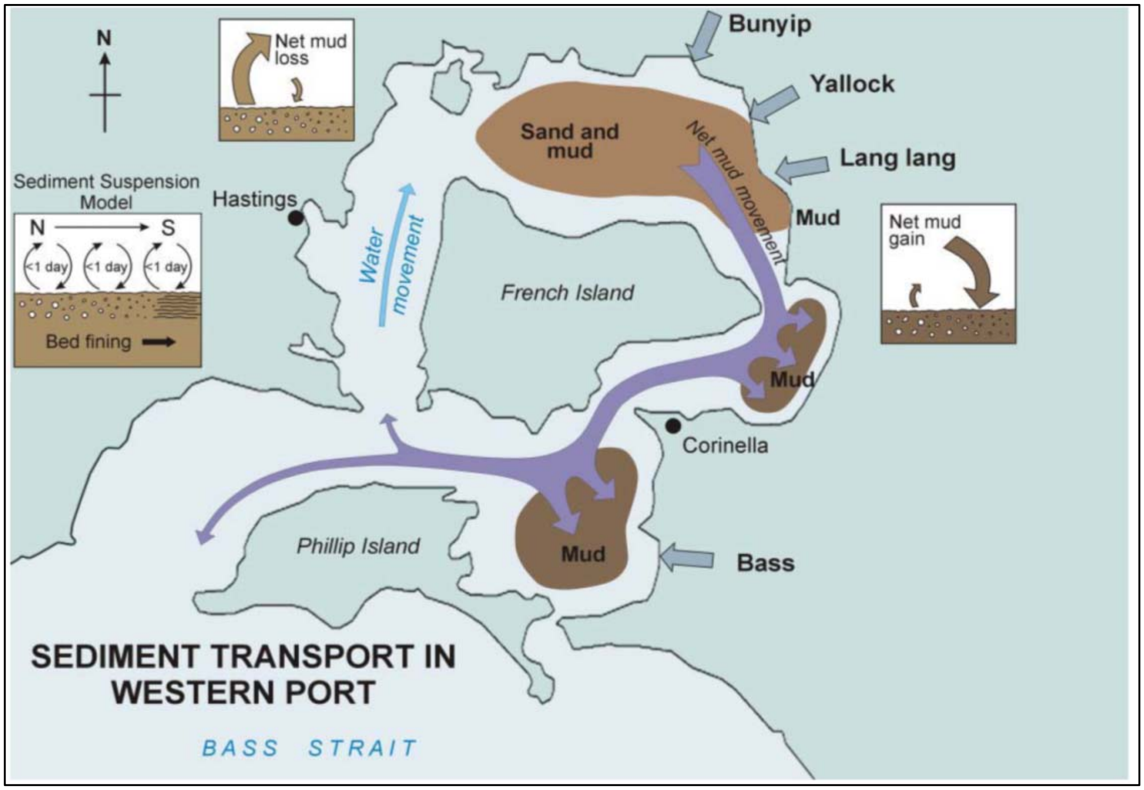

Figure 72. Sediment illustration of sediment transport in Western Port (Hancock *et al.* 2001).

The dominant catchment source of the fine sediment is subsoil from channel and gully erosion of the Bunyip and Lang Lang River systems. Erosion from the clay banks to the north west of the Lang Lang jetty also is an important local source of fine sediment and is now considered to be the largest contributor of sediment directly to Western Port compared to other eroding areas around the bay (Tomkins *et al*. 2014).

4.4.1 Seagrass and sedimentation

Seagrass cover in Western Port is highly variable temporally and spatially. It is most extensive on areas of mud but extensive die-back has occurred. Between the 1970's and 1980s an estimated 90% loss of seagrass was lost from intertidal areas (Gunthorpe and Hamer 2000). Most loss occurred in the northern and eastern sections of the bay and

although there has been some recovery in the northern parts of the bay there has been very little recovery in the eastern parts (EPA 2000). The causes of seagrass loss are not well understood (EPA 2000), but it is considered most likely to be a result of turbidity caused by increased sedimentation and the gradual shallowing of intertidal banks also associated with increased sedimentation (Gunthorpe and Hamer 2000). However, there are substantial knowledge gaps in relation to understanding sediment source and distribution in Western Port and its role in seagrass loss. Morris *et al.* (2000) investigated the potential role of nutrient enrichment in contributing to seagrass loss as a result of epiphyte, macroalgal or phytoplankton growth in shading of seagrass leaves and negatively affecting seagrass health. They concluded based on field experiments that Western Port seagrass habitat is sensitive to increased loads of nutrients

4.5 Coastal Processes

There is a variety of shorelines around Western Port (Figure 4). While mangrove and salt marsh fringed coast is predominant, there are sectors of cliffed coast and sand beaches. Active and relict coastal cliffs and bluffs, mainly in basalt, and sand and gravel beaches with foredunes and beach ridges are predominant on the higher energy ocean-facing coast of Phillip Island and between Flinders and Sandy Point. Inside the bay, cliffed and sand sectors are short and developed where conditions restrict mangrove growth, or are recently developed where there has been disturbance to the mangrove fringe as outlined below (5.5.1).

4.5.1 Mangroves and Coastal Processes

As determined from aerial photographs (NearMap Nov 2016), mangroves occur along about 90% the mainland coast of Western Port between Sandy Point and the drain at the at the former mouth of the Bunyip River. Mangroves occupy the seaward margin of a shoreline complex that includes dune woodland, swamp woodland and scrub and salt. Mangroves extend seaward to approximately mean sea level (Figure 6).

Mangroves provide a mechanism for deposition and stabilisation of coastal sediment by virtue of their ability to: (a) grow in seawater and tolerate variable salinity levels, (b) tolerate submergence of part or all of the plant for up to 6 hours per tidal cycle, (c) colonise areas of saturated substrate, (d) effectively dampen tidal currents and attenuate sea waves, due to drag, as they propagate through the network of pneumatophores, trunks and canopy on the mangrove fringe, (e) buffer the backshore from direct wave impact (Environment

Waikato 2008). Although there is limited experimental data (c.f. Bird 1980) or radiometric dating of mangrove-sediment associations in Western Port, numerous studies in comparable environments have shown the effectiveness of mangroves in promoting and maintaining tidal flat sedimentation (Bird and Barson 1977, Wolanski *et al.* 1992, Kathiresan 2003, Stokes and Healy 2005, Environment Waikato 2008). Since the first maps showing mangrove distribution in Western Port (George Smythe 1842, Commander Henry Cox 1865), there has been a substantial reduction in the extent, continuity and width of the mangrove zone. The mangrove fringe is more fragmented or is of lower density and in some areas the mangroves have gone (Figure 7, Figure 8).

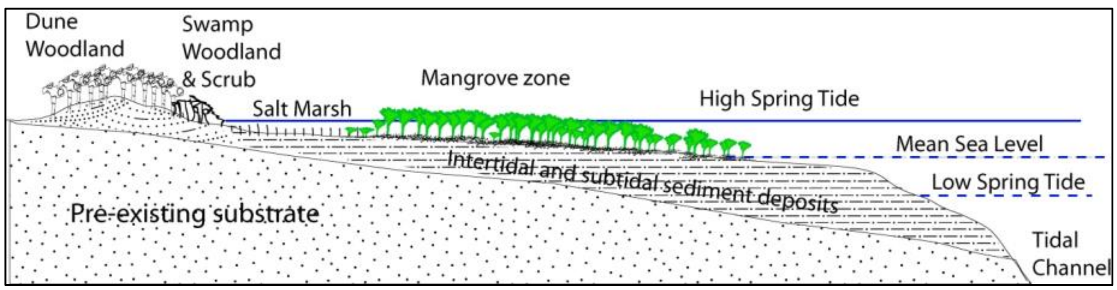

Figure 73. Typical shoreline zonation of mangrove areas around Western Port (after Bird and Barson, 1975).

