INVERLOCH COASTAL RESILIENCE PROJECT

COASTAL GEOMORPHOLOGY

GEOMORPHOLOGICAL VALUES

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Andersons Inlet entrance: 1995 (Photo by Neville Rosengren)

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Executive Summary

- The Inverloch coast—between Flat Rocks and Townsends Bluff—is a seven kilometre long complex geomorphic assemblage of active marine cliffs, shore platforms, coastal bluffs, marine terraces, sand beaches and backshore sand ridges
- A wide gently sloping shore platform fringes the coastal cliffs and extends under a shallow beach cover in front of the dune coast and nearshore
- Part of the coast fringes Andersons Inlet, a large barrier-defined tidal inlet with a mix of marine, estuarine and fluvial landforms and processes
- The coastal landforms are of State geoscience significance preserving past forms and processes and demonstrating a range of ongoing shoreline dynamics
- The broad configuration of the coast and hinterland is determined by faulting producing a sunkland bordered by elevated low plateau and hills
- The detailed geomorphic character of this coastline is determined by sea-level changes across several Pleistocene Glacial/Interglacial episodes
- The geomorphology of the backshore sand ridges and dunes between Flat Rocks and Point Hughes record a history of accretion and recession (erosion) extending across the late Pleistocene and Holocene
- A sector of coast near Ozone Street experienced substantial recession—and subsequent accretion—between the 1970's and early 1990's
- More widespread recession between Flat Rocks and near Ozone Street has occurred since 2013
- Coincident with this recession the adjacent coastline east of Ozone Street has undergone substantial accretion
- Coalescing spits have formed a wide lobate foreland enclosing a lagoon at the mouth of Ayr Creek Point Norman and Point Hughes

- The accretion is accompanied by a lateral shift of the main ebb channel of Andersons Inlet by several hundred metres to the east substantially altering the configuration of the entrance between Point Norman and Point Smythe
- The combined recession and accretion events comprise one of the most rapid changes along a sandy coastline in Victoria over recorded history and far exceed previous changes recorded and observed at Inverloch
- The amount of sand accumulated at Point Norman - Pont Hughes is much greater than that removed from adjacent beach and backshore, indicating that other sources have also contributed to the accumulation. More investigation of these sources will be undertaken in a later separate study
- The cause(s) of rapid recent shoreline recession may include an increase in the frequency and energy of erosion-inducing storms, changes in the direction of approach of high energy waves, rising sea-level and reduction in sediment supply
- Although recession of sandy beaches is widespread on a regional to continental scale, the rate of recession between Flat Rocks and east of the Surf Club at Inverloch is very high to extreme by global comparison
- No single cause or sequence of events to fully explain this very high rate of recession at Inverloch has been identified.
- This present report recommends a range of marine and terrestrial research and monitoring tasks that will give better understanding of the causes of recession and assist management to develop and implement options to accommodate ongoing and future change in shoreline position.

CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

The author gratefully acknowledges assistance from the following:

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- Phillip Heath for meticulous editing of several drafts and excellent suggestions for revisions and inclusions
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- Brian Martin (Parks Victoria) for facilitating access to Point Smythe for sand sampling.
- Darragh O'Sullivan (Parks Victoria) for assistance with sand sampling at Point Smythe.
- Tony Miner (ASMiner Geotechnical) for discussions regarding processes of shoreline change, for defining the coastal compartments and domains of the Inverloch - Point Smythe coast, and for preliminary calculations of the volumes of sediment likely to be involved in the shoreline movements identified.

1 CONTEXT: BASS STRAIT

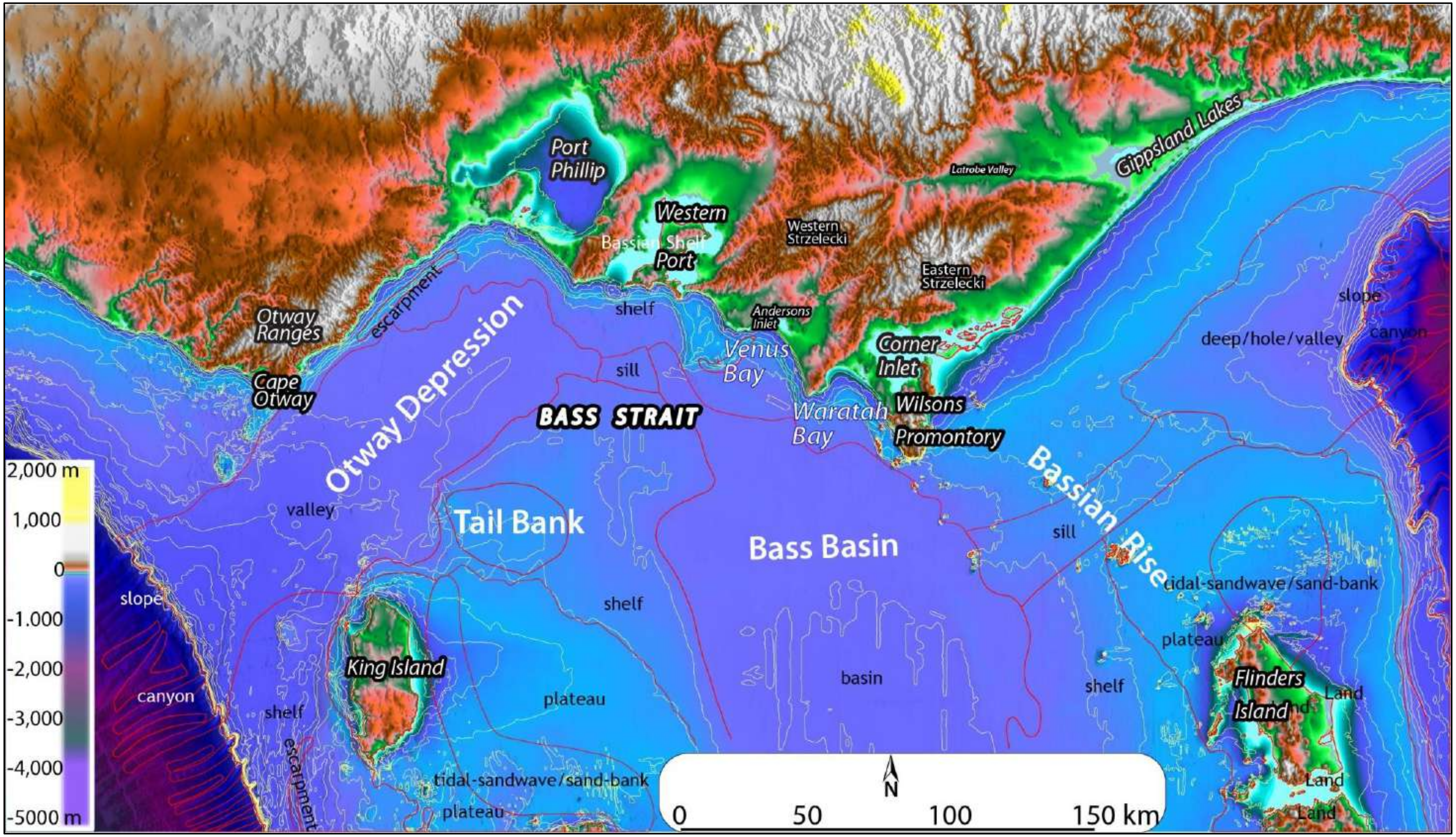


Figure 1. Digital Elevation/Bathymetric model of Bass Strait and Victorian coast.

1.1 Bass Strait & Sea Level Change

- Bass Strait is the shallow waterway between Victoria and Tasmania linking the Tasman Sea with the southern Indian Ocean (Figure 1)

- Two basins, Otway Depression and Bass Basin(deepest 83 m), separated by shallow central ridge (Tail Bank) between Cape Paterson and King Island
- Western entrance restricted by King Island and submarine ridge and islands to northwest Tasmania
- Submarine (Otway Depression) to west - opens between Cape Otway & King Island
- Bass Basin to southeast
- Submarine ridge (Bassian Rise), shallow sill and granite islands between Flinders Island and Wilsons Promontory-
- Abrupt western and eastern margins at edge of continental shelf
- Steep slope at edge of shelf above continental slope: to west (Southern Ocean) and to east (Tasman Sea)
- Deep submarine canyons on the continental slope
- When sea-level fell to -67 m, Bassian Ridge was emerged connecting Wilsons Promontory to NE Tasmania
- When sea-level fell to -80 m most of Bass Strait was isolated from the sea and the Bass Basin was a shallow lake
- At sea-level -120 m the shore line was 70 km south west of Cape Otway and 250 km from Inverloch
- That low sea-level occurred between about 30,000 and 17,000 years ago
- Sea-level rise from -120 m to approximately its present level occurred between 18,000 years and 8,000 years ago
- This is an average rise of 0.12m/year (12 cm/yr or 120 mm/yr)
- In the last 8,000 years sea-level has been slightly higher than present
- No definitive sea-level height above present has been determined for Inverloch
- Evidence for the higher sea-level includes the preservation of low shore-parallel ridges and intervening swales (depressions) between the Cape Paterson - Inverloch Road and the bluff (former seacliff) inland from this (Figure 8).

1.2 Geomorphology: Central Victorian Coast

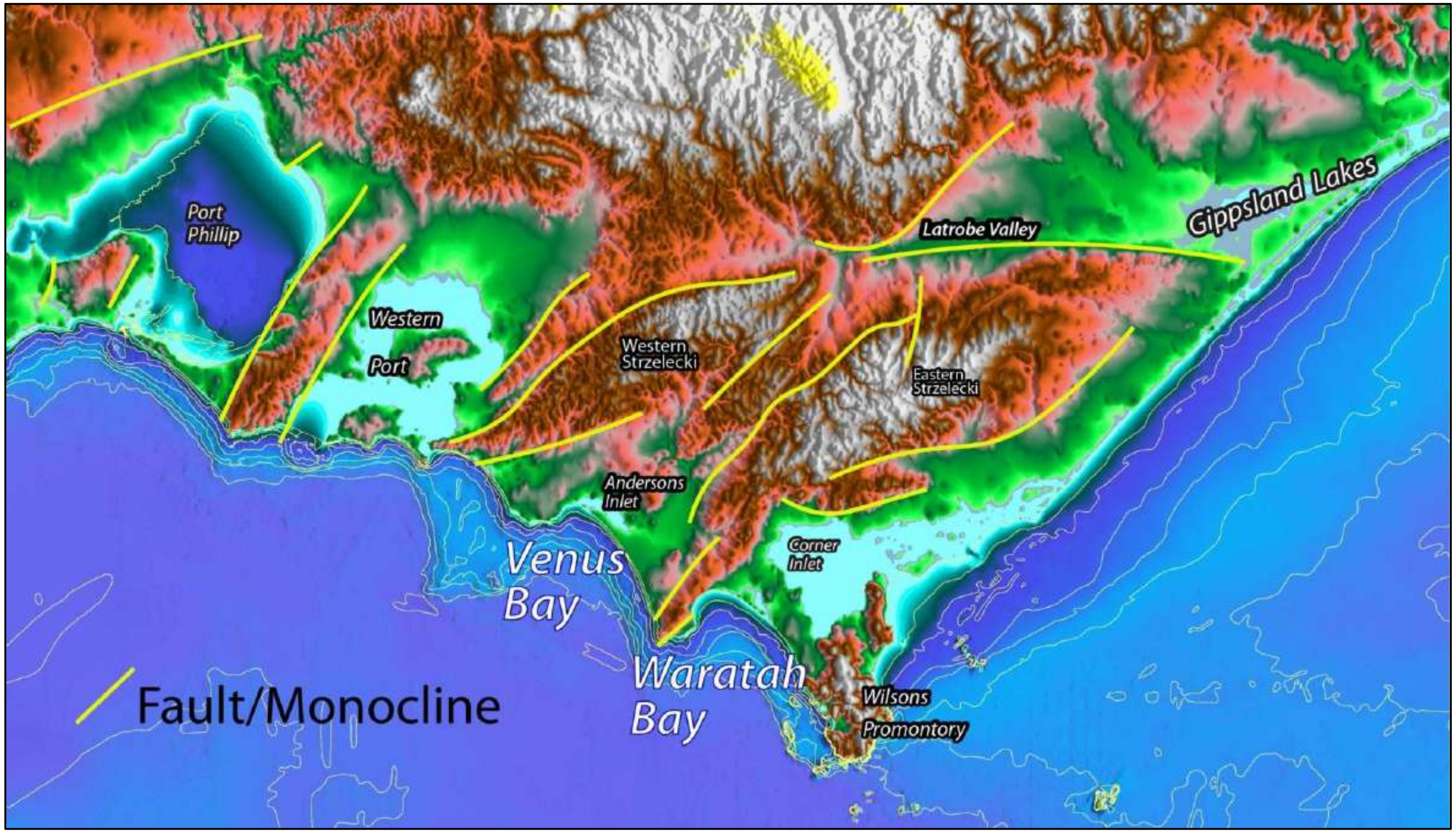


Figure 2. Fault alignment of embayments and topographic highs - Port Phillip, Western Port, Corner Inlet, Gippsland Lakes. Andersons Inlet is a downfaulted depression where the former embayment has been partly filled with fluvial sediment (Tarwin River), marine/estuarine sediment (Andersons Inlet) and coastal dunes (Point Smythe).

- Prominent coastal morphology includes four fault-defined shallow embayments (Figure 2):
    - Port Phillip
    - Western Port
    - Corner Inlet
    - Gippsland Lakes

- Faulted and partially-filled embayment of lower Tarwin River / Andersons Inlet
- Four topographic highs separating the embayments
    - Mornington Peninsula - faulted uplift
    - San Remo / Woolamai Ridge - faulted uplift
    - Hoddle Range -faulted uplift
    - Wilsons Promontory - resistant granitic rocks
- The lower Tarwin River and Andersons Inlet is a former embayment (Tarwin Sunkland) now partially filled with fluvial, coastal and estuarine deposits and coastal dunes
- The orientation (strike) of faults and the alternating directions of uplift/downthrow defines the broad geometry of the Gippsland coast (Figure 3)
- Fault uplift results in headlands and an elevated backshore
- Fault downthrow results in embayments and broad valleys

1.3 Geomorphology: West & South Gippsland

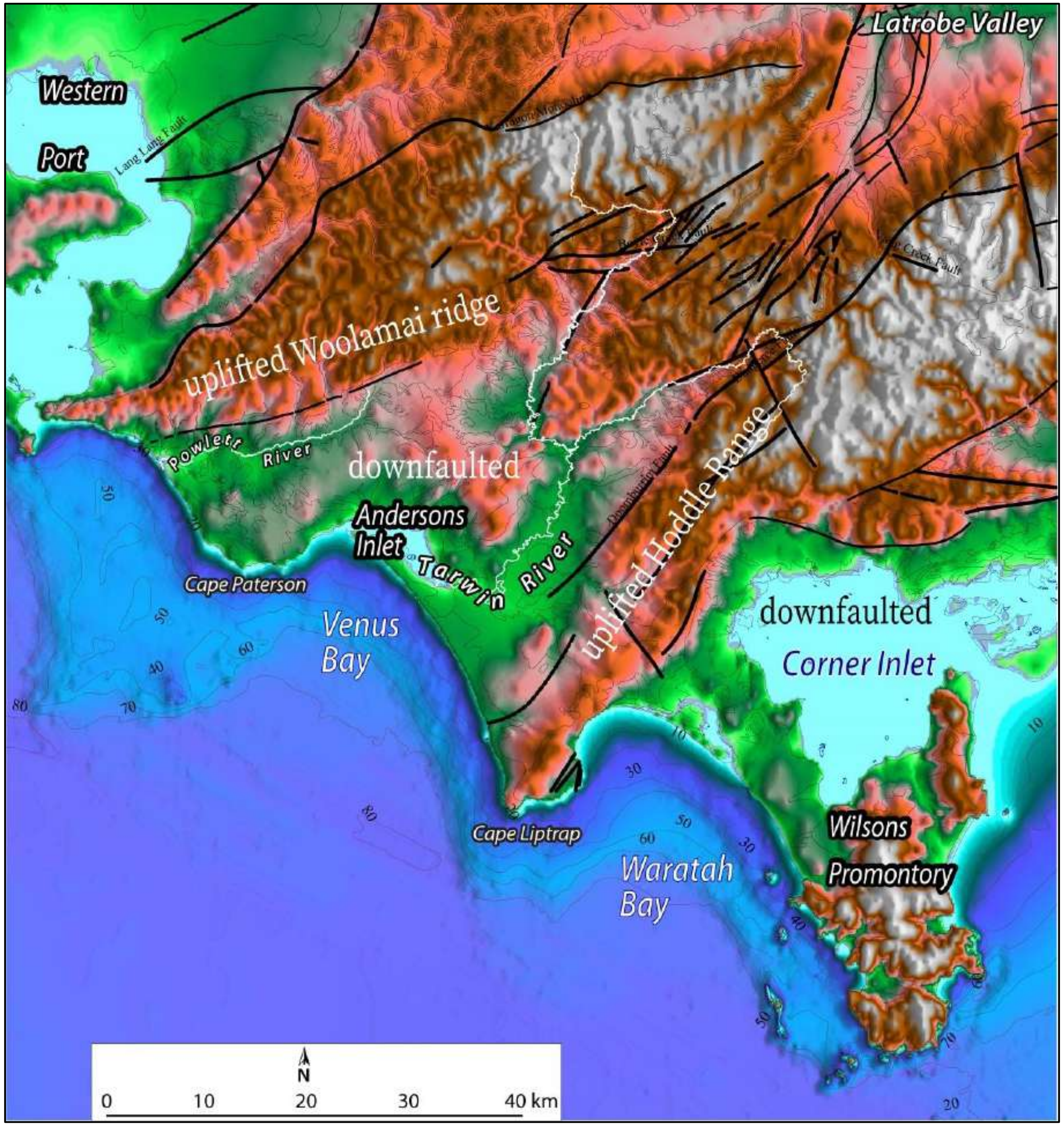


Figure 3. Northeast-trending faults and the residual/resistant granites of Wilsons Promontory define the outline of the west & south Gippsland Coast.

- Northeast-trending faults define the configuration of the coast from San Remo to Waratah Bay
- The coastal planform is three *curving sub-parallel* embayments between San Remo and Wilsons Promontory (Figure 3)
- Venus Bay and Waratah Bay are **zeta bays** - so-called due to the asymmetrical shape like the Greek letter ζ
- The northern end of the bays are in the lee of headlands and are shaped by refracting waves
- The central and southern end of the bays are coastal sand barriers shaped by wave swash and sand drift
- The headlands of Cape Paterson and Cape Liptrap are fringed by wide shore platforms emerged at low tide
- Offshore the seafloor slopes gently as a rock-floored bench with a veneer of sediment to 70 m deep and terminates as a low underwater cliff formed at a lower sea-level
- Between Cap Paterson and Cape Liptrap is a broad submarine valley that was crossed by the channels of the Tarwin River during lower sea-levels.

1.4 Geology - bedrock

- Bedrock from San Remo (Griffiths Point) to Inverloch/Townsends Bluff is Wonthaggi Formation feldspar-rich thinly- bedded fine to medium-grained sandstones (Figure 4)
- Occasional massive sandstone units occur
- Rocks were deposited between 125 million and 100 million years ago in the Early Cretaceous epoch
- Rocks are folded and in places are closely fractured by faults and joints
- Basaltic plugs and dykes cut across the sedimentary rocks.

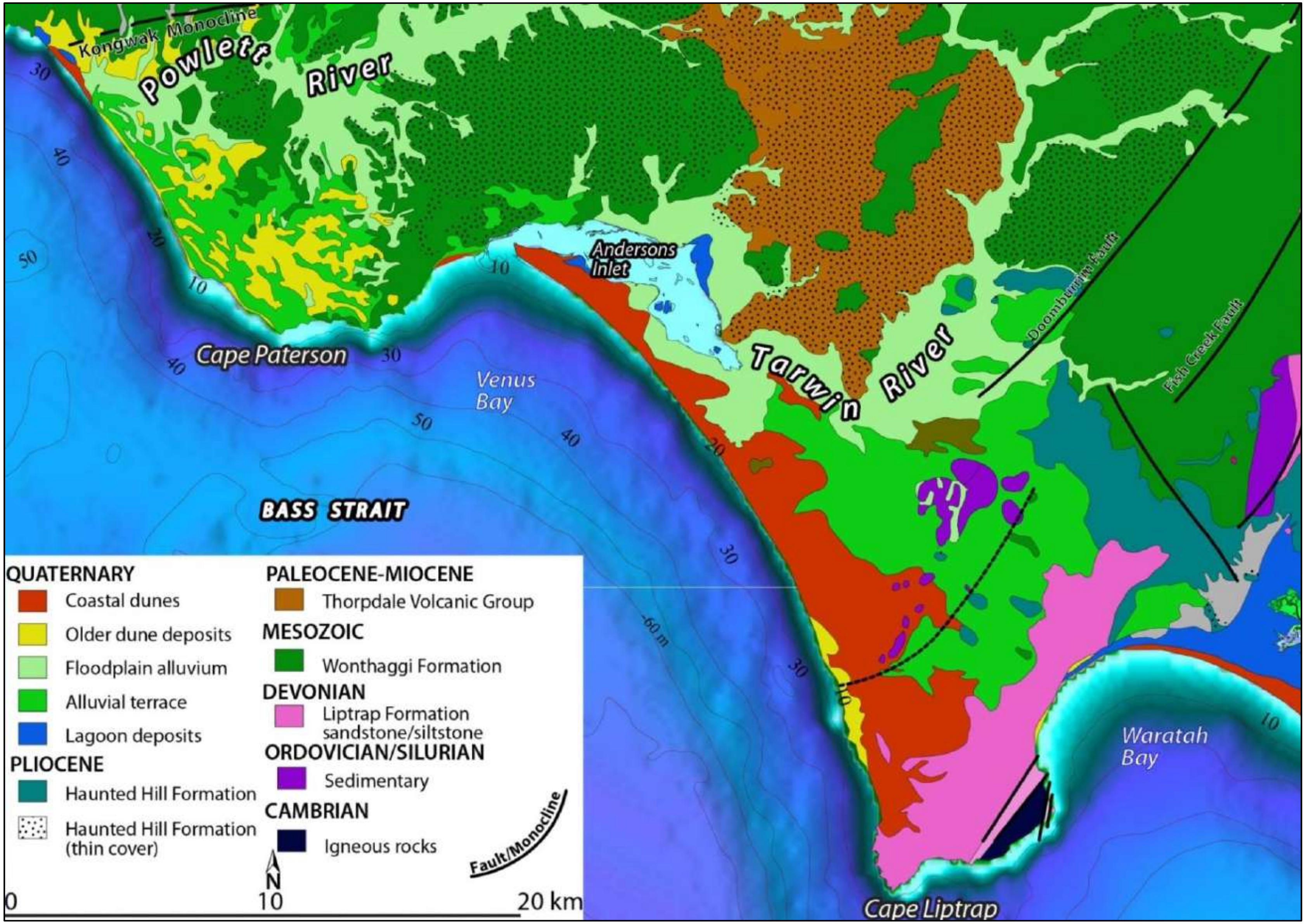


Figure 4. Geology of south Gippsland coast. Best rock outcrops are coastal cliffs and shore platforms.

1.5 Geology - Surficial

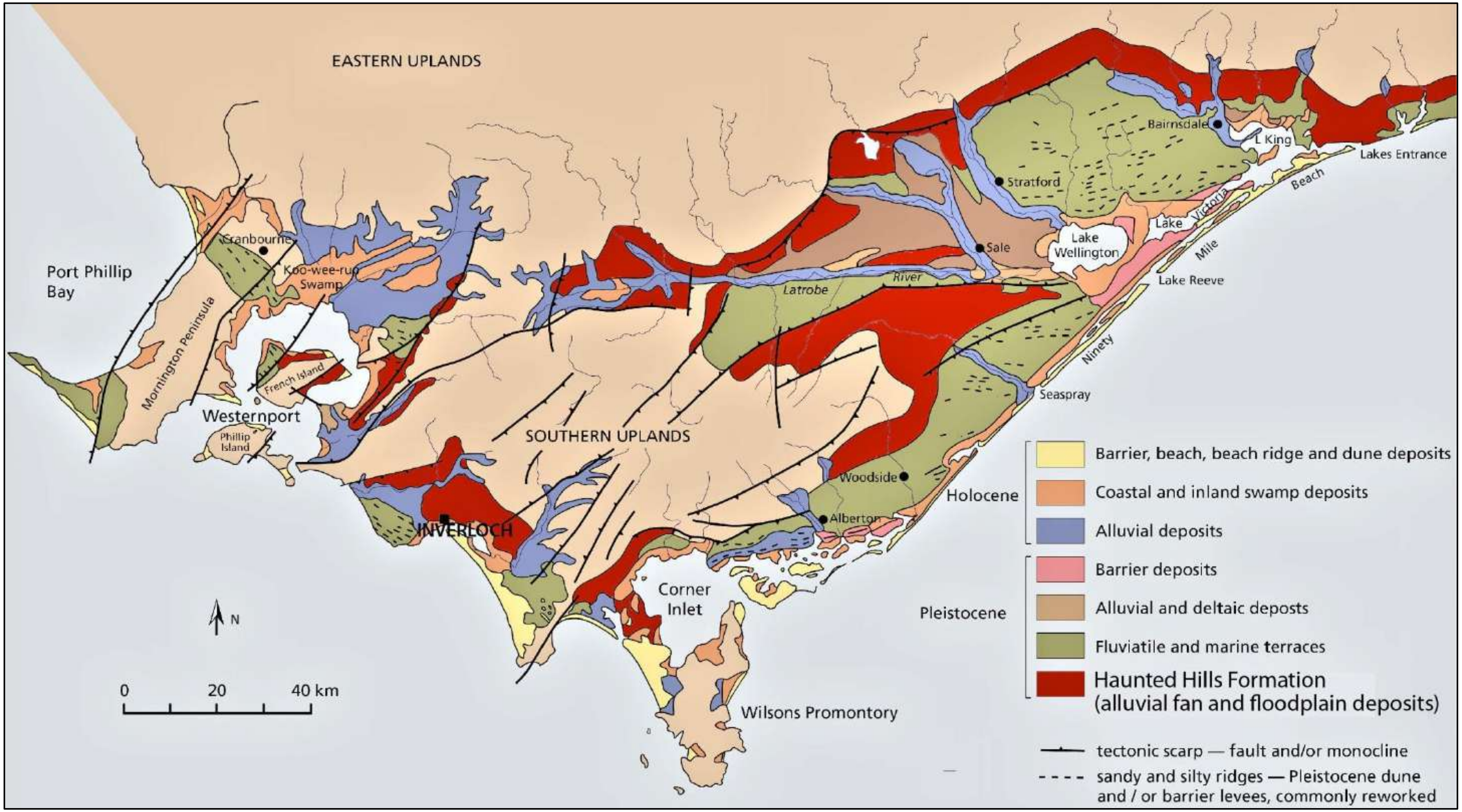


Figure 5. Quaternary geology of South Gippsland showing the extent of Haunted Hill Formation. (After Cupper and White 2003).

- Surficial geology is the weathering cover of the older rocks and younger rocks and sediment
- Deeply weathered volcanic rocks (Thorpdale Volcanic Group) occur as capping over the Cretaceous sediments (Figure 5)
- The basaltic lavas erupted between approximately 20 million to 26 million years ago

- A thin cover of sandy clay occasionally with gravel overlies the Cretaceous and volcanic rocks
- This formation is referred to as White Hills Formation
- The sediments originated as alluvial and colluvial fans and floodplain deposits spread across Gippsland from the Southeastern Highlands of Australia between 4 million and 2 million years ago
- The youngest sediments are those deposited by mass movement (landslides and soil creep) on the slopes of the Strzelecki Ranges
- These processes provide sediment for the Tarwin and Powlett Rivers carried downstream and deposited as floodplains and alluvial deltas
- A wide range of sand dunes occurs across the backshore and in places extend inland for several km
- Some dunes are active, some are “fixed” by vegetation
- Remnants of older sand ridges occur on the Wonthaggi - Cape Paterson plateau between the Powlett River and Inverloch
- A continuous and complex sand body extends from Cape Liptrap to Point Smythe and inland
- The coastal fringe has sand beaches, some with a small component of gravel.
- Some beaches are shore platform beaches i.e. they occur at the back (landward) edge of a rock platform and are infrequently affected by waves and currents.

2 COASTAL PROCESSES

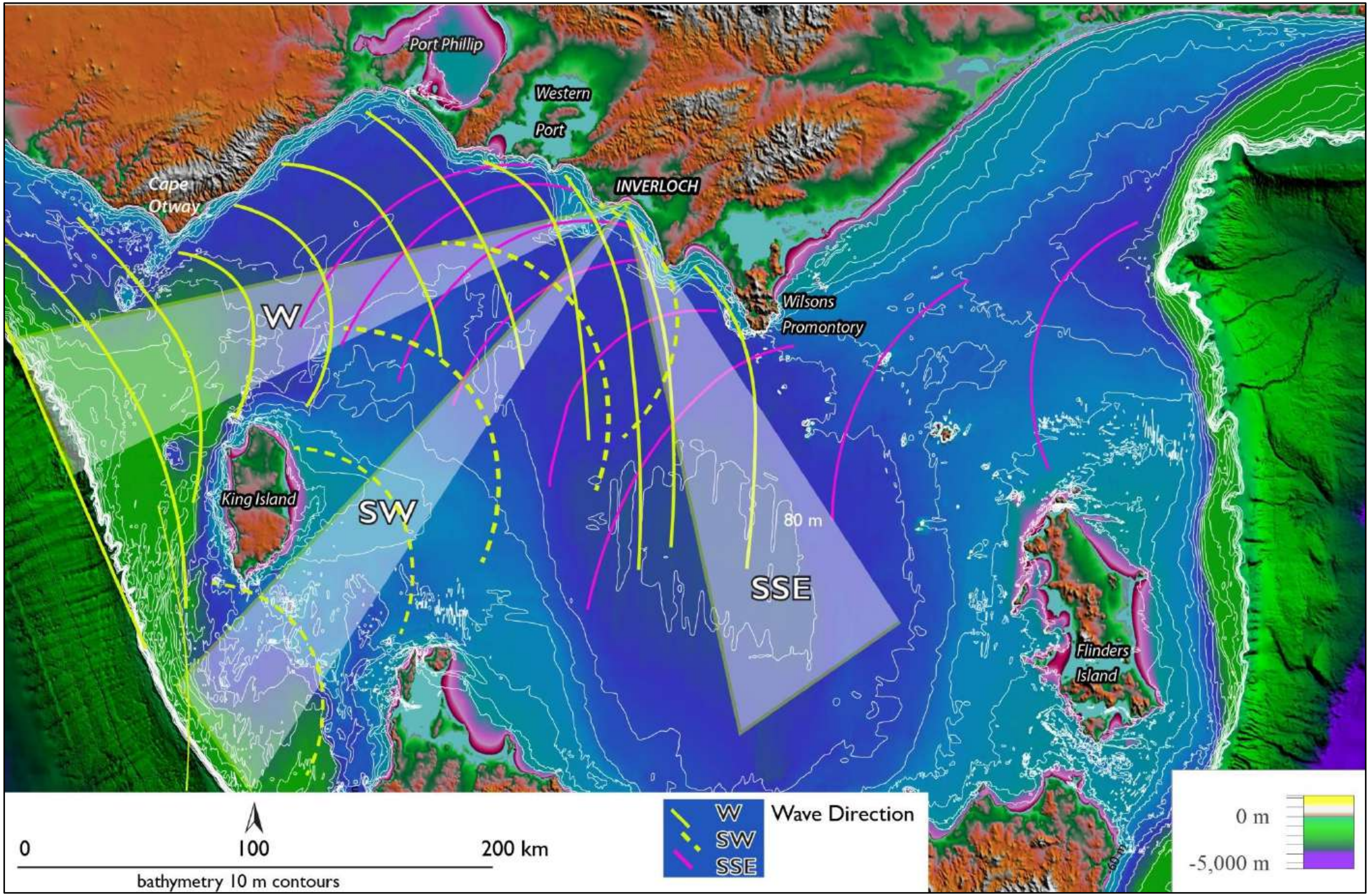


Figure 6. Schematic wave diagram for northern Bass Strait showing "wave windows" for Inverloch and Point Smythe shorelines.

2.1 Swell and Waves

- Swell is generated by storm winds predominantly from the west to south-southeast (Figure 6)
- Waves are determined by the “wave windows” created by the configuration of Bass Strait
- Major wave window for Inverloch is from west across the Otway Depression
- The southwest window is modified by shallow water between King Island and northwest Tasmania
- Waves are modified by the shallowing at Cape Paterson bench and refracted around Cape Paterson headland
- Swell from the south and east is modified and reduced by the Bassian Rise
- W & SW swell breaks with slight angle to shore at and east of Flat Rocks
- This creates a drift to the east and across the entrance to Andersons Inlet (Figure 7).

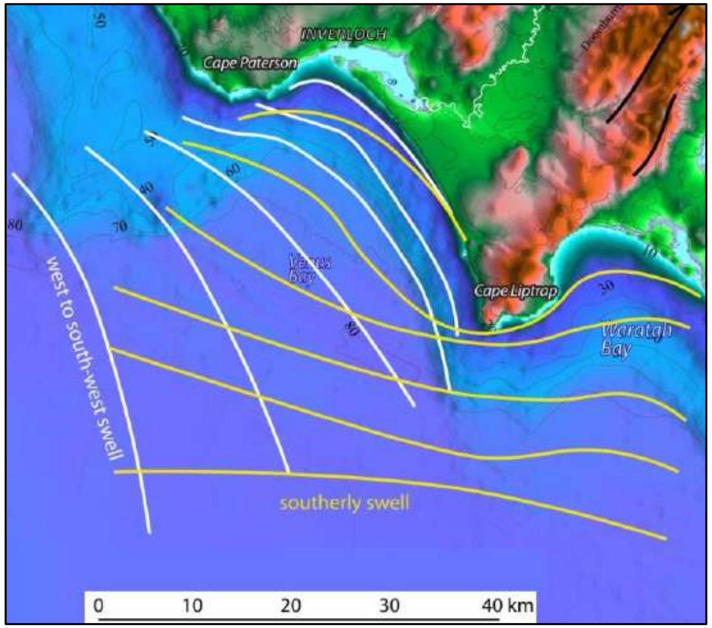


Figure 7. Schematic representation of swell wave refraction across northeast Bass Strait.