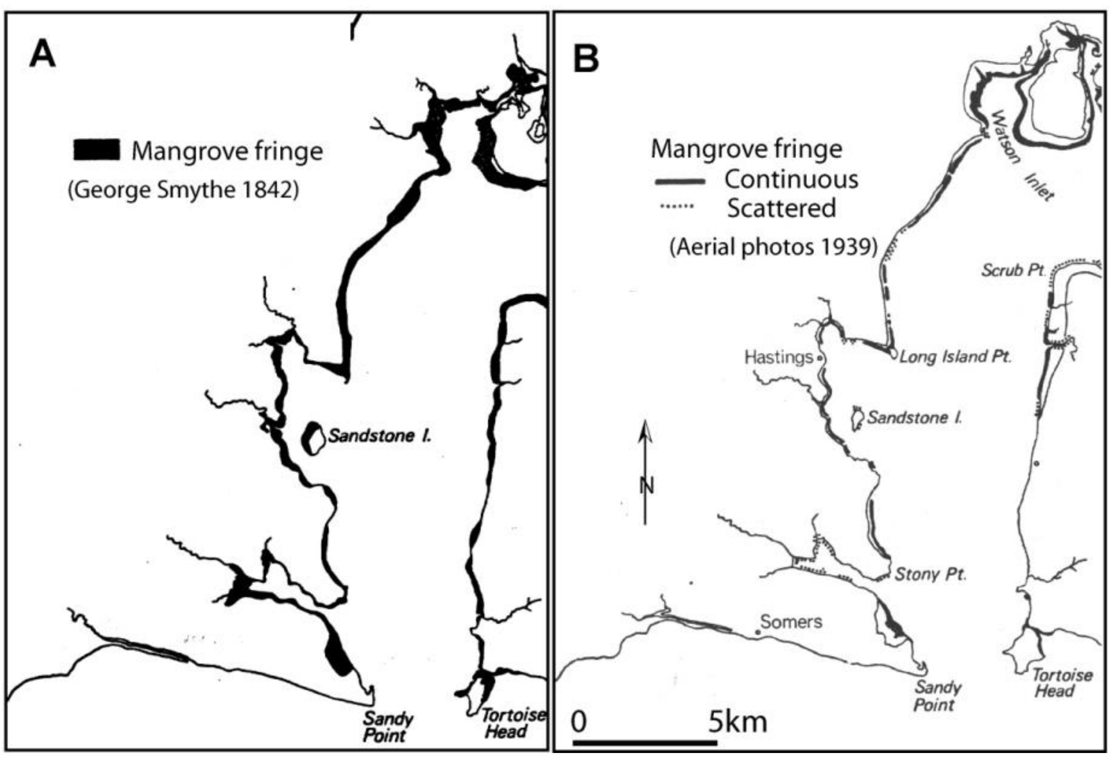

Figure 74. Mangrove extent in North Arm 1842 and 1939 (from Bird and Barson 1975).

In some areas this is due to ambient environmental change, such as frost or arrival of drifting sand or masses of seagrass hay that smother the mangrove pneumatophores and inhibit seedling establishment. However, some loss is clearly due to human actions

including removal of mangroves to make boat landings and harbours, and burial by reclamation of shoreline and intertidal areas for industrial or other commercial use. Some of these direct actions e.g. harbour dredging or breakwater construction, have triggered changes in sand movement that has impacted mangroves as outlined above.

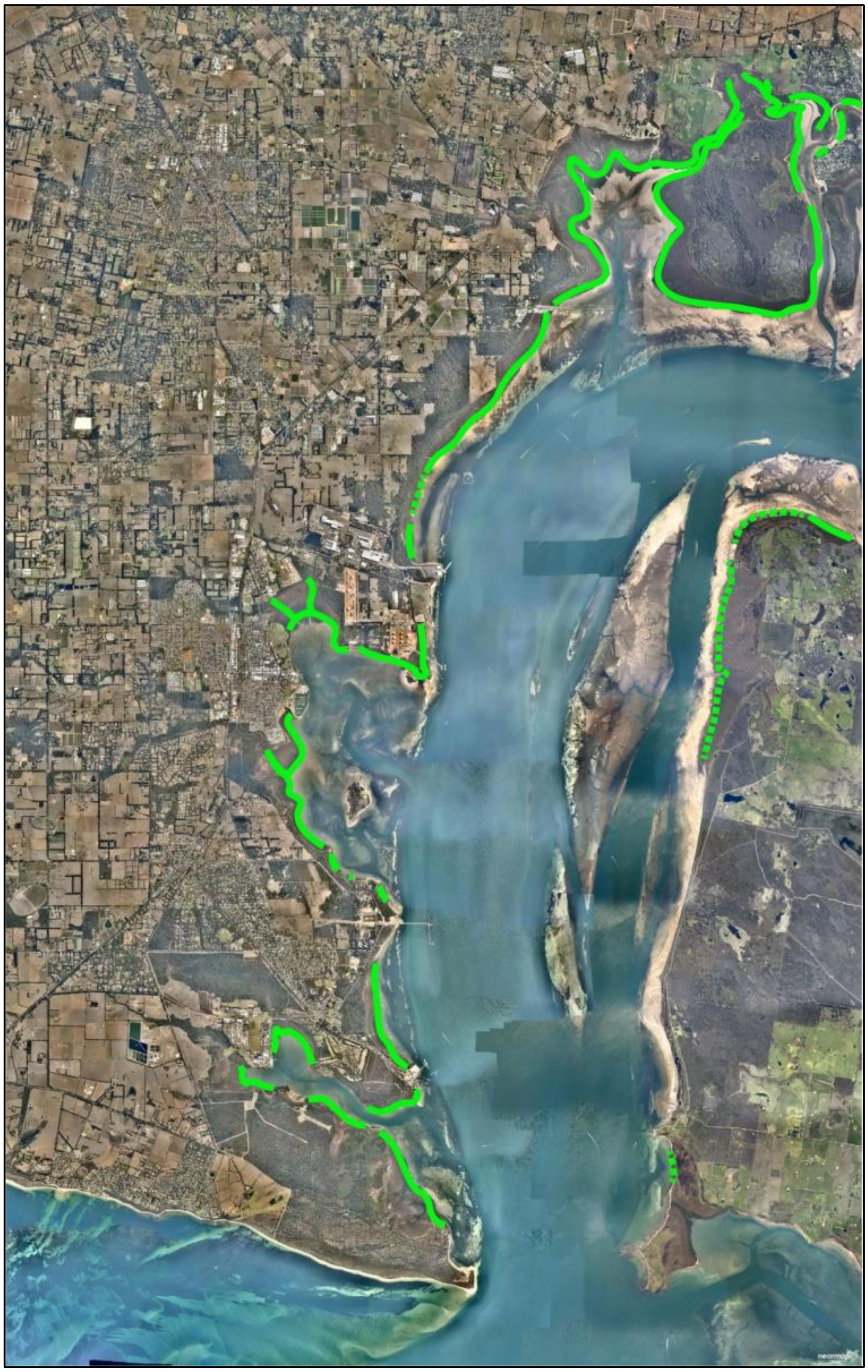

Figure 75. Mangrove distribution North Arm 2014 (NearMap).

4.6 Coastal Morphological Types

The description of the coastal geomorphology of Westernport uses in part the Smartline terminology developed by Sharples *et al.* (2009) as the basis for describing backshore, coastal and intertidal features. For the current project, utilising prior experience in the Westernport catchment by the present author, supplemented by additional references, aerial photograph interpretation, Lidar data, and field work - including low-level aerial inspection of 95% of the shoreline of the study area in 2013 and 2014- the landforms and sectors have been identified independently of the published Smartline records. A classification of coastal landforms that best suits Westernport was developed for the 2013 Local Coastal Hazard Assessment (Rosengren 2913, Water Technology 2013). This differs from the scheme used in this report for Port Phillip.

The following attributes define the Coastal Morphological Type:

A. Backshore landform types:

- Backshore proximal (BACKPROX) = first significant landform type to landwards of the intertidal zone
- Backshore distal (BACKDIST) = dominant distinctive landform type(s) inland of that first landform
- Backshore Profile (BACKPROF) = Generalised topographic profile gradient of the coastal area extending landwards from the inland limit of the intertidal zone.

B. Intertidal

- Intertidal 1 (INTERTID1) = areas extending from Mean Low Water Mark to the upper limit of wave-wash sufficiently frequent as to prevent establishment of terrestrial vegetation

C. Geology

- bedrock or geological substrate type(s) which were present prior to development of the present shoreline

D. Geomorphology & Geomorphic Processes

- inherent or "intrinsic" susceptibility to physical change or instability in response to a variety of coastal processes including sea-level rise.

Seventeen **Coastal Morphological Ty**pes are presented in Table 1. These are grouped into ten **Shore Zone Categories according to sensitivity to change** (Figure 9).