2.2 Wind

- Local winds interact with swell to modify the direction and strength of wave action

- Strong onshore winds can produce unusually large waves as a storm surge
- Storm surge can elevate local sea-level for several hours or days, particularly during high spring tides
- As a result, beach overwash, backshore recession and estuarine flooding can occur during these events
- Summarised wind direction and strength over the years 1968 - 2010 from the (now closed) weather station at Inverloch in relation to shoreline orientation is shown in Figure 8

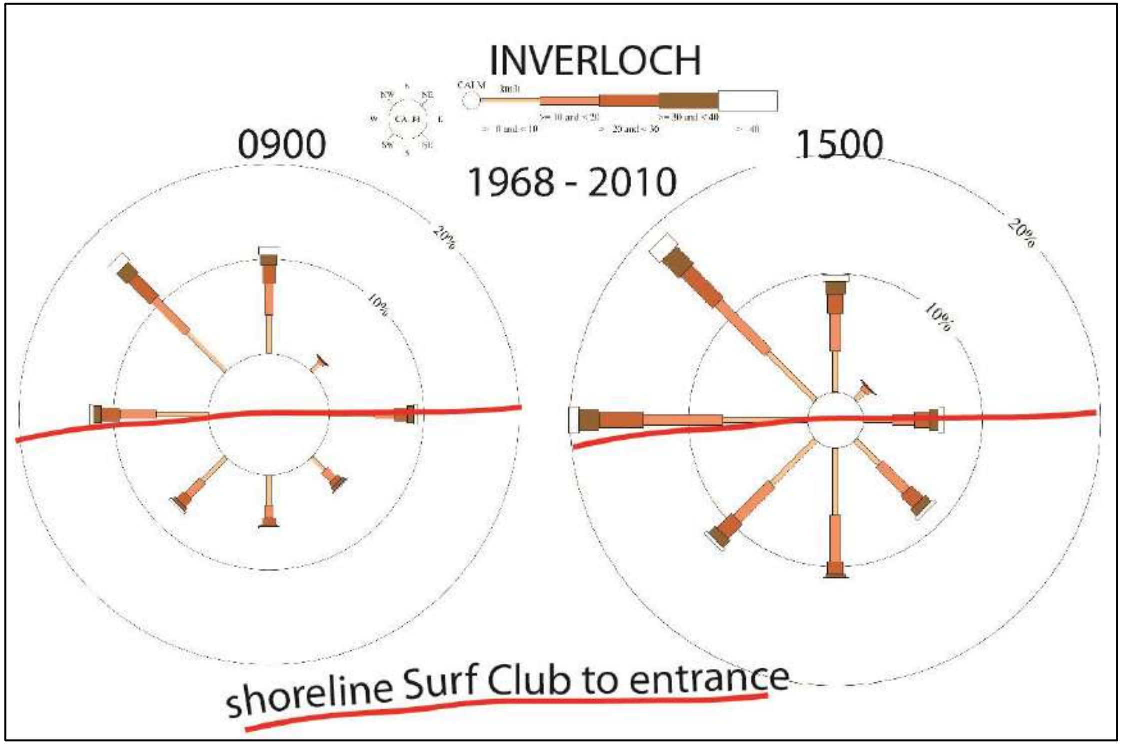


Figure 8. Wind rose diagram for Inverloch 1968 - 2010 (Bureau of Meteorology).

- Further detail of local wind and shoreline change is given in Section 6 of this report (pages 62 to 69).

3 COASTAL GEOMORPHOLOGY: VENUS BAY

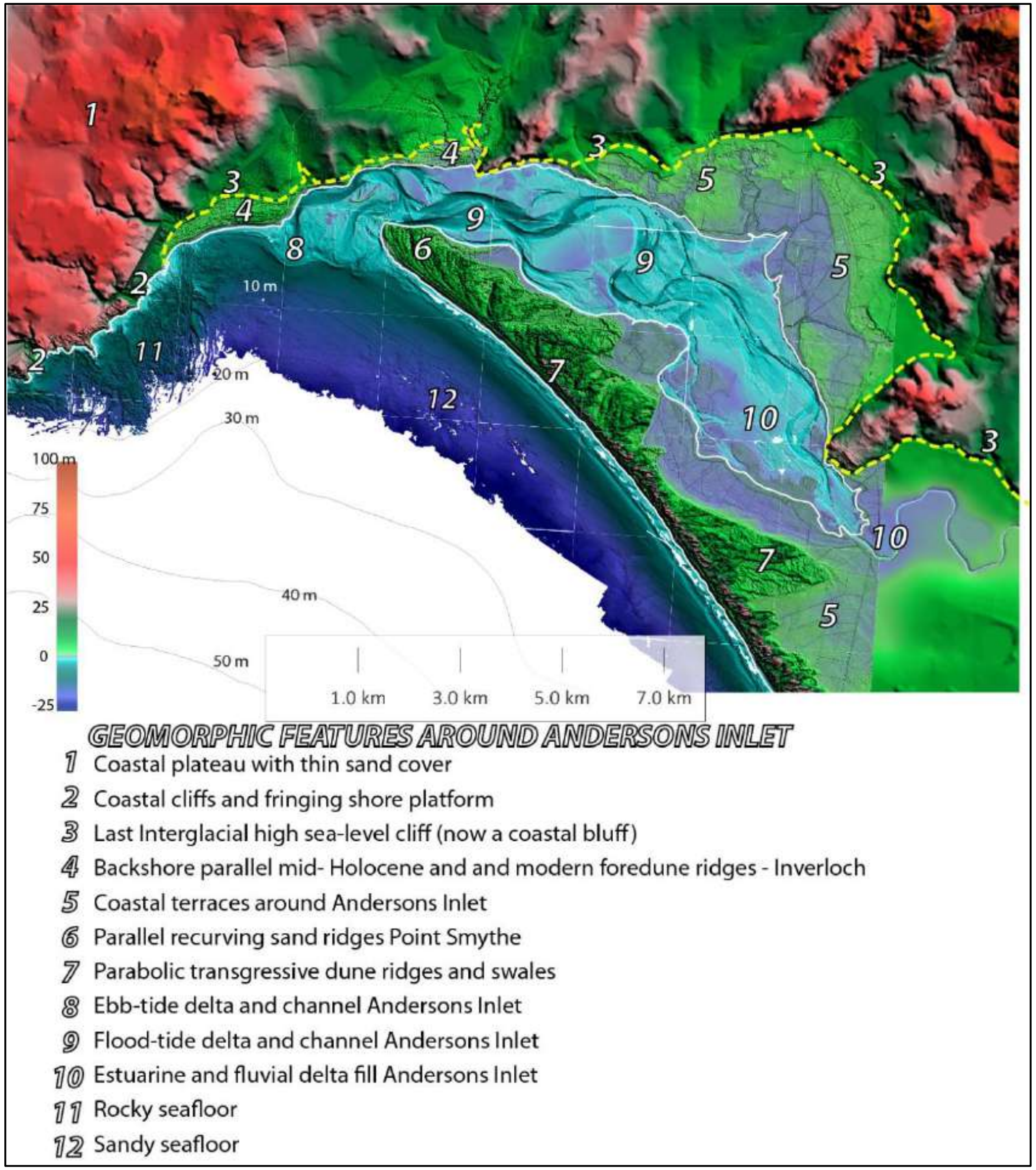


Figure 9. Coastal geomorphology Andersons Inlet and adjacent coast.(Derived from 0.5 m bathymetric and coastal LiDAR and 10 m DEM)

- The coast between Cape Paterson and Venus Bay beaches is a complex of landforms developed at sea-levels that were:
    - Higher than present: Features 2, 3, 6, partially 1 & 9 on Figure 9
    - Lower than present: incised valley of lower Tarwin and partially Features 4, 7, 9 on Figure 9
    - Around present level: Features 2, 4, 5, partially Features 6, 7, 8, 9. on Figure 9

3.1 Sea-Level Changes

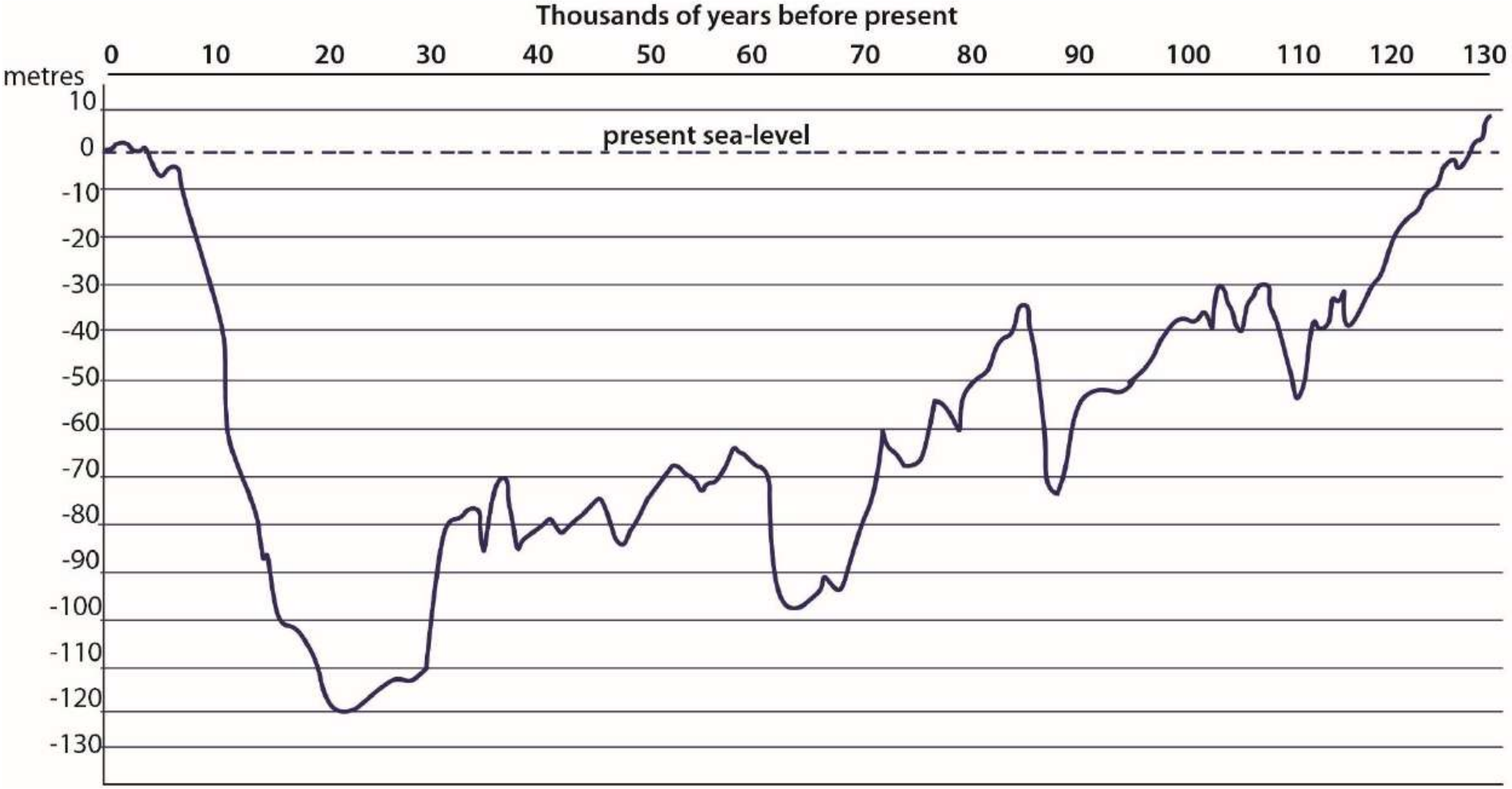


Figure 10. Graph of sea-level changes last 130,000 years (after Brooke *et al.* 2017).

- 130,000 years ago: sea-level between 3 m and 5 - 7 m higher than present (Last Interglacial warmer period)
- 120,000 years ago: rapid fall to -65 metres with onset of Last Glacial Stage (Figure 11)

- 110,000 to 30,000 years ago: between - 20 and -80 metres as global temperatures varied and glacial areas decreased or increased
- 30,000 to 17,000 years ago: rapid fall to -130-140 metres due to global temperature decrease and substantial increase in extent of global glaciation locking up freshwater as ice
- 17,000 to 10,000 years ago: **rapid rise of sea to present level due to global temperature rise and collapse of glaciers in northern hemisphere**
- 10,000 years to 3,000 years: possible higher sea-level 1.0 to 1.5 metres? (Mid-Holocene higher sea-level)

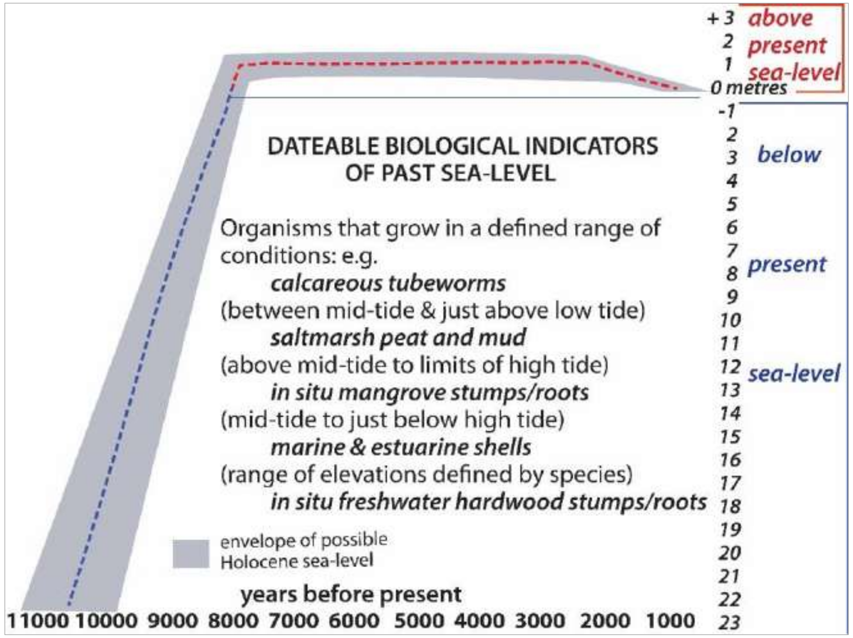


Figure 11. Envelope of possible sea-level changes over the Holocene (last 10,000 years). (After Sloss, Murray-Wallace and Jones, 2007)

3.2 Coastal Plateau

- Between Powlett River and Inverloch
- Planar surface ~ 50 m above sea level
- Is an old seafloor in Lowe Cretaceous rocks uplifted and degraded

- Subsequently a downfaulted block between Woolamai Ridge and Hoddle Range denuded at margins.
    - Northern margin by Powlett River
    - Eastern margin by higher sea-level in Venus Bay embayment and possible faulting
    - Western and southern margins by Bass Strait marine erosion at present and higher sea-level
- Thin capping of Haunted Hills Formation

3.3 Coastal Cliffs & Shore Platform

- Alternating narrow headlands with active cliff and recessed bays with bay head beaches in front of bluffs
- Active marine cliffs have exposed rock faces and are awash at the base at high tide
- Shore platforms are gently sloping rock surfaces extending from below low tide to high tide level (Figure 12)
- Irregular surface of ridges and gutters due to different resistance of sedimentary rock beds.
- Complex origin - should **NOT** be called wave-cut platforms: proper term is **shore platform**
- Some remnants of platforms above present high tide - formed at higher sea-level
- Formed by combination of salt and fresh water weathering and abrasion related to wave action
- Base of cliff may have a sand/gravel beach at base

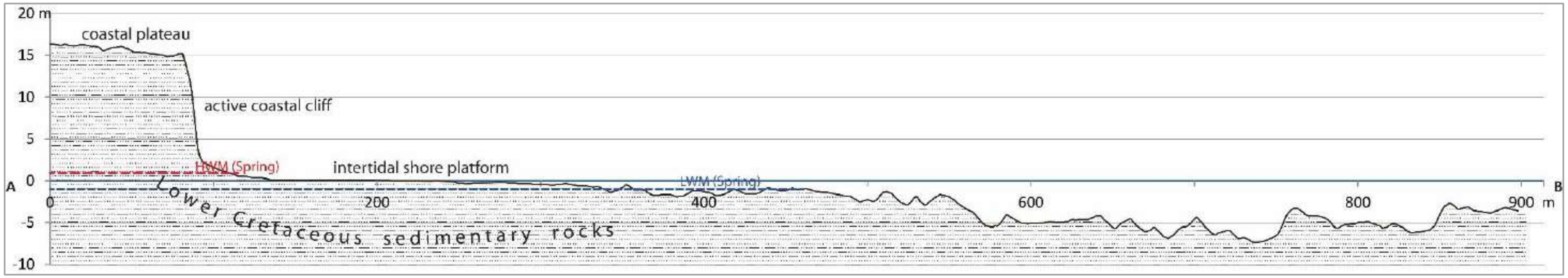


Figure 12. Active coastal cliff and wide intertidal shore platform west of Flat Rocks. Profile drawn from coastal and bathymetric LiDAR. (Vertical Exaggeration x 5).