TABLE 1: COASTAL MORPHOLOGICAL TYPES (1 TO 17)

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
1	**BACKPROX** Active cliff **BACKDIST** Plain **BACKPROF** Steep slopes	Older volcanic basalt and tuff	Minimal beach of mixed sand and gravel overlying wide rock shore platform	Steep slope of exposed regolith and deeply weathered volcanics. Local overhangs at cliff top. Very little beach development – shore muddy of coarse sand and gravel. Wide, planar shore platform with irregular outline. Outer edge exposed at low spring tide in some places or may be mud-covered.	Mass movement (subaerial) produces unstable slopes with local accumulations of talus. Active rill development, Wave action at cliff base only at high tide and storms.	Flinders, Shoreham, Cobb Bluff

Active cliff (Older Volcanic basalt and tuff), minimal beach, shore platform at Cobb Bluff.

Swan Corner , Phillip Island

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
2	**BACKPROX** Active cliff **BACKDIST** Plain **BACKPROF** Steep slopes	Mesozoic sedimentary	Minimal sand beach overlying rock shore platform	Steep slope of exposed regolith and partly weathered Mesozoic rocks. Narrow shore platform with variable sand cover. Narrow intermittent beach at cliff base.	Mass movement (subaerial) produces rock fall, Wave action at cliff base only at most high tide.	Red Bluff (French Island

. Active cliff and shore platform in Mesozoic arkose and mudstone, Red Bluff, French Island.

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
3	**BACKPROX** Active cliff **BACKDIST** Plain **BACKPROF** Steep slopes	Pliocene Baxter Formation sediments	Sand beach, local gravel and boulders, nearshore bars, minimal rock platform	Steep slope of exposed regolith and deeply weathered and ferruginised Baxter Formation. Local overhangs at cliff top. Intermittent sand beach with local boulders fallen from cliff. Minimal shore platform – wide intertidal beach – fine sand and mud.	Mass movement (subaerial) produces unstable slopes with local accumulations of talus. Active rill development, Wave action at cliff base only at high tide and storms. In some cases, cliff has beach and some mangroves so most processes are subaerial.	Red Bluff (Jam Jerrup), Tenby Point (west of Corinella).

Active cliff in Baxter Formation sediments, Red Bluff (Jam Jerrup)

. Partly active cliff in Baxter Formation, Tenby Point (west of Corinella).

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
4	**BACKPROX** Active cliff **BACKDIST** Plain **BACKPROF** Steep slopes	Peat and mud (Tobin Yallok Swamp)	Intermittent sand beach in embayments, no or minimal sand beach on headlands, firm mud shore platform	Simple to compound cliff profile with local overhangs.	Slumping and block detachment result in rapid rates of coastal recession.	Lang Lang north to Yallock Creek

Active cliff in peat and mud, Lang Lang.

Cliff headland and embayments in peat, Lang Lang Beach.

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
5	**BACKPROX** Active cliff **BACKDIST** Plain **BACKPROF** Steep slopes	Unconsolidated to weakly cemented grit, sand, mud and peat.	Minimal sand beach. Evidence of former mangrove fringe.	Benched cliff profile with local overhangs.	Slumping and block detachment result in rapid rates of coastal recession.	Grantville north, Queensferry.

Soft earth cliffs, Grantville.

Soft earth cliffs, Queensferry

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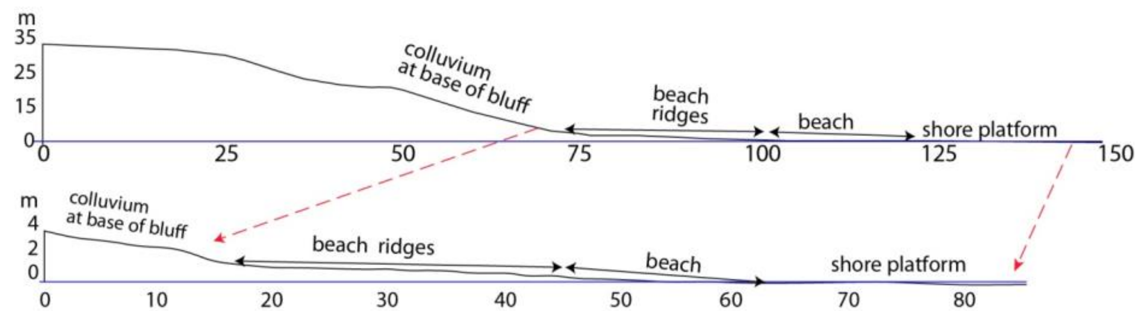
TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
6	**BACKPROX** Active cliff and slope **BACKDIST** Plain **BACKPROF** Moderate to steep slopes.	Older volcanic basalt and tuff	Variable width beach of mixed sand and gravel overlying wide rock shore platform	"Slope over wall" profile. Deeply weathered and/or poorly consolidated regolith.	Occasional slope failure – creep, slump, slide, rotational slide	Flinders, Shoreham, Corinella, Tortoise Head, San Remo

Active cliff and mass movement slope, Tortoise Head.

Bluff with unstable slopes, San Remo.

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
7	**BACKPROX** Bluff **BACKDIST** Low plateau **BACKPROF** Moderate to steep.	Older volcanic basalt and tuff	Narrow beach - sand and gravel overlying shore platform	Stable bluff in deeply weathered and/or poorly consolidated regolith.	Occasional slope failure – creep, slump, slide, rotational slide. Beach overwash.	North of Flinders

Bluff with minimal fringing beach ridge zone, Shoreham.



Profile (from LiDAR) 500 metres south of Shoreham. Narrow zone of beach ridges (5 m to ~ 25 m wide).

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
8	**BACKPROX** Stable bluff **BACKDIST** Plain **BACKPROF** Moderate to steep slopes.	Older volcanic basalt and tuff	Variable width beach of mixed sand and gravel overlying wide rock shore platform	Deeply weathered regolith with soil and vegetation cover. Variable width accumulations – sand and gravel beach ridges and locally with low established foredunes. Bluffs are remnant of higher Holocene and Last Interglacial sea-level. Now have wide fringing beach plain and are isolated from waves.	Slope failure, beach accretion and erosion.	Flinders, Shoreham.

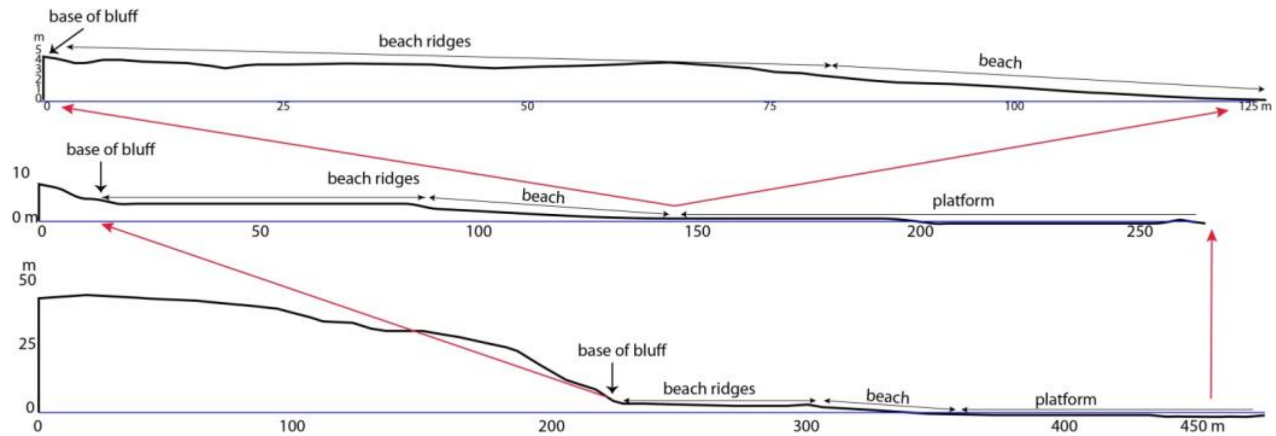
Bluff north of Flinders with beach ridge plain isolating slopes from wave action.

Bluff behind beach ridges, west of Freeman Point, French Island.

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
9	**BACKPROX** Beach ridges **BACKDIST** Plateau **BACKPROF** Moderate to steep slopes.	Older volcanic basalt and tuff	Variable width beach mixed sand & gravel overlying wide shore platform	Variable width accumulations – sand and gravel beach ridges and locally with low established foredunes.	Beach changes. Storm overwash at high tide. Minor wind action.	Flinders, Shoreham.

Beach ridge plain north of Flinders.

(See profile details).



Profile (from LiDAR) 300 metres north of Spindrift Ave, Flinders. No vertical exaggeration (H scale = V scale).

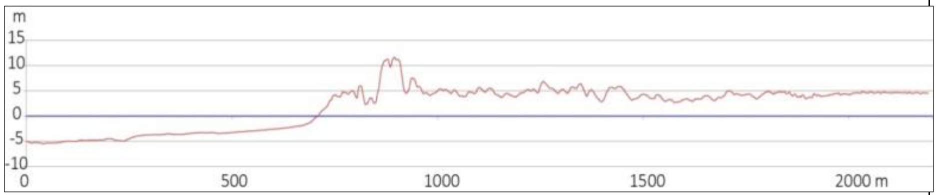
TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
10	**BACKPROX** Foredune sand barrier **BACKDIST** Plain **BACKPROF** Moderate to low slopes.	Quaternary sand	Sand beach	Elongate coastal sand barrier deflects mouth of Merricks Creek 2 km to the east.	Progradation of barrier continues diversion of creek outflow. Beach changes. Storm overwash at high tide. Minor wind action.	Merricks Creek

Coastal sand barrier deflects mouth of Merricks Creek

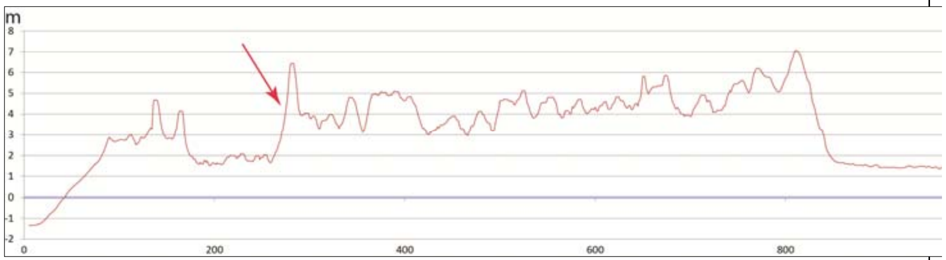
Engineered structures at mouth of Merricks Creek

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
11	**BACKPROX** Foredunes and sand barrier **BACKDIST** Ridged sand plain **BACKPROF** Moderate to low slopes.	Quaternary sand	Sand beach	Multiple beach ridges and established foredunes and swales.	Incipient foredune and established foredune development with vegetation succession. Alternating episodes of progradation and recession.	Sandy Point

Sandy Point multiple beach ridges and foredunes. Broken line shows erosion scarp defining inner edge of newer sets of ridges.



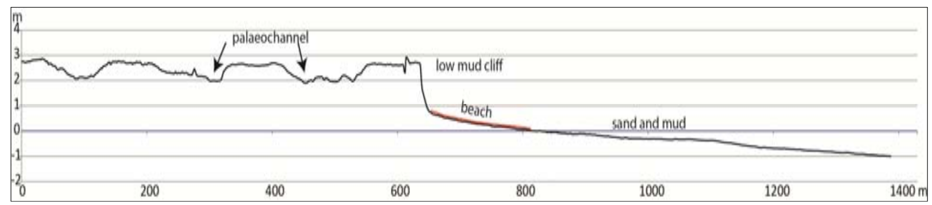
Profile A – B



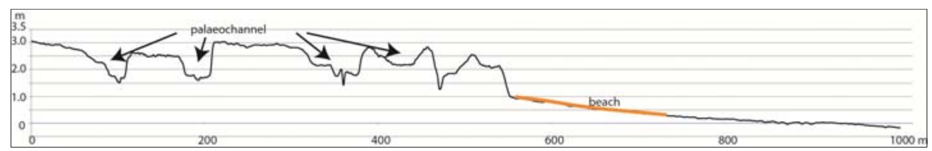
Profile C – D. Arrow shows change in ridge sets.

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
12	**BACKPROX** Beach **BACKDIST** Drained swamp **BACKPROF** Flat to low slopes.	Quaternary alluvium, swamp and sand	Mudflat, sparse mangrove	Low angle beach as a veneer on mud and swamp deposits.	Longshore and across-shore sediment transfer, storm overwash.	Yallock Creek

Narrow beach fringing low alluvial coast, Yallock Creek drain.



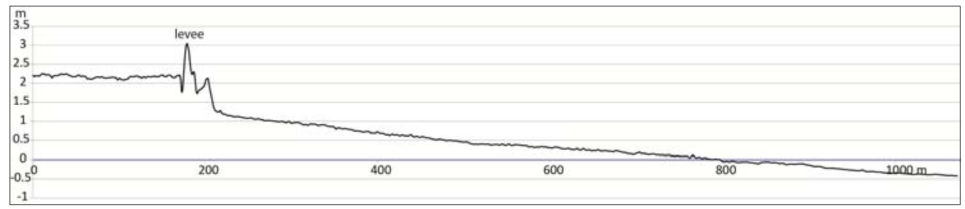
Profile A – B



Profile C - D

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
13	**BACKPROX** Saltmarsh **BACKDIST** Drained swamp **BACKPROF** Flat to low slopes.	Quaternary alluvium, swamp and sand	Mudflat, saltmarsh at backshore. No or very sparse mangrove.	Flat to very gently sloping surface with varied saltmarsh and bare flats	Tidal and wave erosion of surface and backshore.	Pioneer Bay

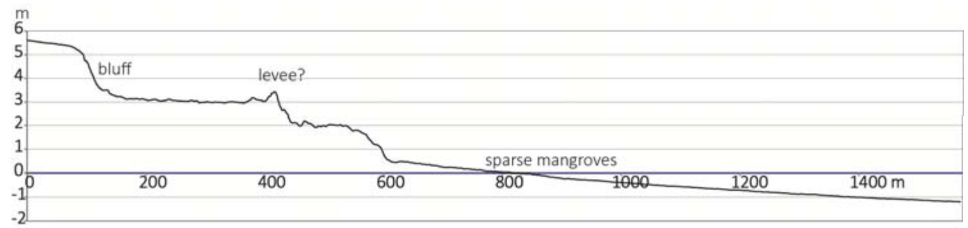
Saltmarsh with no mangroves, Pioneer Bay.



Profile A – B saltmarsh with no mangroves, Pioneer Bay.

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
14	**BACKPROX** Saltmarsh **BACKDIST** Drained swamp **BACKPROF** Flat to low slopes.	Quaternary alluvium, swamp and sand	Mudflat, sparse mangrove	Flat to very gently sloping surface with varied saltmarsh and bare flats.	Tidal and wave erosion of surface and backshore. Sparse and irregular mangrove colonisation.	Grantville.

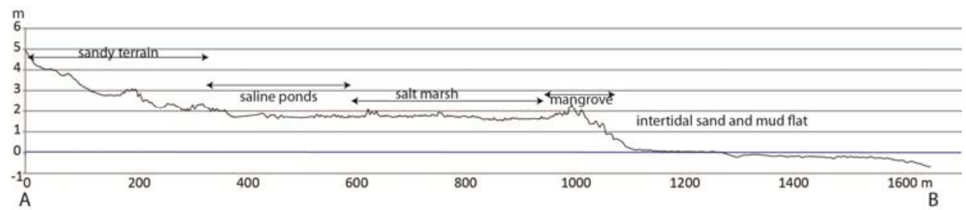
Sparse mangrove fringe, Pioneer Bay.



Profile A – B across mangrove fringe at Pioneer Bay.

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
15	**BACKPROX** Saltmarsh **BACKDIST** Drained swamp **BACKPROF** Flat to low slopes.	Quaternary alluvium, swamp and sand	Mudflat, dense mangrove	Flat to very gently sloping surface with varied saltmarsh and bare flats.	Tidal and wave erosion of surface and backshore. Often dense mangrove colonisation.	Tooradin, Quail Island.

Wide mangrove and saltmarsh, Tooradin.



Wide mangrove and saltmarsh, Tooradin.

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
16	**BACKPROX** Stream mouth **BACKDIST** stream mouth **BACKPROF** Stream banks	Quaternary alluvium, swamp and sand	Sand, mud	Flat to very gently sloping surface bordered by banks, mangrove, saltmarsh and bare flats.	Tidal and wave erosion of surface and backshore.	Tooradin, Quail Island.