3.4 Coastal Bluffs: Inactive and Abandoned Sea Cliff

- Bluffs represent former active cliffs initially cut at higher sea-level now stranded (Figure 13)
- Clear example inland from Flat Rocks as a continuation of the active marine cliffs to the west as a steep slope 20 metres high at edge of coastal plateau north of Cape Paterson - Inverloch Road

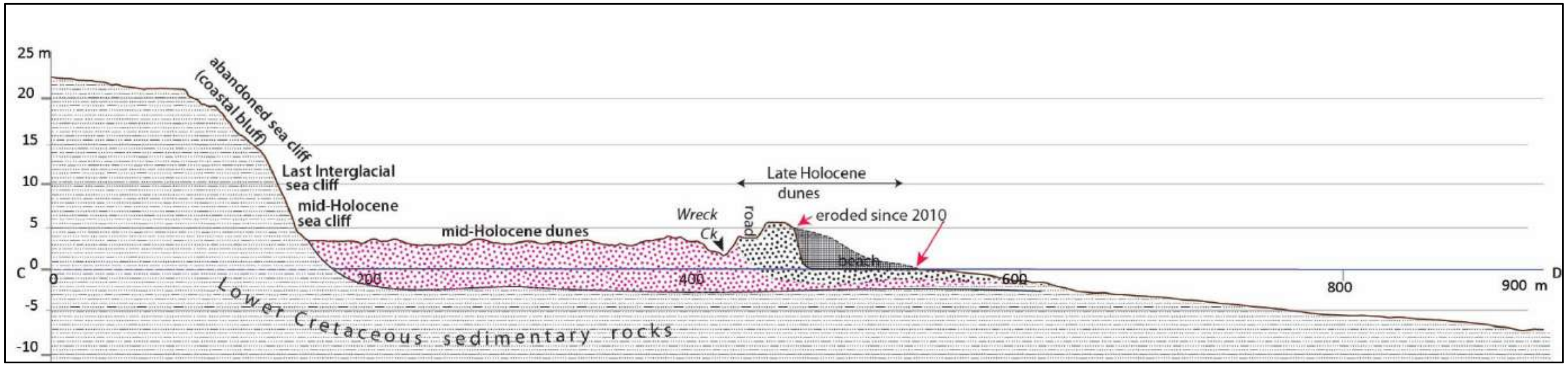


Figure 13. Last Interglacial / Mid-Holocene High Sea-Level Cliff and mid-Holocene and modern dunes. Profile drawn from coastal and bathymetric LiDAR. (Vertical Exaggeration x 5).

- Was an active cliff at Last Interglacial Stage high sea-level (-120,000 years ago) and again during mid-Holocene high sea-level (-8,000 years ago)
- During low sea-level of Last Glacial Stage, the cliffs degrade by slumping and weathering and develop a cover of soil and vegetation.
- Area in front of the degrading bluff is an exposed former sea floor and accumulates alluvium and colluvium
- With rising Holocene sea-level, that surface is submerged and base of the bluff becomes reactivated as a cliff about 8,000 years ago.
- Beaches and dune ridges similar to modern-day shoreline develop at the base of the bluff.

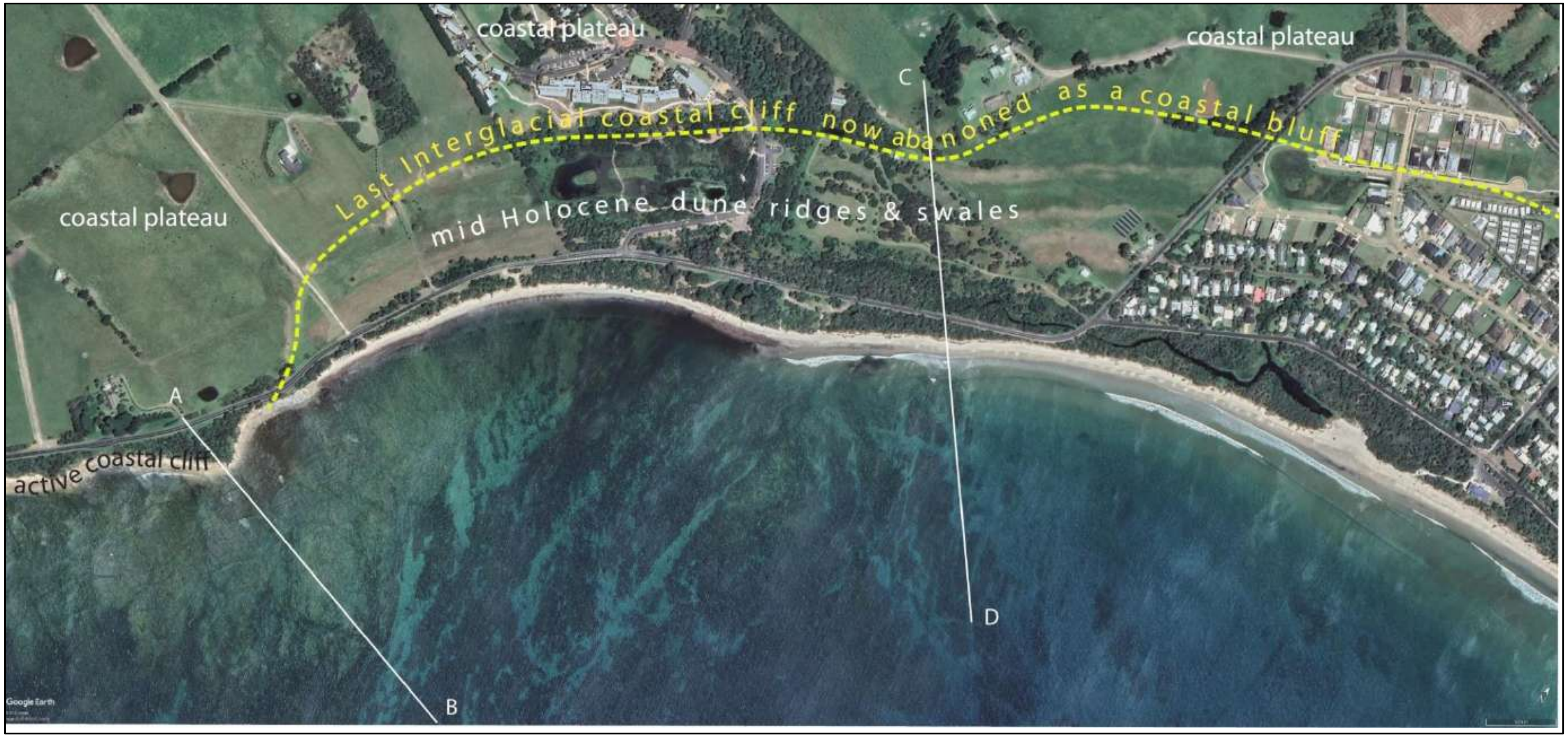


Figure 14. Active cliffs, Last interglacial bluff, older and modern Holocene dunes west of Inverloch. Location of profile A-B (Figure 12) and C-D (Figure 13). (Image from Google Earth Dec 2018).

3.5 Coastal Dune Ridges and Swales

- With the sea at a constant level (stillstand) or falling, swash deposits (wave action) at the rear of the beach are built upward by wind action into ridged or terraced foredunes.
- Initial ridges are called incipient foredunes with areas of bare sand and pioneer grass species
- As vegetation accumulates the ridge becomes fixed by shrub and then tree species and become established foredunes or rear dunes
- In areas of plentiful sand supply the beach face migrates seaward forming new ridges in front of established foredunes, thus developing a beach ridge plain

- Ridges form episodically according to sand supply, wave conditions and sea-level.
- New ridges tend to build slightly seaward of the established dune ride and a depression or swale separates each ridge
- The swales can become wetlands and a conduit for watercourses
- Wreck Creek occupies a defined swale between the higher seaward ridge and the youngest of the older ridges
- When sea-level stabilized at the present level about 3,000 years ago, the sandy shoreline stopped accreting seaward and the foremost (outer) dunes were built higher by wind action
- There are at least eight older dune ridges between the base of the bluff and Wreck Creek (Figure 13, Figure 14)
- The older ridges have subdued topography (partly due to land use modifications) compared with the youngest outer ridges
- Although much modified by continuing residential and other built structures and landscaping of this surface, they are visible on LiDAR and with varying degrees of clarity in the field
- A comparable series of ridges occur east of Screw Creek but are obliterated by past and most recent residential and other built structures

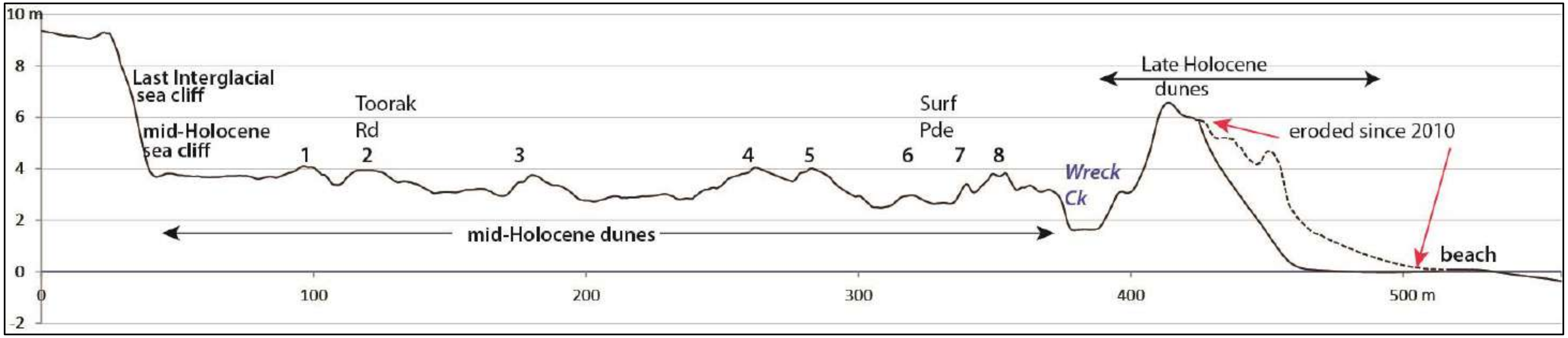


Figure 15. Detail of older (early-mid Holocene) dune ridges between the bluff and Wreck Creek and the modern (late Holocene) higher outer ridges (From LiDAR 2007).

3.5.1 Established Foredunes (Late Holocene)

- The ocean coast between Flat Rocks and Point Hughes is backed by a continuous zone of late Holocene to modern established vegetated foredunes
- Based on the norphology of the dunes—height, width, number of ridges, history of dune recession and aggradation/accretion— the backshore is divided into six (6) sectors (Figure 16)

3.5.1.1 Sector I: Southwest

- Sector **I** is in the southwest and extends from where the dunes commence at the base of the bluff for 635 m to the beach access track 330 m east of the RACV Inverloch Resort road
- This sector has a single established shore-parallel Holocene foredune between 5 m and 7 m high
- The seaward face is continuously scarped (May 2019) fringed by a steep beach of coarse sand and fine gravel

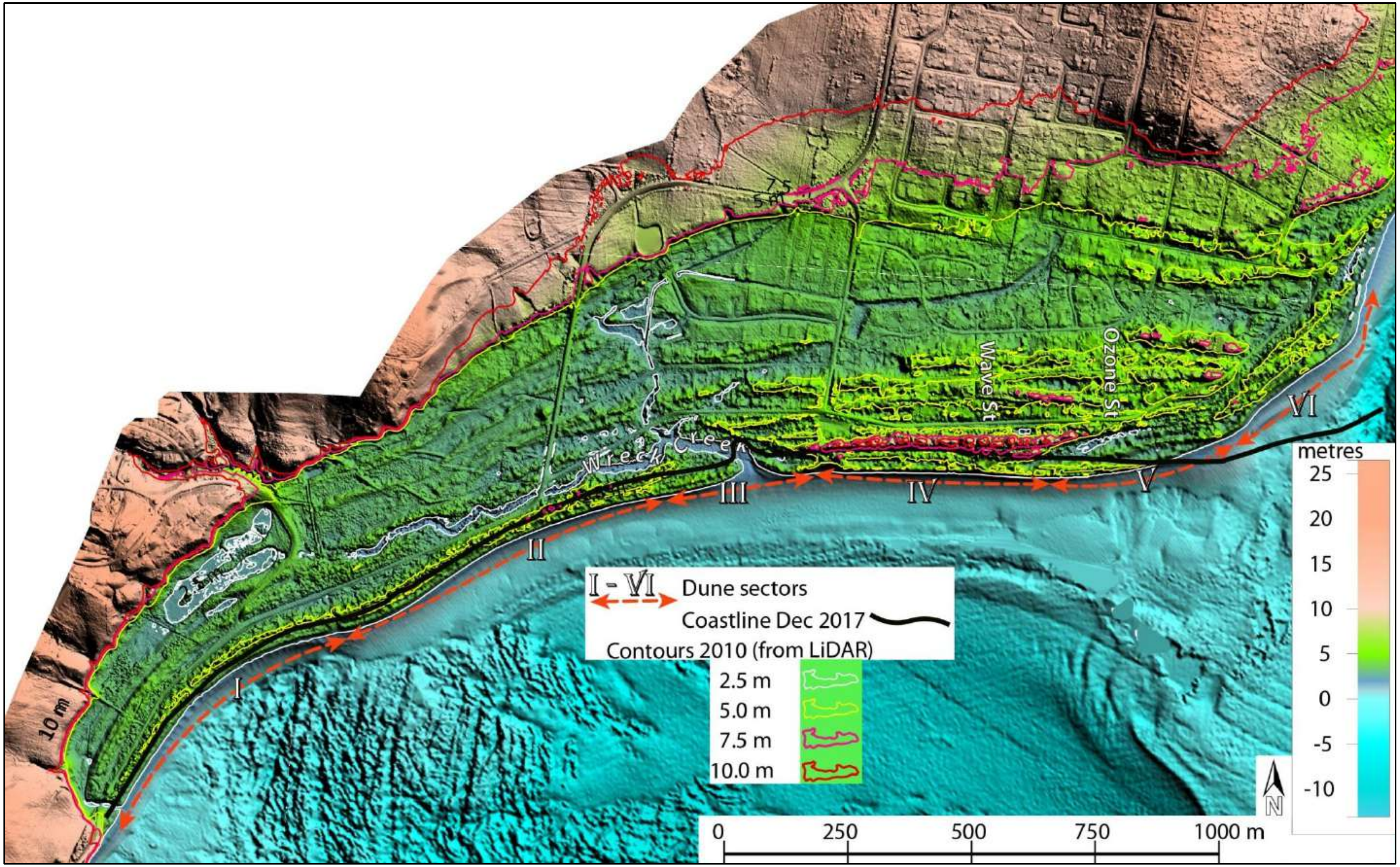


Figure 16. Foredune sectors along the Inverloch coast east of Flat Rocks. (For explanation of sectors see text).

- Foredune vertical accretion along this sector is limited due to the southeast aspect of the shoreline reducing the frequency of onshore dune-building wind

3.5.1.2 Sector II: Flat Rocks

- Sector **II** extends east from the beach access to west of Wreck Creek
- The zone of Holocene dunes is wider and slightly higher (up to 7.5 m) than in sector 1.

3.5.1.3 Sector III: Wreck Creek

- Sector **III** extends for 300 m across the mouth of Wreck Creek (Figure 17)
- The terrain is a complex of low curving ridges and hummocks due to the shifting position of the mouth of the creek
- The predominant easterly longshore drift results in extension of recurving barrier spits across the estuary mouth and erosion of the older higher dune ridges to the east towards the Surf Club building

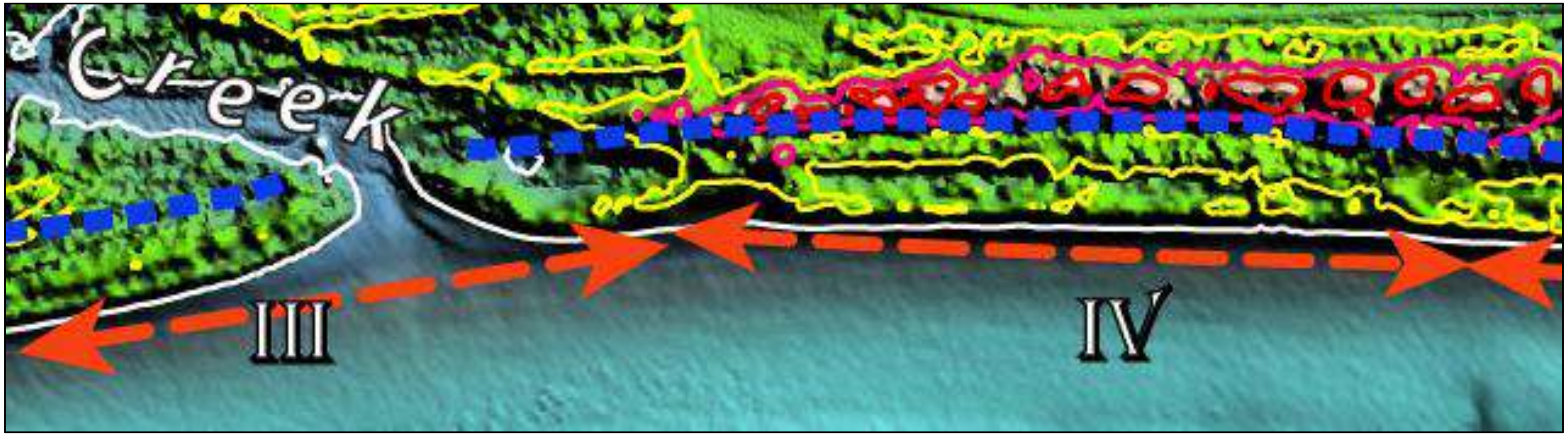


Figure 17. Sector III and Sector IV. Broken blue line shows position of high water marl in December 2017

3.5.1.4 Sector IV Surf Club

- Sector **IV** extends 400 m east from the Surf Club building to approximately midway between Wave Street and Ozone Street (Figure 17)
- Prior to 2010 this sector had developed three parallel dune ridges with the highest reaching 12 m

- Since 2013 the two seaward ridges have been eroded leaving a high scarp on the remaining dune in front of and east of the Surf Club Building

3.5.1.5 Sector V: Ozone Street to Point Norman

- Sector **V** extends 450 metres from midway between Wave Street and Ozone Street to the parking area beside Surf Parade 280 km northeast of Ozone Street (Figure 18).

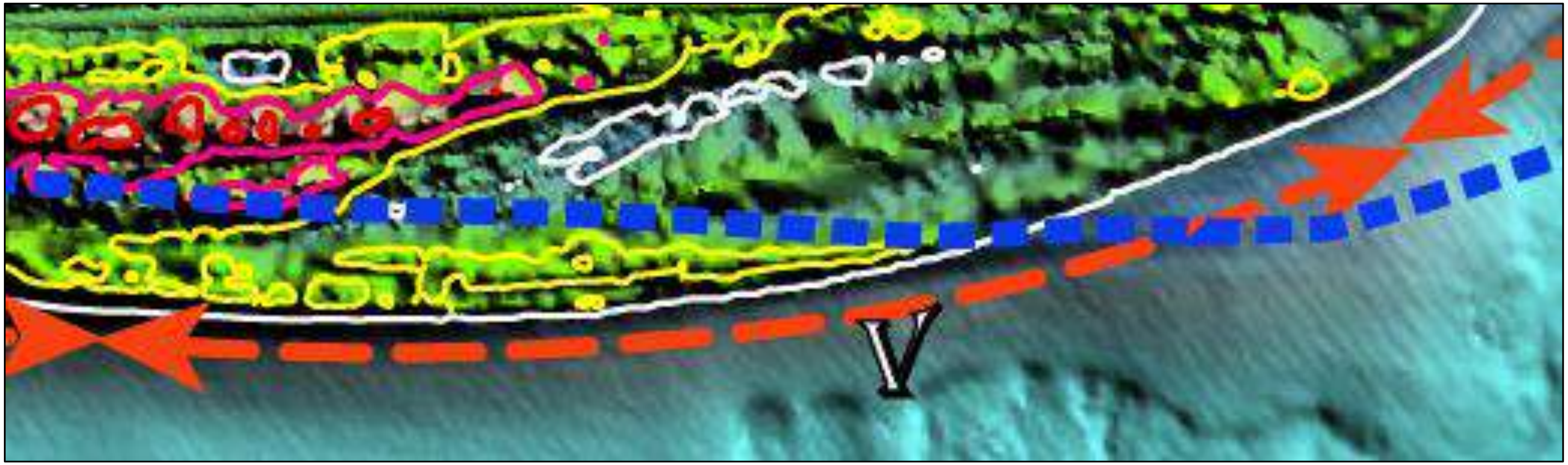


Figure 18. Sector **V** Ozone Street to Point Norman. (LiDAR base 2007 with 2017 shoreline shown by broken blue line).

- This is a highly dynamic coast with episodes of shoreline recession and accretion recorded in aerial photography from 1950 to the present day
- Details of changes are described in Section 5.2.3 (pages 41 - 44) below

3.5.1.6 Sector VI: Point Norman to Point Hughes

- This sector includes the spits, barrier and foreland that have dev eloped since 2012 and are described in Section 4.2 (pages 32-34) below.

3.6 Coastal Terraces - Andersons Inlet

- Three flat to gently sloping surfaces between 1.0 m and 6.0 m above sea-level surround the middle reaches of Andersons Inlet (Figure 19)
- They contain sediments deposited in different environments (Li *et al.* 2000) between 120,000 and 4,000 years ago
- The oldest sediments in Terrace T3 (±120,000 years) are 6.0 m above present sea-level on the north of Andersons Inlet
- This is the Last Interglacial high sea-level surface - equivalent to the formation of the bluff north of Wreck Creek
- Terrace T2 is dated at 7,000 to 6,000 years and at 2.0 m above present sea-level is a mid-Holocene higher sea-level deposit. The terrace sediments and dates show that the Point Smythe barrier is a Holocene feature.
- T2 is limited to an area east of Townsend Bluff
- Terrace T1 is dated at 5,500 to 4,000 years and at 0.5 m is widespread around both sides of the middle to upper Andersons Inlet.

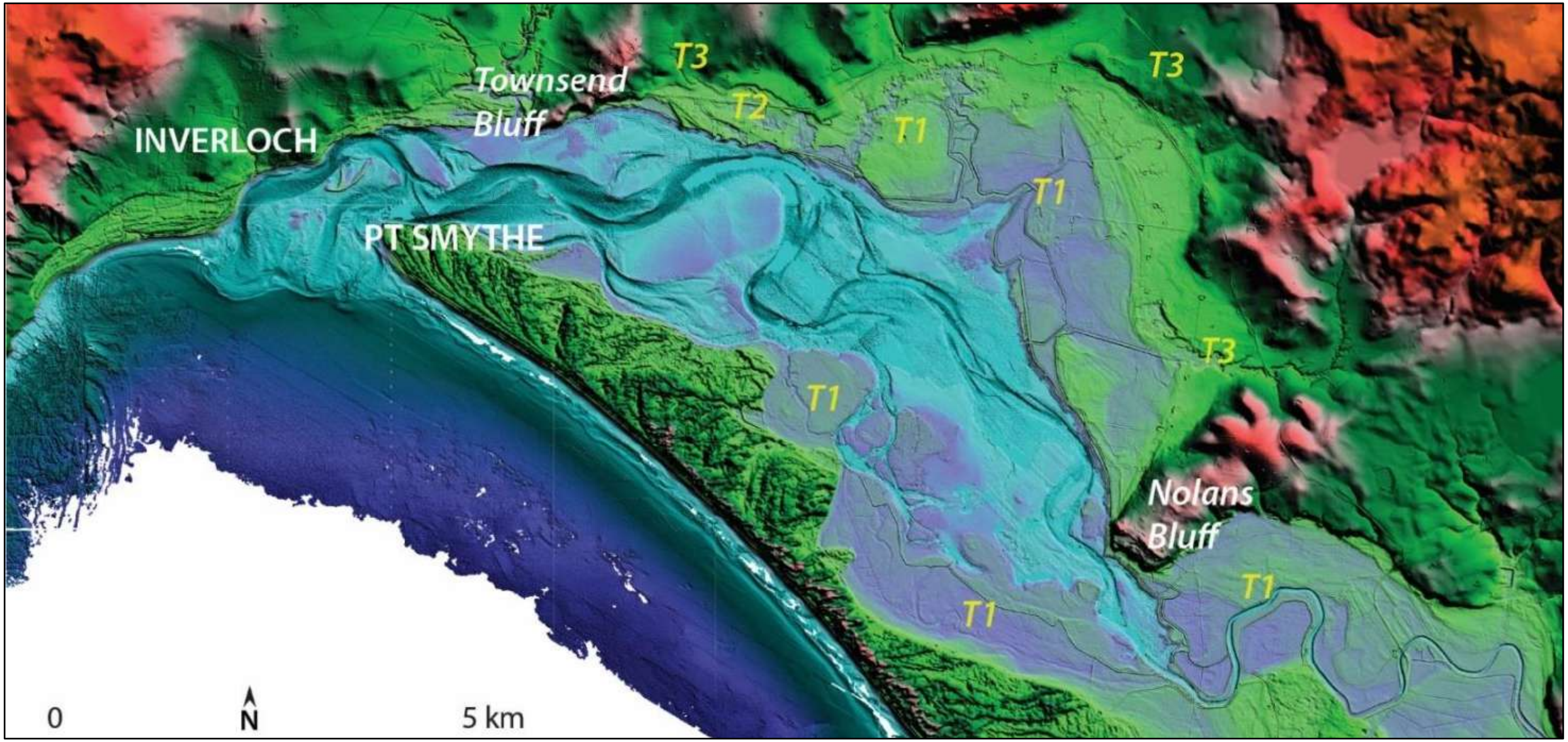


Figure 19. Terrace surfaces representing different depositional environments around Andersons Inlet. (After Li *et al. 2000).*

4 GEOMORPHOLOGY OF ANDERSONS INLET

4.1 Tarwin Embayment

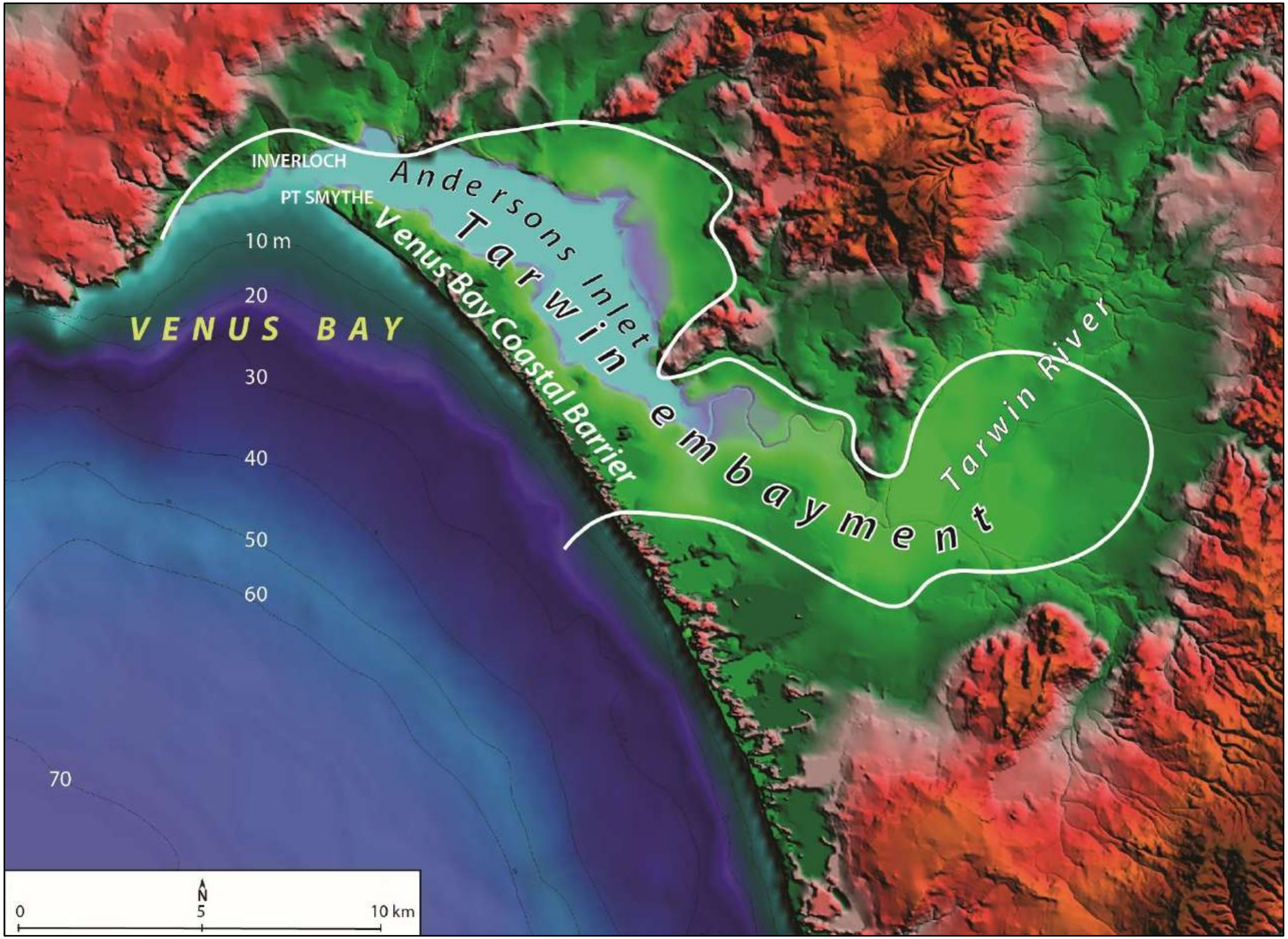


Figure 20. The Tarwin embayment and lower Tarwin River valley enclosed by the Venus Bay barrier. (From 10 metre Victorian DEM).

- Tarwin Embayment is a former open marine embayment opening SW from the lower Tarwin River valley (Figure 20)
- The north of the embayment is the coastal plateau of Lower Cretaceous sedimentary rocks around Inverloch
- The south embayment margin is the coastal plateau of Palaeozoic bedrock sloping to below sea-level south of Tarwin Lower
- The embayment is largely enclosed by Venus Bay Barrier - a 12 km long and sand body extending northwest from the Cape Liptrap plateau
- Carbonate and siliceous sand has been emplaced as a barrier spit migrating landward and northwest
- The sand is carbonate rich in the south and has been blown up by strong onshore wind from SW to NW as transgressive dunes onto the coastal plateau north from Cape Liptrap
- Blowouts in the foredunes have lengthened as transgressive parabolic dunes across the backshore for 00's metres to km inland.
- North of Tarwin Lower the present topography is a series of curving sand ridges built as a barrier spit migrating towards the north-northwest
- The sand has been moved by swash-derived longshore currents from SW and S swell waves.
- Refracted westerly swell waves around Cape Paterson have supplemented the sand supply and extended the barrier to the NW

4.2 Point Smythe

- The distal (far NW) end of the barrier is Point Smythe - the southern edge of Andersons Inlet entrance
- Point Smythe is composed of multiple curving ridges shaped by north-trending longshore drift (Figure 21)
- The spits are truncated by flood tide currents as tidal channels migrate south inside the entrance

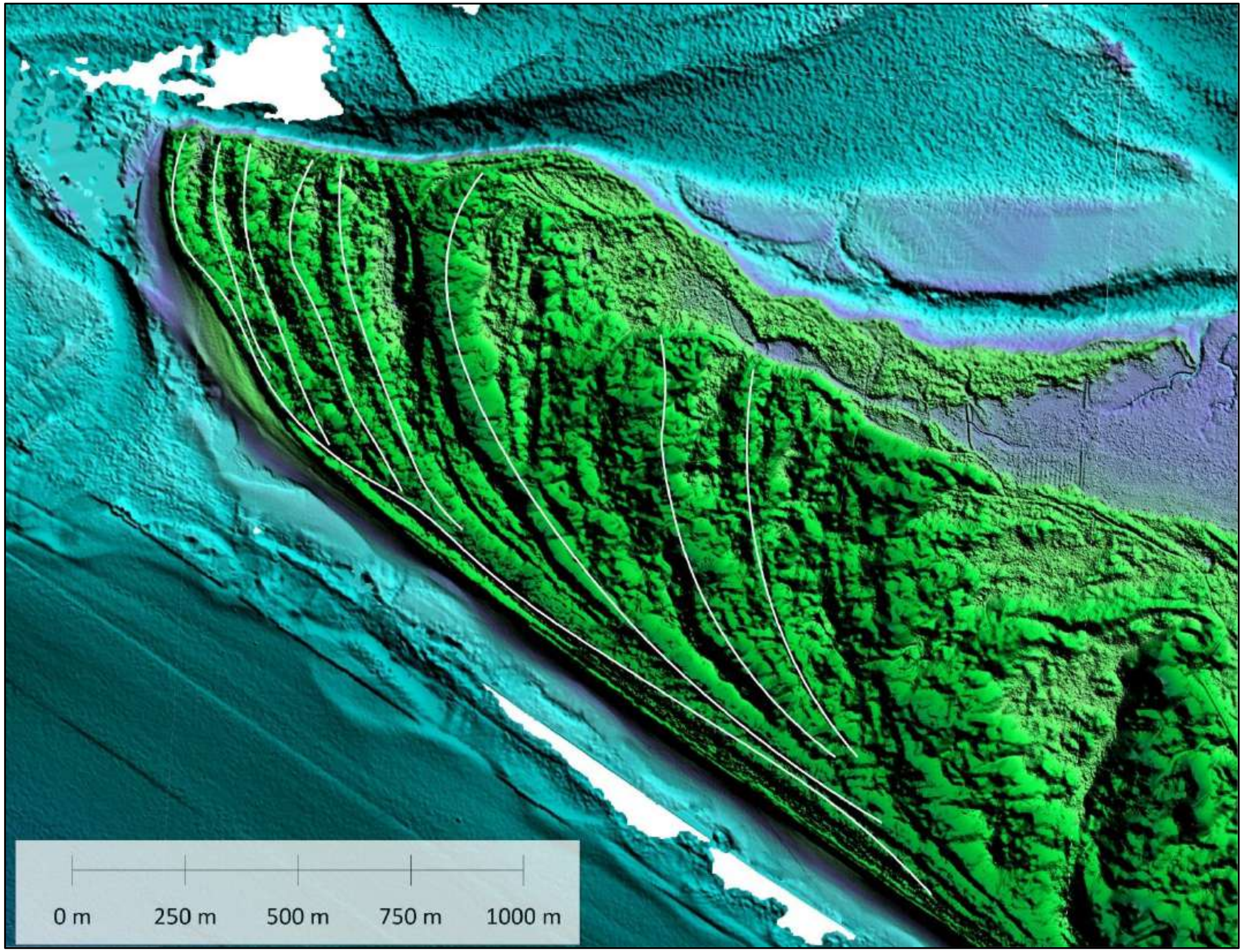


Figure 21. Multiple recurving sand ridges form the distal end of Point Smythe. Ridges are truncated at the northern end by flood and ebb tide currents.