Mouth of Bunyip River drain

Mouth and delta of Bas River

TYPE	BACKSHORE	GEOLOGY	INTERTD1	GEOMORPHOLOGY	GEOMORPHIC PROCESSES	EXAMPLES
17	**BACKPROX** Engineered **BACKDIST** Engineered **BACKPROF** Flat to steep slopes.	Variable	Variable	Wide variety of structures including vertical & sloping masonry, rock, timber and waste materials.	Wave reflection, refraction, scour, overtopping.	Jam Jerup

Formal engineered structure Hastings including rock wall, fill, and wharves.

Rockwall at landslide base, San Remo.

Unauthorised private structures, Grantville.

4.7 Shore Zone Categories

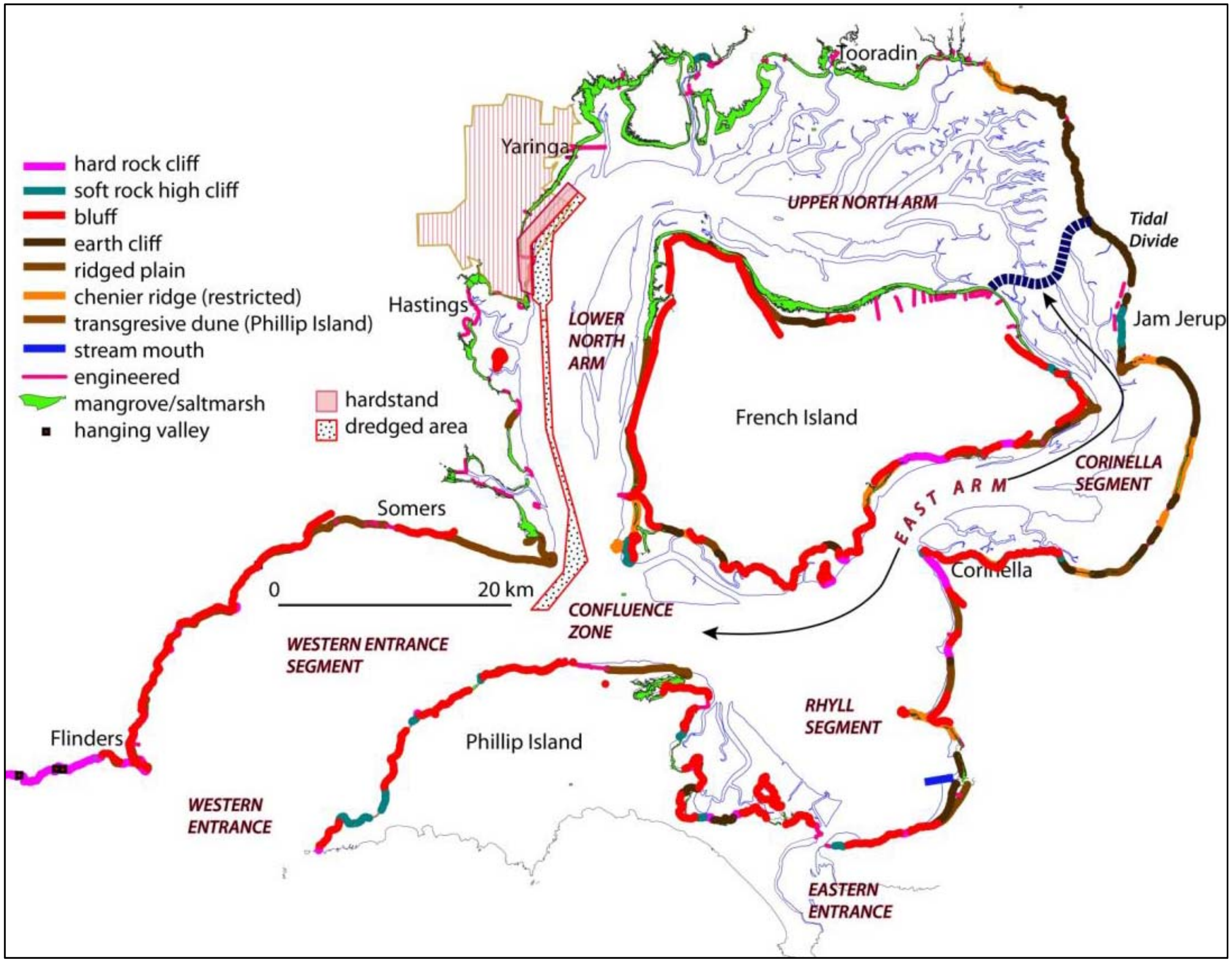


Figure 76. Shore zone categories Western Port with overlay of proposed container terminal and associated dredged area.

5 POTENTIAL IMPACT OF PROPOSAL ON SHORE ZONE GEOMORPHOLOGY OF WESTERN PORT

5.1 The proposal

The development of a container port in Western Port at the Port of Hastings, requires construction of a land backed berth with extension to the north east, dredging of new berths and swing basin, as well as deepening existing channels to facilitate access for larger draft vessels. The proposal will affect directly and continuously the 320 hectares (3.2 km^2) of subtidal, intertidal and backshore terrestrial environments at the site to be covered by hardstand supporting the terminal and associated port facilities. An area of similar size adjacent (seaward) to the terminal will be affected by dredging to accommodate shipping movement (Figure 10).

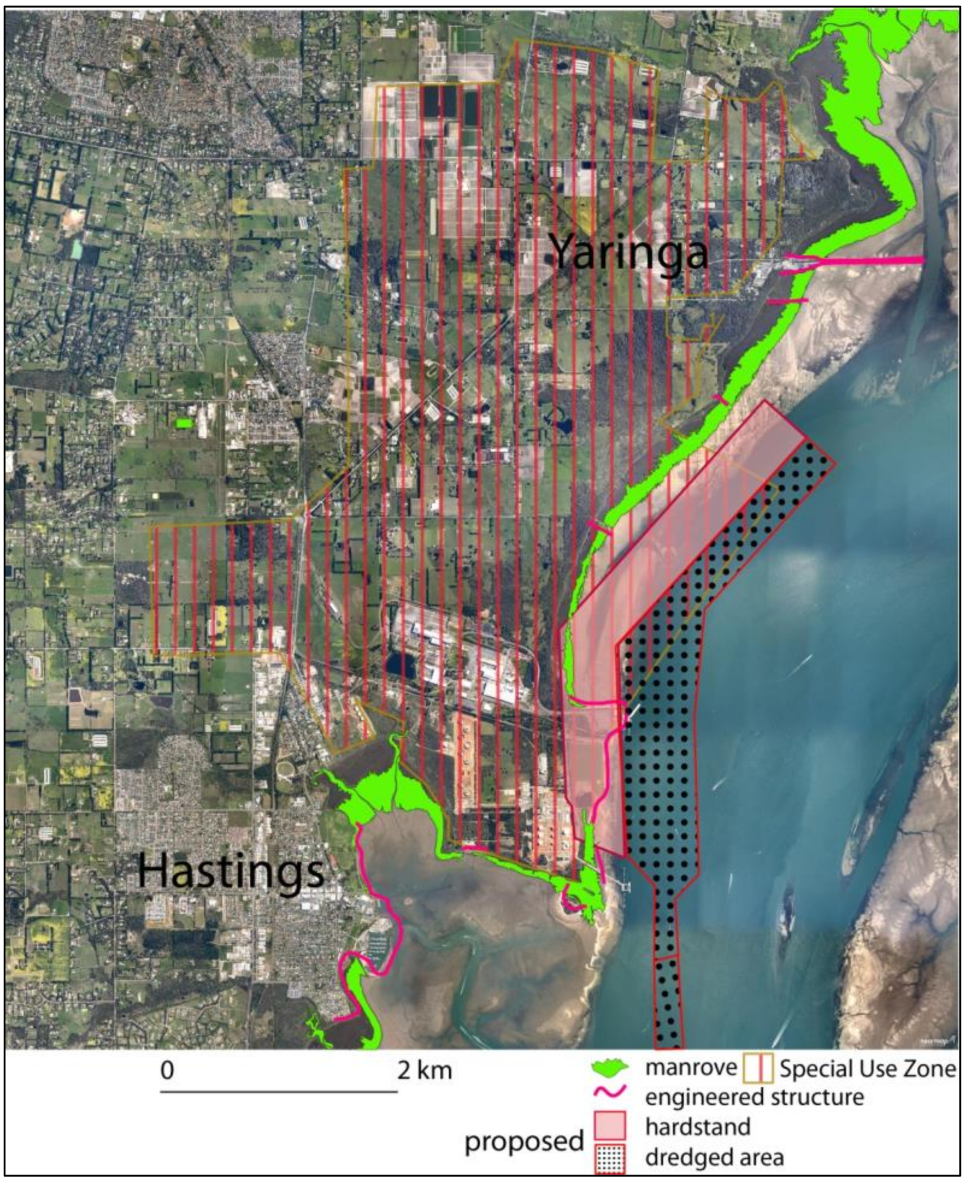


Figure 77. Proposed container terminal and dredged area.

5.2 Hastings Site: Existing Conditions

5.2.1 Geology and Geomorphology

The proposed container hardstand site and associated dredged channel and swing basin extends from Long Island Point on the northern side of Hastings Bight for five kilometres in the channel and western shore of North Arm (Figure 11).

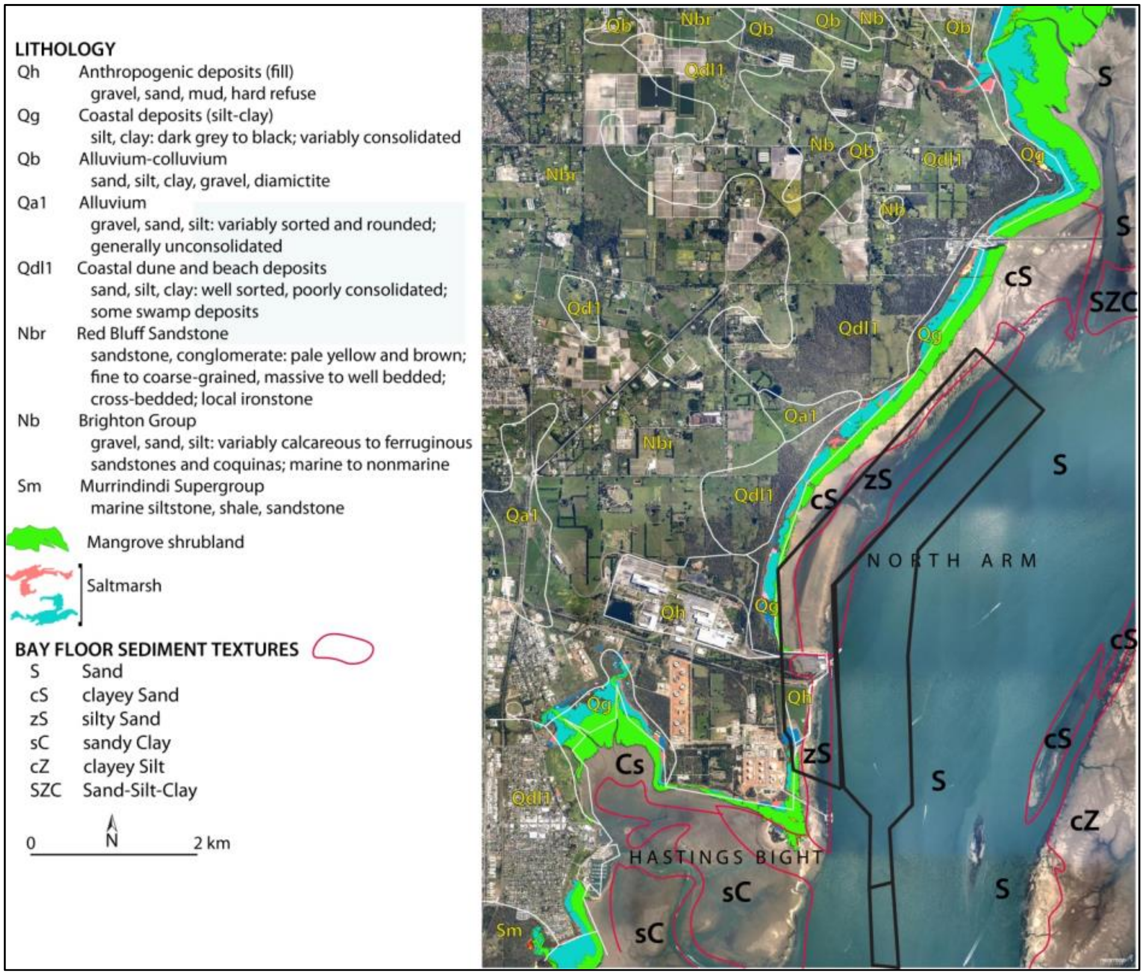


Figure 78. Bottom sediment texture of North Arm and adjacent terrestrial surficial geology of proposed terminal and dredging site, Hastings.

Hastings Bight is a tidal embayment defined by the low headlands of Long Island Point in the north and Crib Point in the south. Steeply dipping, folded Silurian sedimentary rocks crop out along the shoreline northwest of Crib Point and at Sandstone Island. There is no outcrop of the Eocene volcanic rocks or overlying Miocene Sherwood Marl around the shoreline and the surficial geological unit in the north of Hastings Bight and at Long Island Point is Brighton Group. The 1:63,360 Western Port Geological Map (Geological Survey of Victoria 1963) annotates “Ferruginous sand and limonite” at Stony Point and limonite is also indicated on the shoreline to the north. Outcrop of Brighton Group is very limited elsewhere around Hastings Bight due to the extensive development of mangrove and salt marsh and

associated sediment cover, and the reclamation of the shoreline for port and industrial development at and north of Long Island Point (Figure 12).