4.2.1 Andersons Inlet Estuary

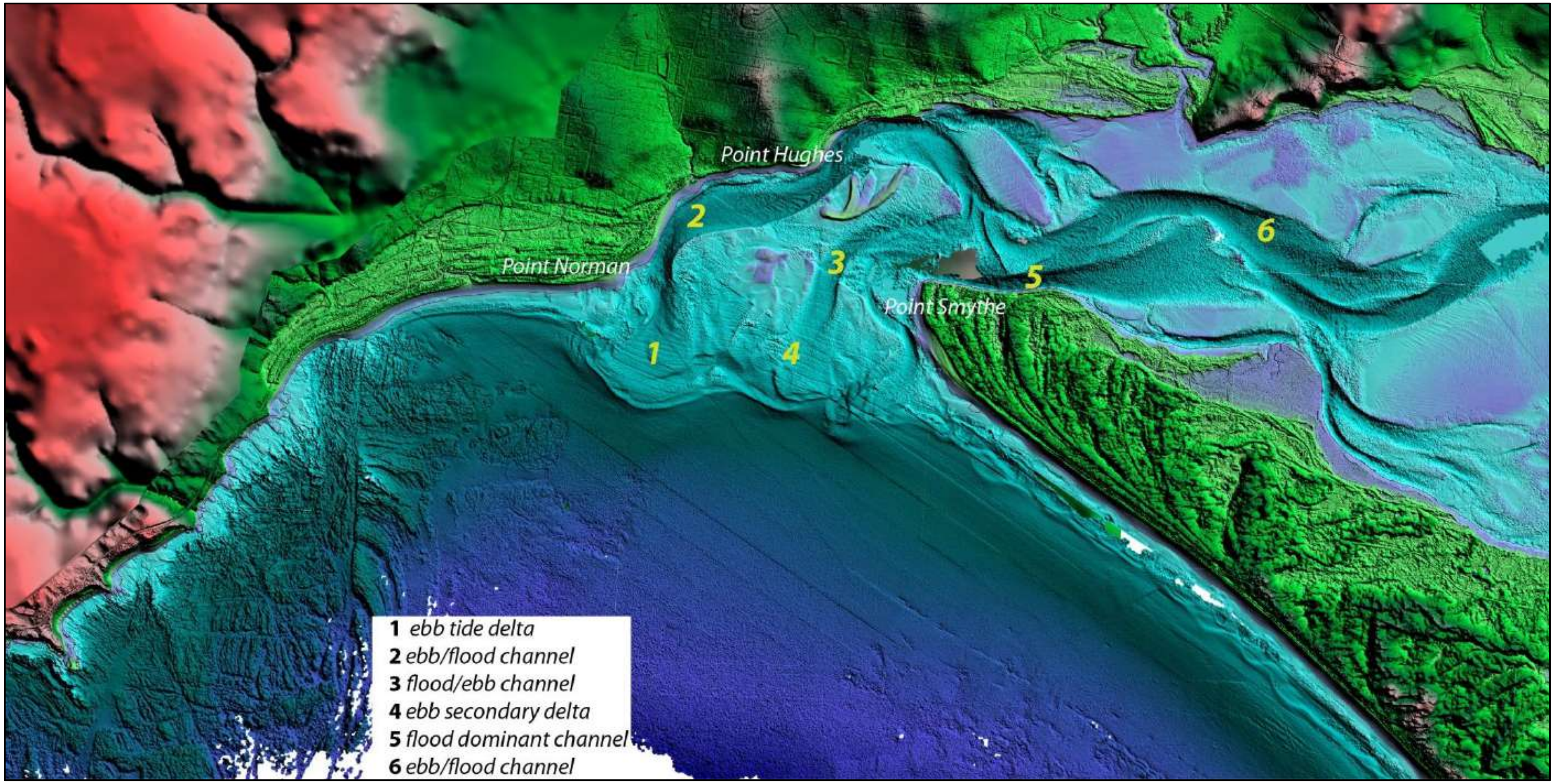


Figure 22. Ebb/flood channels and tidal deltas, Andersons Inlet recorded by bathymetric LiDAR 2010. The configuration in 2018 as recorded by a bathymetric survey is very different (Source: Coast LiDAR 2017 and Bathymetric LiDAR (2010).

- Andersons Inlet is the permanently open, tide-dominated barrier-enclosed estuary of the Tarwin River (Figure 22)
- The entrance is one of only three on the Victorian coast that has no record of closing
- Estuary has tidal length of 17.6 km from entrance to limit of tide penetration into Tarwin River channel
- The estuary has complex geomorphology with strong ebb and flood tide currents in a network of shifting channels (Figure 23)

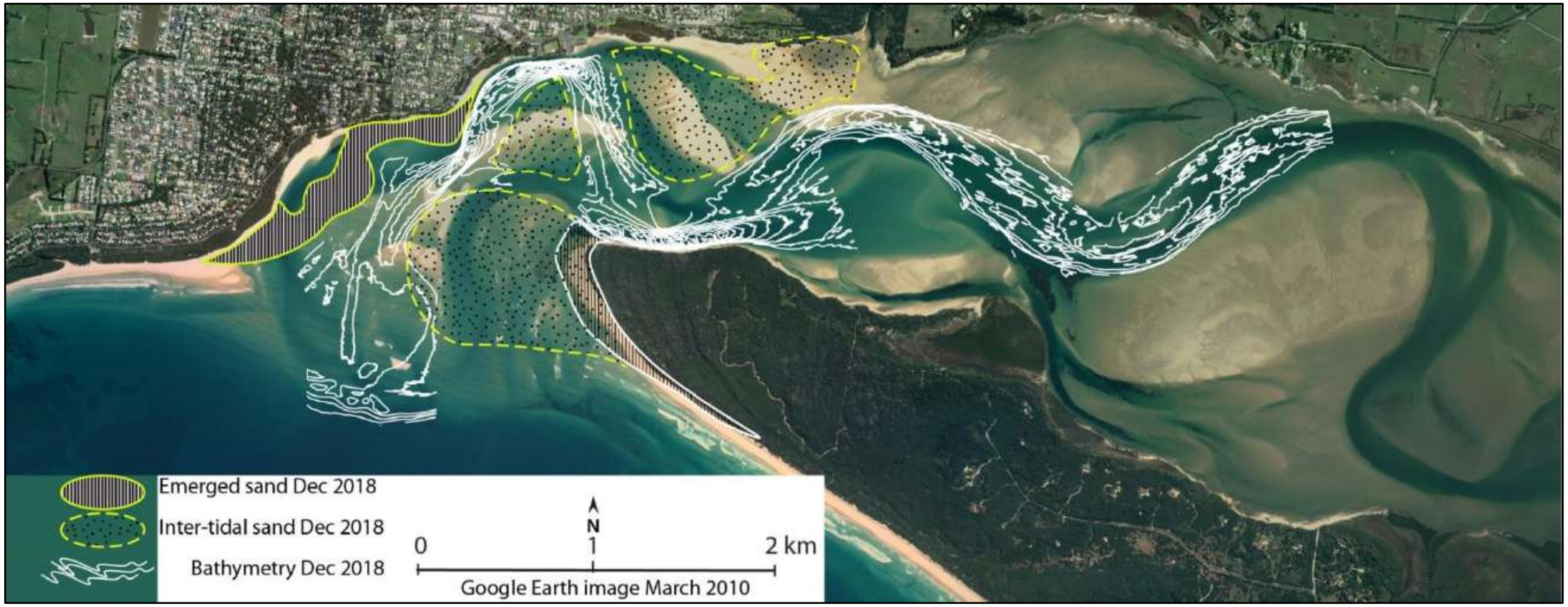


Figure 23. Bathymetry and intertidal sand bars and shoals 2018 overlay on 2010 Goole Earth image. Bathymetry from Gippsland Ports survey: Dec 2018)

- Mangrove and two species of the introduced *Spartina* are widespread across the middle and upper estuary
- Spread of *Spartina* since introduction in 1930's has reduced the area of open water in the inlet
- *Spartina* is widespread along southern shore and several mud islands
- Main areas of on northern shoreline are Pound and Cherry Tree creek mouths
- This has implications for tidal ventilation and the dynamics of tidal channels
- Substantial and rapid shifts in the location, width and depth of tidal channels is evident on aerial photographs and bathymetric surveys (Figures 24 - 26)
- The most obvious movement since 2010 is the migration of the main channel to the east in response to—or as a partial cause of—the growth of the sandy foreland between Point Norman and Point Hughes

Figure 24. Physical change in Andersons Inlet 1950 (aerial photo - Adastra Airways) and December 2019 (Google Earth).

Figure 25. Ebb tide delta and channels 2010 and 2018. Multiple ebb-tide channels in 2010 are replaced by a single ebb-flood channel in 2018. Lines join same point on both images (Google Earth)

- These changes are both a cause and consequence of accumulation and removal of subaqueous and subaerial sand bodies along the western sides of the entrance
- Physical changes at a range of time scales are to be expected due to:
    - High energy - wave and tidal currents
    - Unconsolidated sediment

4.3 Ayr Creek Barrier

- A now enclosed lagoon behind a looped and lobate sand barrier/spit
- Present configuration developed since 2013 (Figures 25 - 26)
- 2010: sand accumulated initially in as a spit extending SSE from the southern side of Point Norman
- 2014: spit began to recurve into Andersons Inlet moved by wave-currents augmented by flood tide current
- 2015: paired spit developing towards SSW from southern side of Point Hughes
- 2016: paired spits overlap and coalesce enclosing a lagoon - tidal washover frequently occurs
- 2017: coalesced spits form a continuous low tide coastal sand barrier linking Point Norman to Point Hughes
- 2018: rapid sand deposition as a lobate bulge extending E into Andersons Inlet
- Wind action builds hummocky dunes on the main southern foreland - pioneer grasses and now shrubs establish (Figure 27)

The rapid development of two spits forming a continuous barrier between Point Norman and Point Hughes results in the migration of the main tidal channel to the east and enclosing of the mouth of Ayr Creek forming a lagoon.

(Google Earth images 2010 to 2014)

Figure 26. Sand accumulation at Point Norman enclosing the outlet of Ayr Creek creating a lagoon (Google Earth 2013 -2018).

Figure 27. Pioneer species and dune plant succession on newly deposited incipient foredune sand south of Point Norman (Feb 2019).

5 SHORELINE CHANGES: FLAT ROCKS TO INVERLOCH (SURF BEACH, POINT NORMAN, AYR CREEK, POINT HUGHES)

A key task in this study as outlined in the study brief from the South Gippsland Conservation Society is to:

"Develop a chronology of shoreline change and identify episodes of shoreline recession and progradation, including the period since 2013".

Mr Tony Miner (AS Miner Geotechnical) in collaboration with the present author prepared the following response.

5.1 Introduction

- Previous studies of changes in shoreline position along the Inverloch coast were reviewed:

  G.Byrne: Vantree Pty Ltd. (2000). "Inverloch Foreshore. Coastal Process Assessment. Final Report" March 2000.

  Oldfield Consulting Australasia (2011). *"Wave Erosion and Storm surge at Abbott Street, Inverloch Foreshore Reserve. An investigation into Management Options."* Report to Bass Coast Shire Council. February 2011.

  Water Technology Pty Ltd (2016) *"Geomorphic & Ecological Investigation between Western St and Cape Paterson- Inverloch Road, Inverloch"* March 2016.

  Riverness Pty Ltd. (2018). *"Ayr Creek Lagoon Investigation and Option Analysis".* 20 August 2018

  GHD Pty Ltd (2018). *"Inverloch Coastal Protection Options DRAFT Advice".* September 2018.

  Department of Environment, Land, Water and Planning, Victoria (2017). *Inverloch Coastal Erosion - Historical Erosion events.* Aerial photograph 2017 Flat Rocks to Ozone Street with shoreline position overlays 1985, 1991, 2006, 2008, 2012, 2013, 2014, 2015, 2017).

- Historical charts and plans and vertical aerial photographs from varied sources were georectified and compared with the most recent imagery:

  George Douglas Smythe (1848) *"Survey of the coast from Cape Paterson to Cape Liptrap with Andersons Inlet-Tarwin River, Lakes, creeks, swamps scrubs marshes and Ranges"*

  Lieutenant H J Stanley (1868-69) *Cape Wollamai to Cape Liptrap Coast Survey*

  "Geological Quartersheet t0013_76SW-31. County of Buln Buln" 1903 Geological survey of Victoria

Vertical aerial photographs (various sources) from the following years: 1950, 1956, 1968, 1977, 1881, 1985, 1991, 2006, 2008, 2012, 2013, 2014, 2015, 2017

- The discussion has subdivided the coast from Flat Rocks to Townsend Bluff into three main geomorphic domains and the following sections summarise change as presented in key reports and data sources which include:

5.2 DOMAIN 1: Flat Rocks to Point Norman incorporating Cape Paterson-Inverloch Road and Inverloch Surf Club and Main Beach

- The earliest known mapping and depiction of the coast is the 1848-49 survey by George Smythe. The shore platform at Flat Rocks is shown prominently before a long sweeping sandy coast up to a less prominent depiction of the rock outcrop/shore platform at Point Norman (Figure 28).

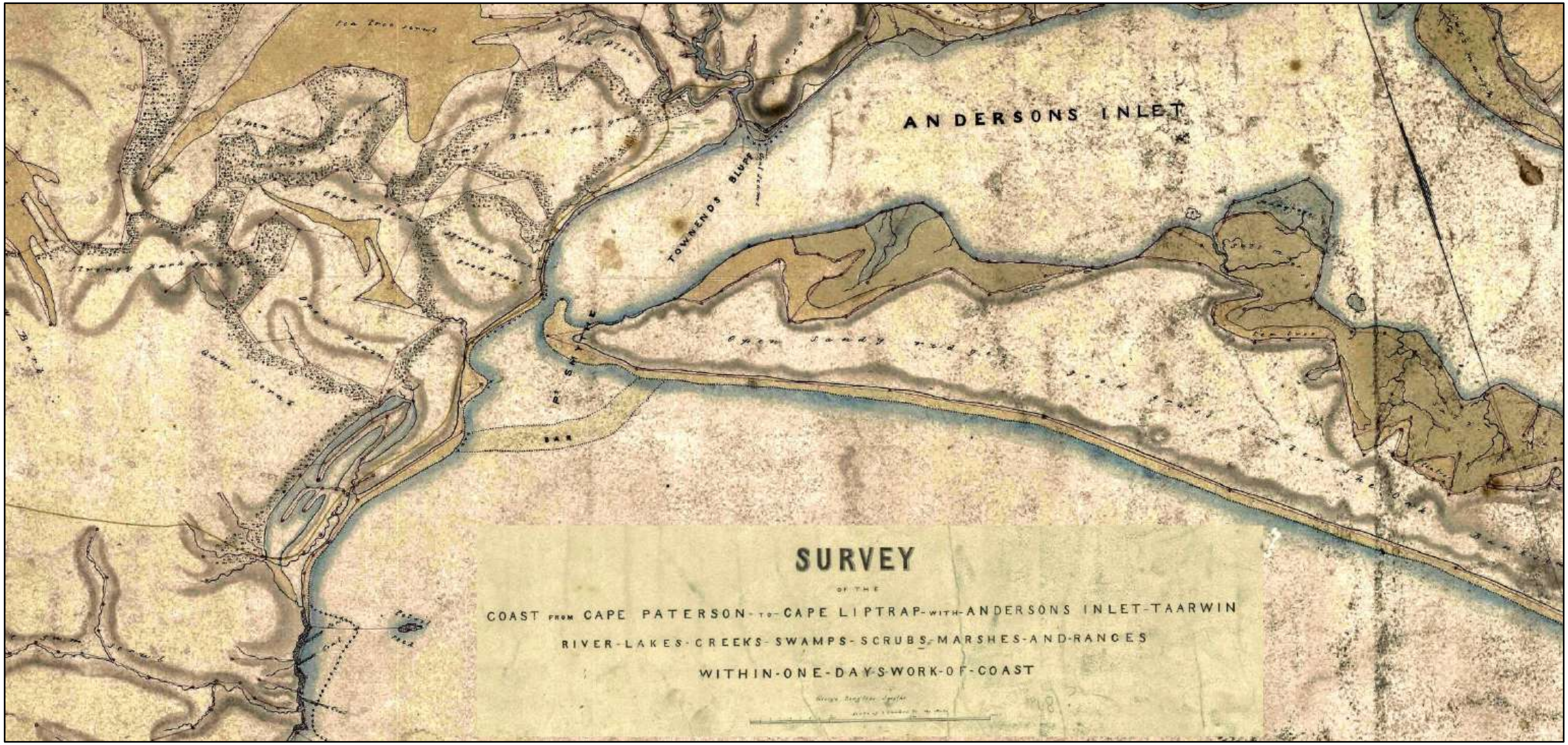


Figure 28. Extract from Coast Survey by George Smythe 1848-49.

- A coast survey from Cape Wollamai [*sic*] to Cape Liptrap by Lieutenant H J Stanley in 1868-69 shows details of the shore and soundings including Andersons Inlet (Figure 29).

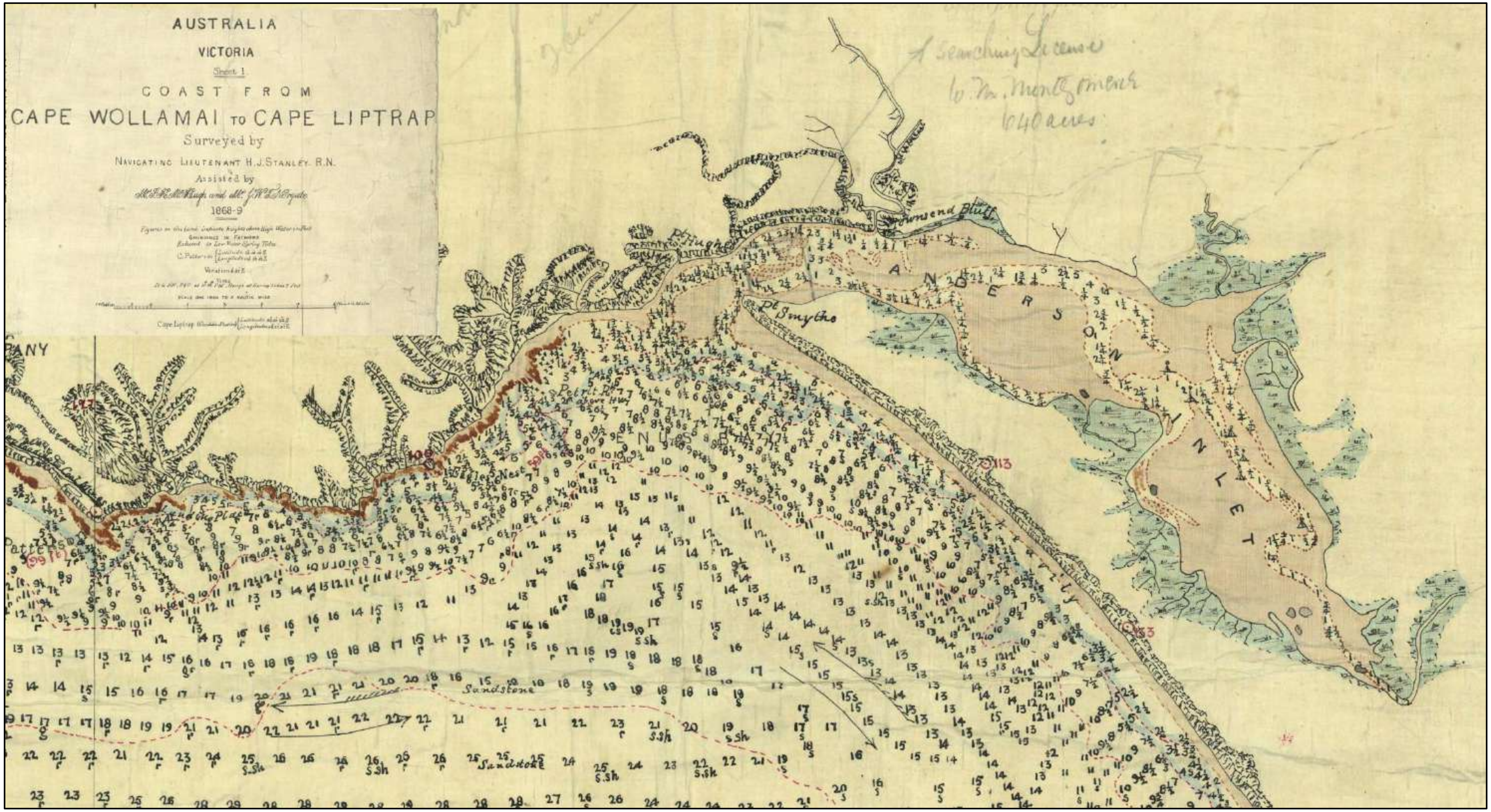


Figure 29. Extract from coast survey by Lieutenant H J Stanley 1868-69.

- The Stanley map show the entrance open with tidal channels on both sides of the entrance.
- The geological Quarter Sheet 76SE (Ferguson 1909) shows a shore platform at Flat Rocks with a limited length of sandy backshore and a prominent depiction of “massive sandstone” shore platform at Point Norman (Figure 30).

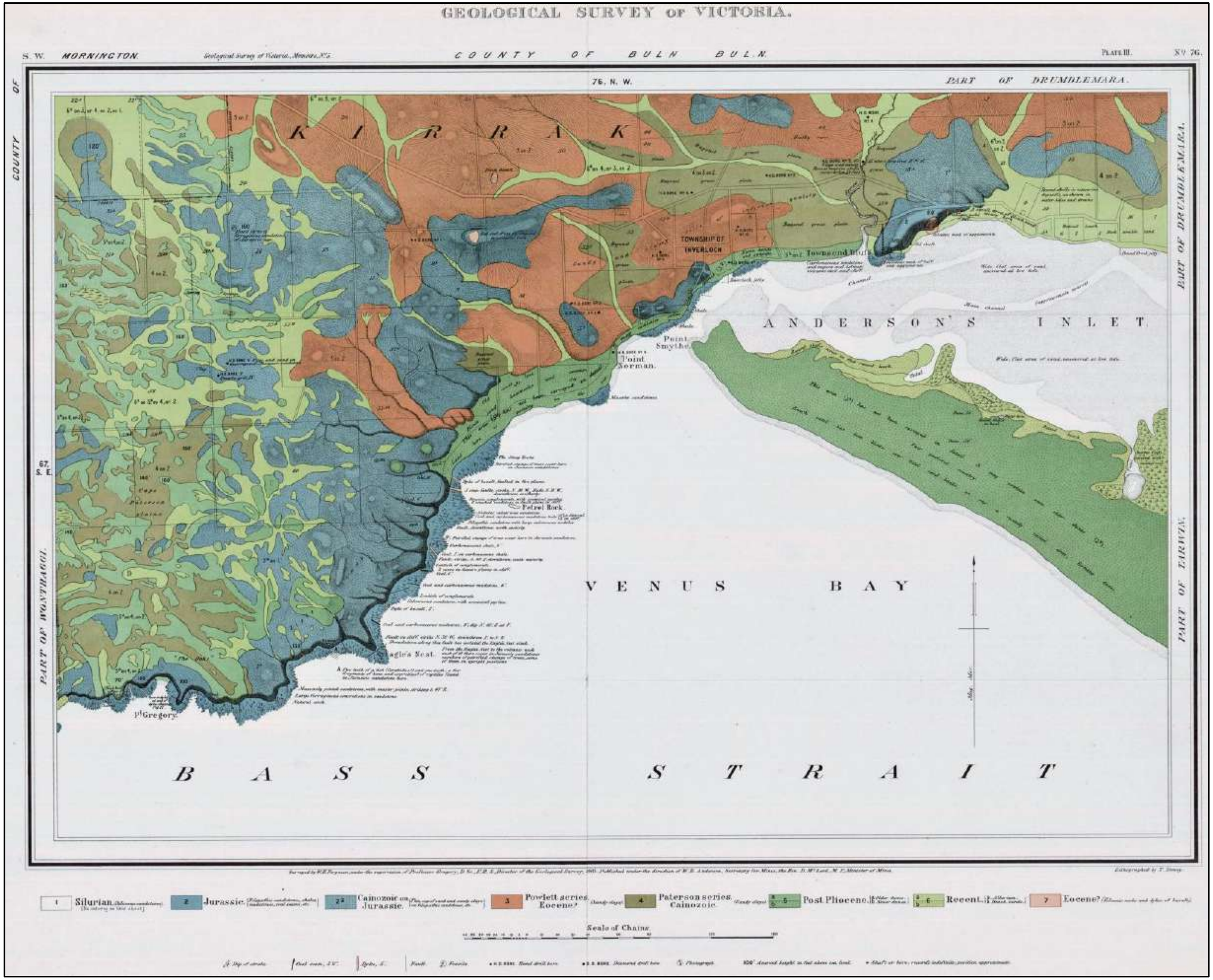


Figure 30. Geological Quarter Sheet 76SE (Ferguson 1909)

- The comment on the map *"land here is gaining on the sea"* between the two shore platforms suggests the surveyor had the perception that this was an accumulating coast at the time of field observations (1903).
- The earliest aerial photograph (1950) shows the shore platform at Flat Rocks and then a broad sandy beach to Point Norman where the rocky shore platform is almost completely covered in sand (Figure 31).

Figure 31. Extract from aerial photo mosaic 1950 (Adastra Airways).

- The buffer between the Cape Peterson -Inverloch Road and the edge of visible vegetation is similar to the current conditions although aerial photographs between 1960 and 2010 indicate a much wider strip of vegetation. Mature coastal banksias have been a feature of the Flat Rocks section of dune vegetation until their removal since 2012 due to coastline recession.
- Qualitative and quantitative assessments of shoreline change in this geomorphic domain based on a review of available aerial photos have been made in a number of key studies and include the following comments:

5.2.1 Flat Rocks to Wreck Creek

- The high water mark at the base of the vegetated dune here represents the closest approach of the erosion escarpment to any road at Inverloch (May 2019)
- No previous historical assessment of this specific stretch of the coast until GHD (2018) who covered only the period from Mar 2006 to Aug 2018
- GHD commented: "At the western end of the beach near Cape Paterson-Inverloch Road the coastline has retreated 36 m over 7 years, with an average rate of 5m/yr and a maximum rate of approximately 10 m/yr
- Significant erosion was noted to commence from sometime between Jan 2012 and Jan 2014

5.2.2 Wreck Creek

- The mouth of Wreck Creek has generally migrated east under the influence of eastward drifting sand (Bird 1993)
- The mouth of the creek is intermittently closed with flows from the creek keeping it open and deposition of sand from wave action periodically causing closure
- Migration of the creek mouth to the east has been halted with the construction of a rock revetment on the eastern side
- Based on aerial photograph analysis, the alignment of Wreck Creek has not changed significantly from 1968 to 2014 (Water Technology 2016), although the width and height of the enclosing barrier has changed alternately open-closed

5.2.3 Main Beach (Wreck Creek to Point Norman) including the Surf Club

- Water Technology (2016) reviewed historical aerial imagery between 1956 and 2014 and concluded there was little variation in the beach *alignment* along the western and central sections of Main Beach east of Wreck Creek
- Water Technology (2016) also noted that aerial photographs showed the seaward *position* of established vegetation over that period indicated episodes of shoreline recession and accretion of up to 65 m had occurred
- Episodes of shoreline recession with scarp development and subsequent accretion of ridges and hummocks are recorded in LiDAR imagery (2007) and successive aerial photographs (shown in Figure 32and Figure 33).

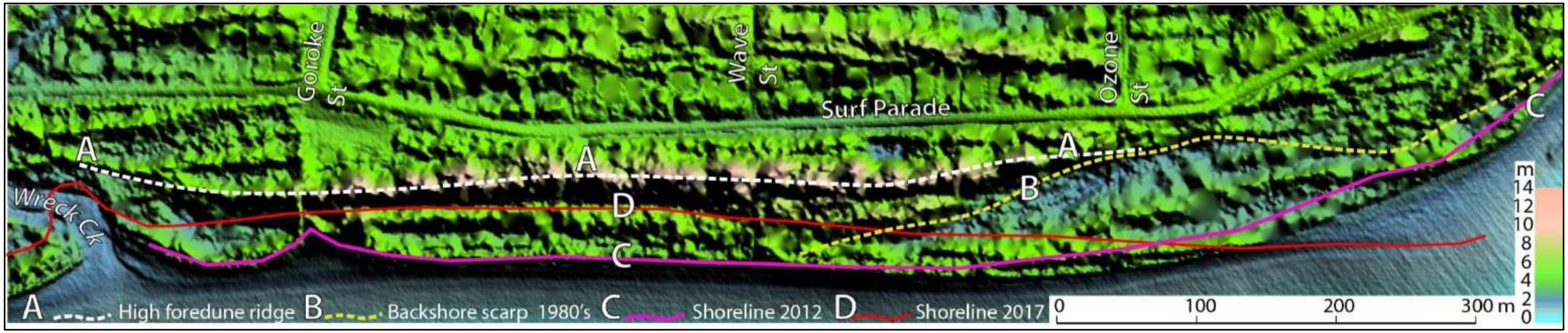
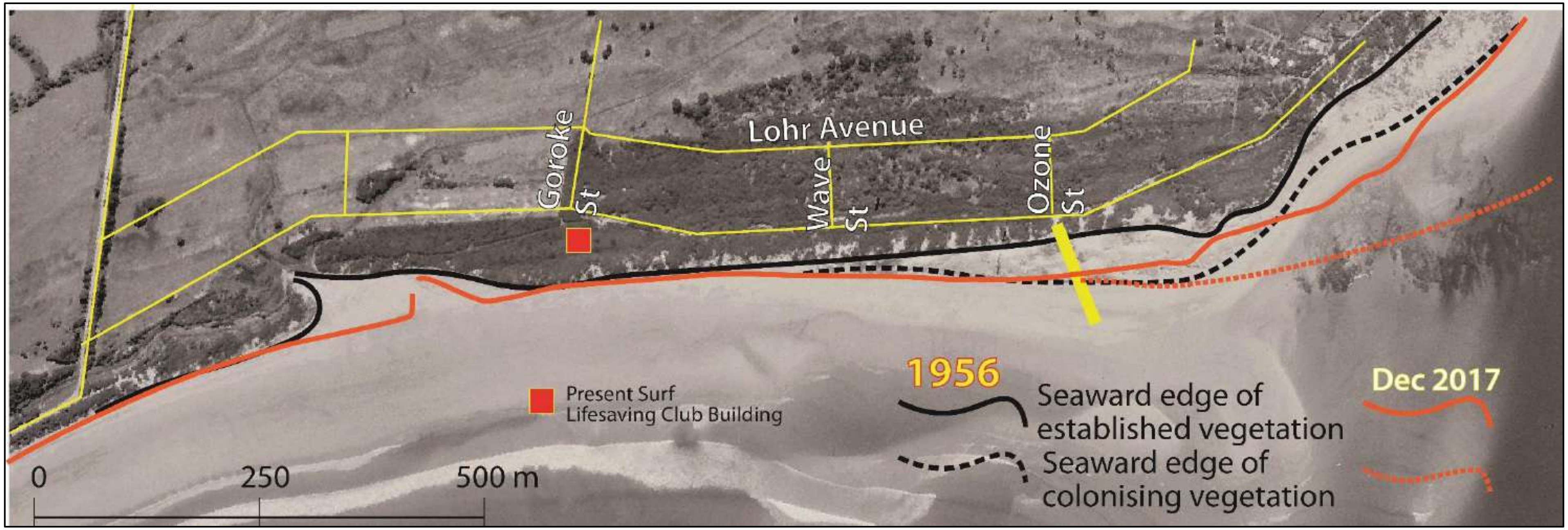


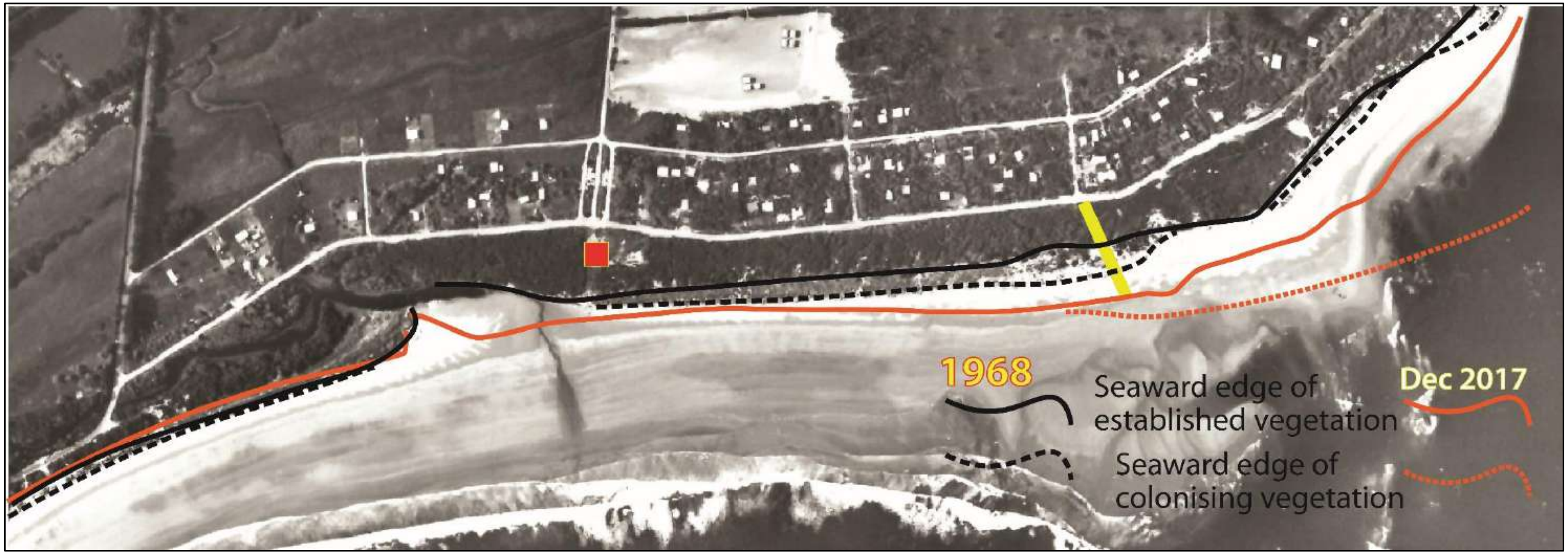
Figure 32. Episodes of shoreline recession and accretion are recorded in the ridges, scarps and hummocky dunes between Wreck Creek and Point Norman.