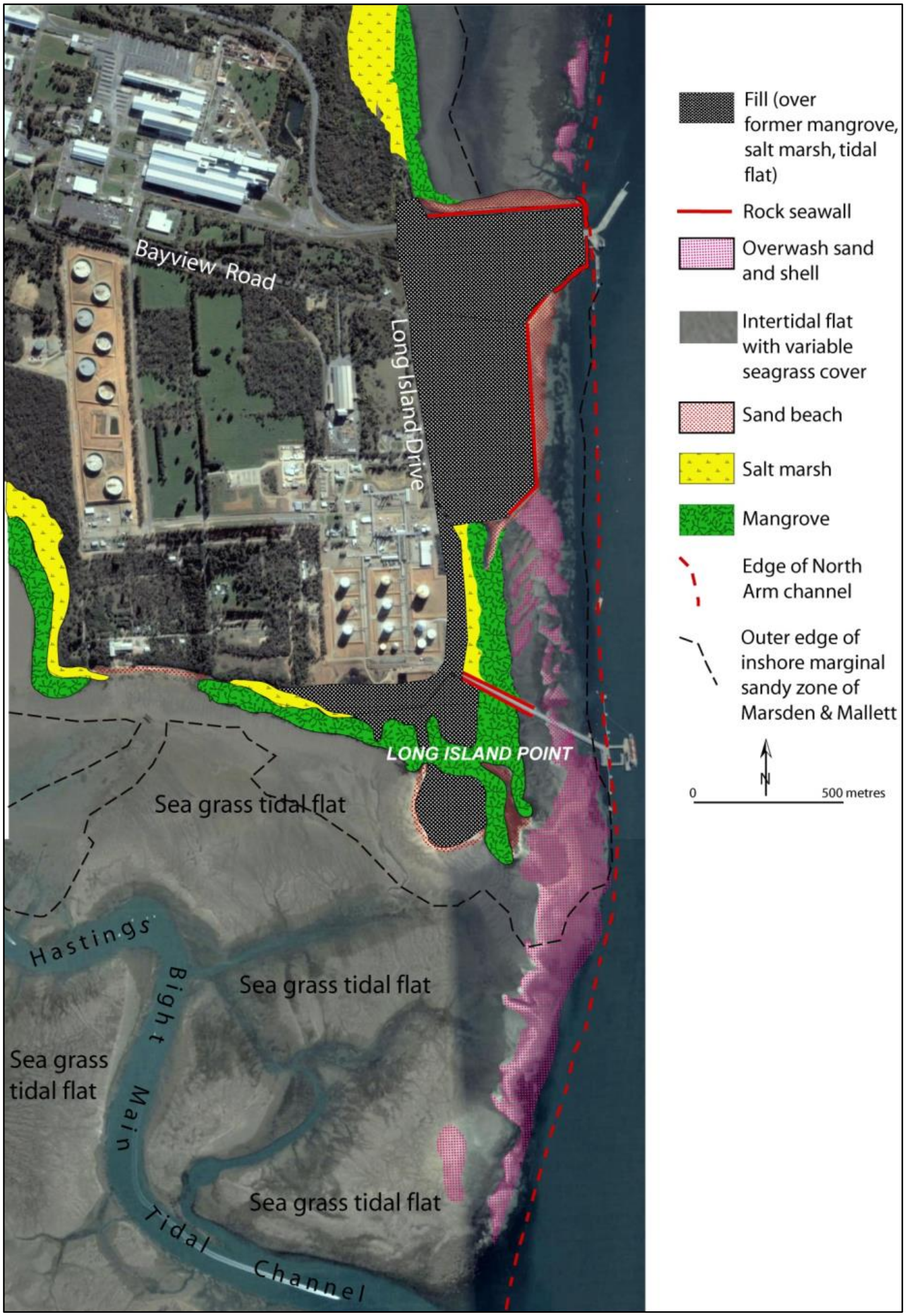


Figure 79. Coastal and nearshore geomorphology, Long Island Point to BlueScope Steel (Rosengren2009).

The northern shoreline of Hastings Bight is broad, low and mangrove-fringed with a defined embayment forming the estuary of the drowned valleys of King Creek and Olivers Creek. A meandering central tidal channel with tributary systems connects the Hastings Bight to the deep North Arm channel. Marsden and Mallett (1975) provide a detailed map of Hastings Bight as representative of the shoreline and intertidal morphology of the several tidal inlets of Western Port (Figure 11). There is considerable variability in the composition and morphology of the intertidal and subtidal flats. The substrate is a weathered former terrestrial surface of Brighton Group overlain by alluvial sediments with a veneer of sand-rich sediments with varying proportions of quartzose and biogenic carbonate interspersed with mud (Spencer-Jones *et al.* 1975). Varying amounts of sea grass (*Zostera muelleri*, *Amphibolis antarctica* and *Heterozostera tasmanica*) occur across the subtidal and intertidal surfaces.

The Special Use Zone inland from the proposed terminal is a gently undulating surface underlain by Brighton Group and Red Bluff Sandstone with areas of low sand ridgs and wetland depressions.

Terrestrial and marine geotechnical and geophysical surveys conducted during 2013-2014 provide detailed geological data onshore and offshore (Worley Parsons 2014; Aurecom 2014). The surveys confirm that the bulk of the materials in the areas to be dredged and overlain by the hardstand are fine-grained (clays and silt) with moderate component of sand. A small quantity of Silurian sedimentary rock may need to be removed in the dredging area in North Arm.

5.2.2 North Arm Sediments

Surface seafloor sediments in North Arm were mapped by Marsden and Mallett (1975) (Figure 11 above). Detailed marine geophysical and geotechnical investigations including side-scan sonar, sub-bottom profiling, seismic reflection, Cone Penetration Testing, grab-sampling and coring undertaken in 2013-2014 (Worley Parsons 2014; Aurecom 2014) showed the seafloor and subsurface materials to and below proposed dredge level were predominantly loose sand overlying variably consolidated sedimentary formations (Holocene marine, Pleistocene terrestrial and weathered Neogene sediments (Brighton Group or Sherwood Marl). Surface rock was encountered in six only of the 94 drill holes.

Borehole locations are shown on Figure 13 and examples (Section 2 and Section 3) of the log graphic is shown in Figure 14. A high percentage of the sub-bottom materials are fine-grained - silt and clay.

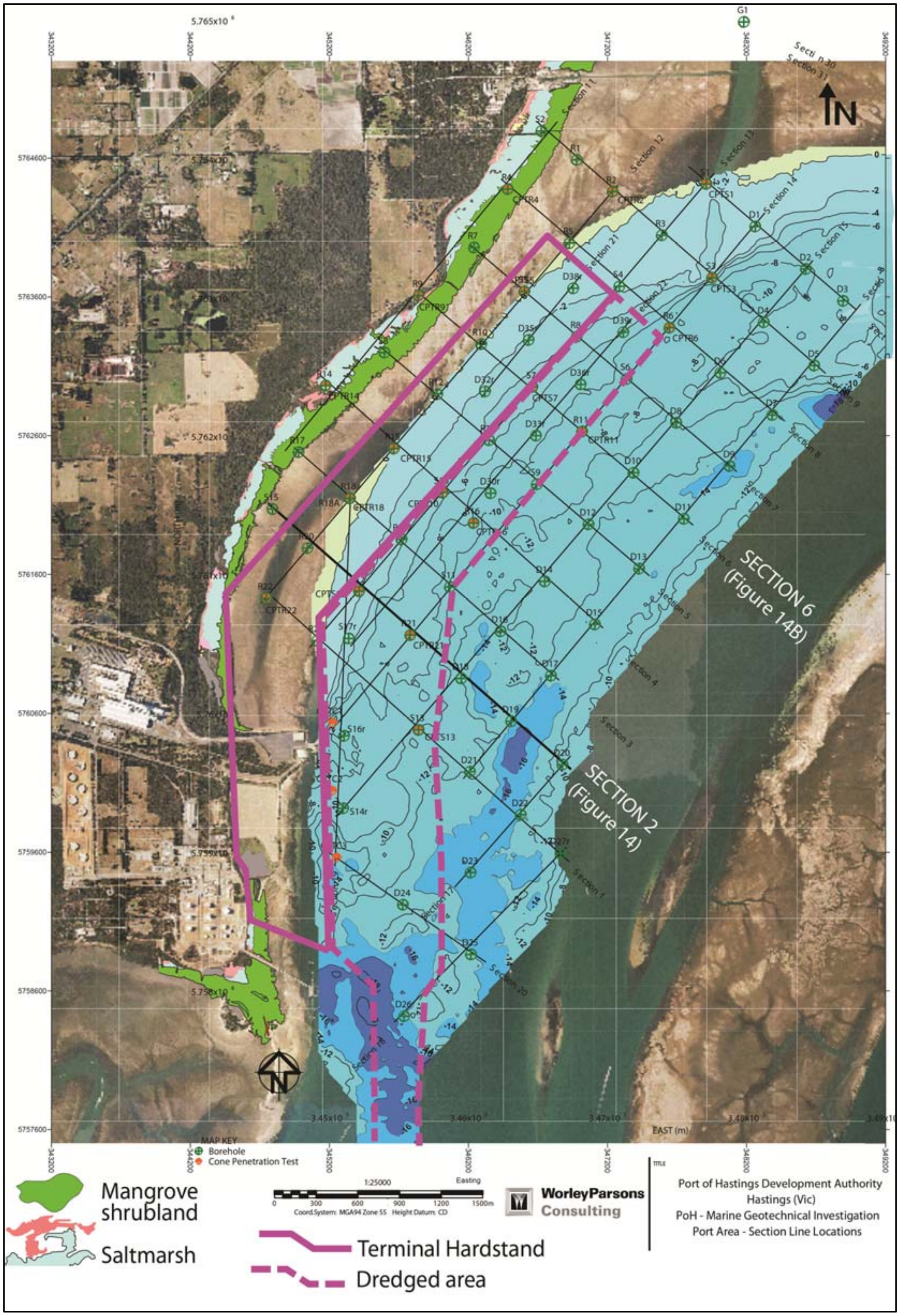


Figure 80. Bathymetry, mangrove and saltmarsh extent and location of boreholes, North Arm. (Worley Parsons Consulting 2014).

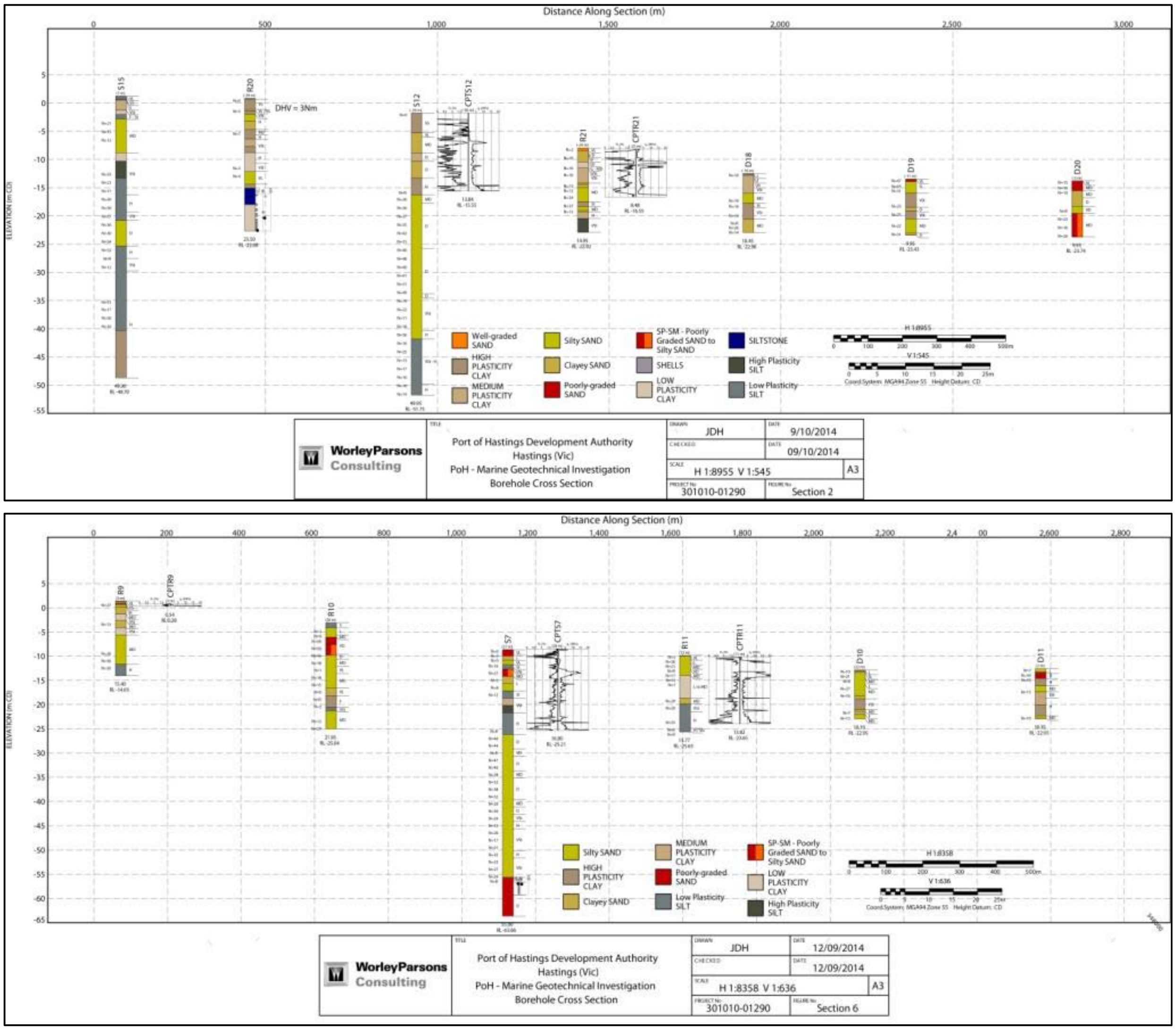


Figure 81. Borehole cross sections 2, and 6, Port Area (Worley Parsons 2014).

5.3 Summary of Environmental Impacts of Port Development

This report is not scoped as an engineering assessment of constraints on building and operating the facility. Its purpose is to identify: (a) how the physical features at the sites will respond, (b) what effects can be transferred beyond the immediate site of operations.

Potential effects of construction and operation of the new facility at Hastings can be assessed as on-site, near-site and removed/remote:

(a) location in relation to existing environmental character and structures;

(b) construction of the hardstand for the terminal both on-shore and in water, including transport of construction materials;

(c) dredging for ship access and manoeuvring and disposal of dredged materials;

(d) port operation including ship-related factors such as vessel size and traffic frequency, and maintenance dredging, and cargo-related factors such as types of containers, hazardous materials management and transport to and from vessels.

Some on-site and off-site environmental effects, relevant to this study, during and post-construction of developing a new port includes:

- Construction effects on marine—near-shore (subtidal, intertidal), shore—and terrestrial—geology, soils (including Acid Sulphate Soils) and landforms—physical form, coastal and marine processes and ecosystems.
- Effects of dredging and earthworks on configuration of seafloor and shore and consequent changes in waves, currents and water circulation.
- Release of pollutants previously deposited in sediments
- Changes in runoff and ground water.
- Reduction of wetlands.
- Soil contamination.
- Discharge to water from port and transport activities.
- Accidental spills from cargo, bunker oil and other fluids from ships.
- Maintenance dredging and spoil disposal.
- Degradation of natural (and cultural) heritage features.

5.3.1 On-site Impacts

The surface beneath the hardstand will be completely obscured or in part removed during construction and will have total loss of existing character—no remediation is required or possible. In all areas to be dredged, the surface will be removed along with varying thickness of marine substrate. Both onshore and offshore, the existing substrate is Neogene sediments ranging from loose sand and shell layers to more competent stiff clays and sand of variable density (Worley Parsons 2014). Potential consequences of the mass of the structure include deformation of adjacent ground surfaces and interception of ground water. Dredging will change the longitudinal and cross-profile of the North Arm and alter current flow and expose new materials at the seafloor. These may have different cohesion and entrainment properties from the existing sea-floor potentially leading to channel scour and slumping with implications for turbidity and sediment transfer. Deeper channels will allow further propagation of ocean and local wind waves into the confluence zone and North Arm with implications for shoreline stability and dispersal of mangrove seedlings.

Figure 82. Intertidal, mangrove and saltmarsh zone adjacent to proposed container terminal (NearMap 2010).

The proposed container hardstand would lie parallel to the shoreline and across most of the intertidal zone of four kilometres of shoreline north of BlueScope Steel (Figure 15). One kilometre of this structure will overlie a mangrove and some saltmarsh in a zone 150 metres wide. Beyond this the tidal flooding and emergence regime will be fundamentally altered and ecological and sedimentological impacts would follow. Provision

for tidal ventilation under the hardstand could be made but will require detailed assessment of the present flooding duration and condition of the mangrove stock along the entire four kilometres.

5.3.2 Off-Site Impacts

The characteristics of Western Port most sensitive and/or responsive to change in physical processes are:

- tide-driven circulation
- dominance of wind-driven waves across most of the bay
- shallow water and extensive inter-tidal area across the Upper North Arm and Embayment Head
- complex dendritic tidal channel systems
- tidal divide in northeast
- long sectors of shore zone of earthy and poorly-consolidated sediments and peaty sediment
- long sectors of low muddy shoreline with mangrove fringe of variable width and density.

Although all of Western Port is hydrologically linked to the site and may experience relayed impacts from dredging and construction, any impacts would be most acute in areas immediately adjacent to the to be confined to the area of development and dredging, i.e. western shore of French Island and western shore of North Arm. The potential impacts to be considered or expected are:

- changes in water level, tidal phase, wave and current action
- increased suspended sediment transfer
- changes to habitat as a consequence of changed submergence and sediment transfer regimes that may alter biological systems e.g. aquatic macroalgae, seagrass, mangrove and saltmarsh and shellfish beds with resultant feedback to the physical environment and processes.
- potential deepening of water across the Upper North Arm and Tidal Divide and increased effectiveness of wave action reaching the erosion sensitive earth cliff shoreline east of Main Drain and Bunyip River. This considered to be a minimal change and not distinguishable from changed ambient conditions due to climate change and associated sea-level rise.

These affects may be experienced only during the construction and immediate post-construction stages but in some systems will be of longer term duration and varying

intensity. Hydrodynamic, sediment and ecosystem responses that may accrue from this proposal need to be compared with ambient conditions and expected future changes due to climate, including sea-level rise and storm frequency. The hydrodynamic model developed by Cardno (2013, 2016) showed minimal changes in sea-level and tidal phases compared with the natural range of existing processes, implying that potential direct hydrodynamic impacts across the system may also be minimal. The change in channel form in Western Channel and confluence zone by dredging will have minimal effect on wave and current processes that would relay to the shore zone and effect coastal geomorphology.

Many shorelines of Western Port will have minimal to imperceptible response to the hydrological and sedimentological changes referred to above. These include the long sectors of hard rock and steep coast, areas of wide shore platform, areas of wide mangrove fringe and those with existing substantial engineered sea frontage.

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