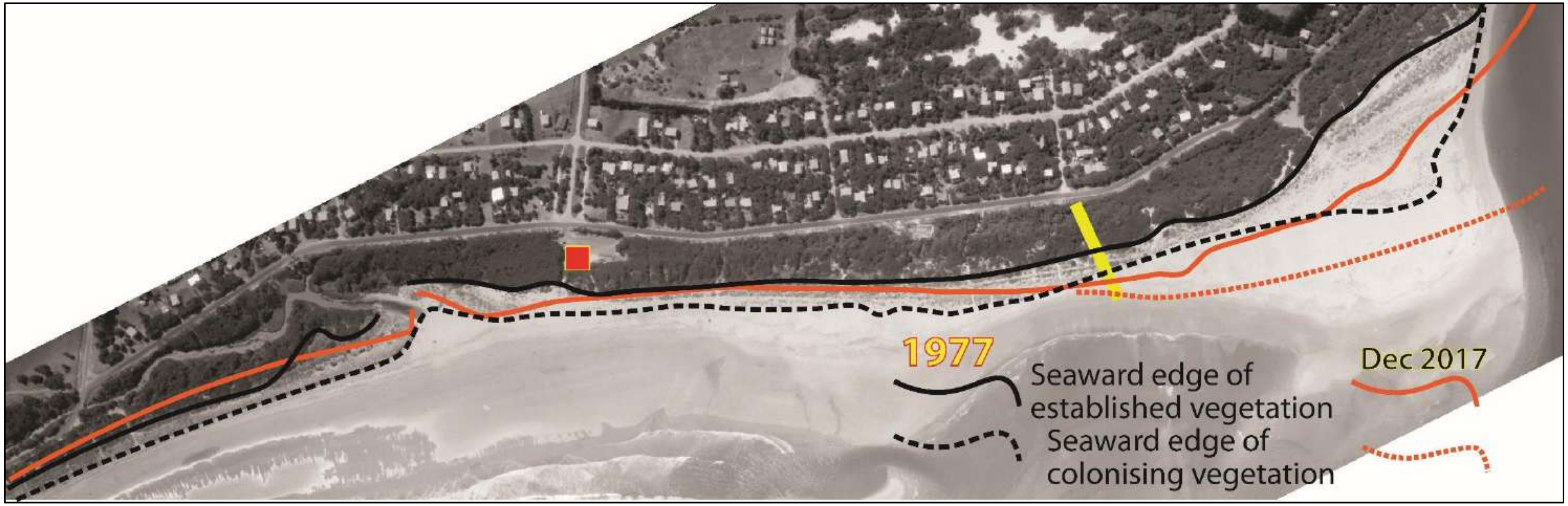
5.2.3.1 Ozone Street Recession and Accretion 1977 to 2017

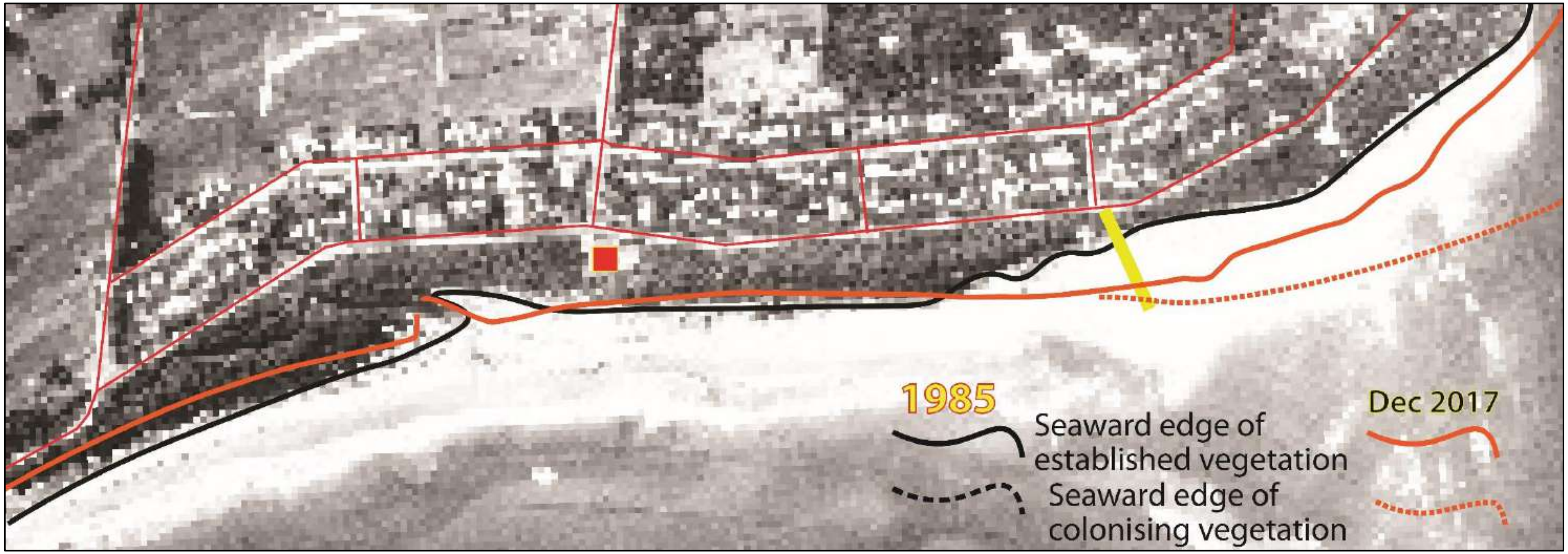
- The backshore east of Wreck Creek has a shore-parallel dune ridge extending 600 m east with a crest elevation between 8 m and 12 m above sea-level
- Significant recession occurred at Wreck Creek and adjacent to and east of Ozone Street track between February 1977 and September 1985 (vertical aerial photography, and see Figure 30 to 33)
- A sector of coast almost 500 metres long receded between 50 metres and 80 metres resulting in erosion of foredune ridges and developing a scarp over 5 m high in the high ridge at the backshore opposite Ozone Street (B on Figure 29)

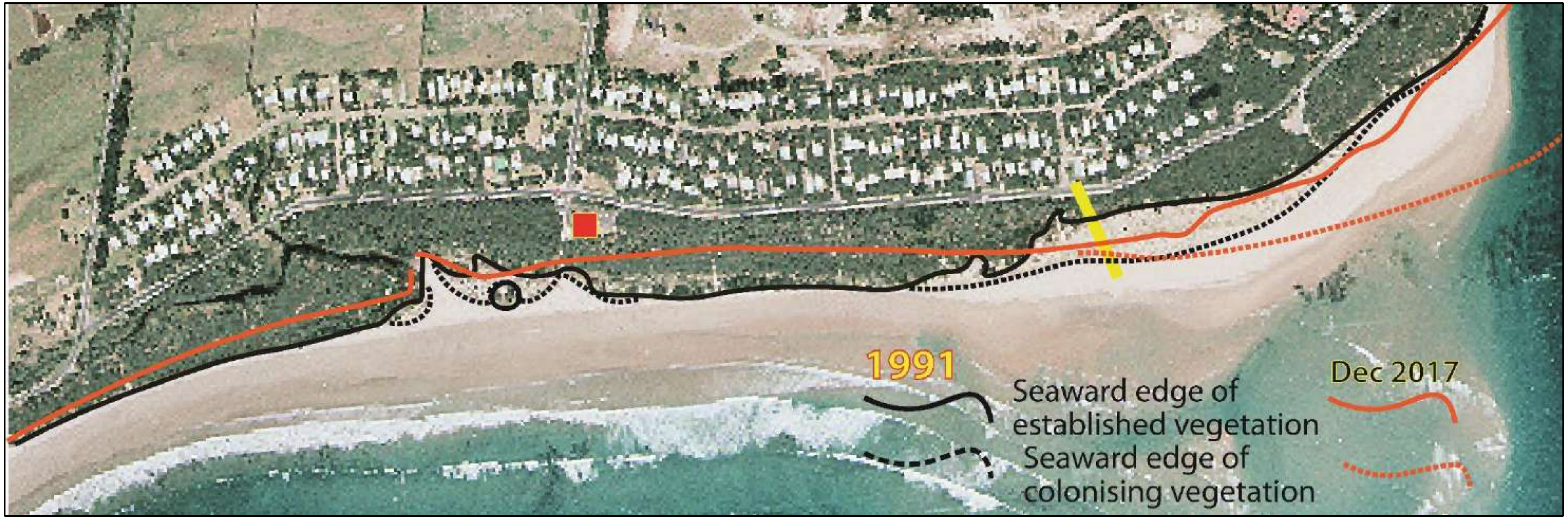
- The recession truncated the high dune ridge (A on Figure 29) and created a shallow embayment or bight between Ozone Street and Point Norman
- The bight was for a time in the late 1970’s to early 1980’s enclosed by a sand barrier and the resulting lagoon was deep enough for swimming (Dave Sutton *personal communication*)
- By 1985 the lagoon was filled with sand and by 1990 a vegetated foredune had accreted in a zone ~20 metre wide
- Accretion continued post-1990 and by 2006 the shoreline was back to the approximate pre-1977 position
- The shoreline between the Surf Club and Wave Street track was affected to a much lesser degree (DELWP aerial photograph ‘Inverloch Coastal Erosion - Historical Erosion Extents’) during these recession/accretion events
- The recession at Ozone Street between 1977 and 1985 was not accompanied by excessive sand accumulation at Point Norman or Point Hughes—in marked contrast with the growth of the forelands there since 2014
- Figure 33 (pages 45 to 49) is georectified extracts from aerial photographs 1956, 1968, 1977, 1985, 1991, 2006, 2012, 2014, 2017 with an overlay of the edge of established vegetation (woody) and pioneer colonising (grassy) vegetation


Goroke St
Lohr Avenue
Wave St
Ozone St
Present Surf Lifesaving Club Building
1956
Seaward edge of established vegetation
Seaward edge of colonising vegetation
Dec 2017
0
250
500 m


1968
Seaward edge of established vegetation
Seaward edge of colonising vegetation
Dec 2017


1977
Seaward edge of
established vegetation
Seaward edge of
colonising vegetation
Dec 2017


1985
Seaward edge of
established vegetation
Seaward edge of
colonising vegetation
Dec 2017


1991
Seaward edge of established vegetation
Seaward edge of colonising vegetation
Dec 2017


2006
Seaward edge of established vegetation
Seaward edge of ephemeral vegetation
Dec 2017


2012
Seaward edge of
established vegetation
Seaward edge of
colonising vegetation
Dec 2017


2014
Seaward edge of
established vegetation
Seaward edge of
colonising vegetation
Dec 2017

Figure 33. Shoreline changes at intervals 1956 - 2017 east of Wreck Creek and near Ozone Street, (Source: vertical aerial photography LandData Vic)

5.2.3.2 Recession East of Flat Rocks 2006 - 2018

- Analysis by Water Technology (2016 cited by GHD 2018) noted that in the middle part of the beach near the SLSC, the coastline has retreated by 43 m over 7 years (2012 - 2014) with an average rate of 6 m/yr and a maximum rate of approximately 10 m/yr
- This recession commenced in the period between Jan 2012 and Jan 2014 (Dave Sutton personal communication Jan 2019)
- The eastern end of Main Beach was noted by Water Technology to be highly variable with imagery showing large sand lobes at various locations and times over the period of assessment (1968 to 2014) with beach widths varying in places by over 100 m
- Generally there has not been a significant exposure of the shore platform at Point Norman that matches that depicted in the 1903 geological survey plan although there have been times where some exposure of rock has been evident in aerial photos (1991, 2009)

5.2.4 Comment: Domain 1

- Maps from the mid-1800's and aerial photographs from 1950 onwards shows shoreline position from Flat Rocks to Point Norman has varied considerably, but the current shoreline position between Flat Rocks and west of Wreck Creek and between the Surf Club to west of Ozone Street is at the most landward location recorded.

- The most significant recession recorded is in the sections between the Surf Club and Ozone Street, and From Flat Rocks to Wreck Creek
- These fluctuations include periods progradation of the foredune between 1968 and 1981 with evidence of colonisation by grasses from 2002.
- There are also periods of localised recession post-1981 - as is currently being observed where the rate has accelerated since 2013.
- Significant localised recession has occurred at Wreck Creek and adjacent to Ozone Street path, with other sections of main beach coastline largely unaffected
- <u>No cyclic pattern or trend should be inferred</u> from the historical analysis given ongoing uncertainty as to the factors involved in the process and the irregular intervals between aerial photographic monitoring.

5.3 DOMAIN 2: Point Norman to Point Hughes (mouth of Anderson Inlet)

- The Smythe (1848-49) map indicates rock exposed in shore platform at Point Norman and both west and east of Point Hughes
- The Geological Quarter Sheet (Ferguson 1903) shows a near continuously exposed shore platform from just east of the mouth of Ayr Creek to beyond Point Hughes and further east to the current location of the Bowling Club.

<u>Review of other reports indicates:</u>

- Based on early chart surveys of the mouth of Anderson Inlet (1868, 1890 and 1910) the backshore between Point Norman and Point Hughes was in a similar position to that in 1998 (Vantree 2000)
- The extent of sand however did show variation which suggests fluctuating cover over the exposed shore platform shown by Ferguson (1903)
- Based on a review of aerial photographs and charts provided in Vantree (2000)
    - Sand cover on the Point Norman shore platform appeared to be consistent from 1950 to 1979
    - Progressive loss of sand cover adjacent to Point Hughes from 1979 to 1998
    - The shore platform west of Point Hughes remained prominent in aerial photos until 2013

- Riverness (2018) noted that since December 2012 there has been a gradual change in the alignment of the main channel entrance of Anderson Inlet which has moved east(away) from the shoreline at Inverloch
- This movement coincides with the growth of the spits and foreland at Point Norman and Point Hughes
- Aerial photographs in November 2013 showed a large sand lobe forming at Point Norman which had increased in size and volume by November 2014 and was curving towards the shore near Abbott Street isolating the previous deep water tidal channel (Riverness 2018)
- What is now known as “The Ayr Creek Lagoon” became completely enclosed by December 2015 with a small overwash high tide connection to the inlet which was subsequently closed by April 2017 (Riverness 2018)
- Presently (March 2019) there is a large expanse of sand between Point Norman and Point Hughes with Ayr Creek lagoon totally isolated
- Maximum progradation of the shoreline of the order of 300 m has occurred between 2013 and March 2019
- Vantree (2000) noted that there does not appear to be any general build-up of sand near the mouth of the estuary although it was noted that there is a very large amount of sand that is moved around on sandbars and in the channels
- There is a temporal relationship between the position of the main inlet ebb-flood channel and accumulation of sand at the Point Hughes foreland
- This may in part be a function of the ebb-jet acting as a hydraulic groyne intercepting sand drifting east and south east across the inlet entrance
- During strong southwest swell and strong longshore currents, some sediment can be deflected into the inlet and accumulate at Point Norman initially as a spit
- During peak ebb flow sediment will be deflected offshore to nourish the subaqueous ebb tide delta
- Sediment in suspension during slack and reversing flood tide flow can be transported into the western side of the entrance to further nourish the Point Norman foreland.
- Flow in tidal channels is complex with reversing current directions and periods of slack water allowing deposition.
- Tidal channel meanders develop by a combination of properties of fluid flow and sediment deposition and entrainment by currents
- Meander migration may therefore be a cause and consequence of the development of the new forelands.

- As the sediment bed and suspended load in the lower inlet is sand rather than fines, responses to changed current direction and velocity are rapid as sand can be entrained and deposited more readily than is the case with muddy sediment.

5.3.1 Comment

- Oldfield (2011) specifically addressed an issue of coastal erosion on a 70 m length of coast prior to the formation of the Point Norman spit and enclosure of Ayr Creek lagoon
- Previous revetment works had been undertaken at the shoreline here and concern for ongoing erosion at this location had been expressed
- However since the formation of the lagoon, this area now forms the stable northern shoreline of the lagoon and is effectively isolated from coastal processes in the inlet
- The rapid and dynamic change in this location effectively places the Oldfield report as an important historical document
- Vantree (2000) noted that the area between Point Hughes to Townsend Bluff showed a trend of accumulation of sand on the northern shore of the estuary
- Riverness (2018) also noted the earlier formation and persistence from the early 1960's to early 1970's of what was known as "Toys Backwater", a spit-enclosed lagoon to the east of the present Bowling Club Domain 3
- Note that the area of erosion at Abbott Street coincides with the break in shore platform as detailed by Ferguson (1909)
- Such a break in the platform was also noted at the site of isolated erosion and subsequent revetment works in front of the Bowling club (see Section 6.4)

5.4 DOMAIN 3: Point Hughes to Townsend Buff

- Smythe (1848-49) did not map a shore platform on the coast between Point Hughes and Townsend Bluff but a prominent shore platform was depicted at Townsend Bluff
- The geological survey plan (Ferguson 1903) shows a very prominent shore platform between Point Hughes and Inverloch jetty at the location of the current Bowling Club

- A short break in the exposure is indicated before the platform continues to the east of the jetty for about 485 m
- The coast and backshore are then shown as sandy until Screw Creek and a very prominent outcrop and shore platform at Townsend Bluff.

Significant observations and comments from previous reports for this section of coast include:

- The sand spit-barrier that formed in the 1950's at and east of Point Hughes was stabilised with a rock revetment built to protect the Bowling Club
- Since then the sand has moved eastwards and sand barrier now reaches approximately 700 m east of the Bowling Club (Vantree 2000)
- Vantree (2000) stated that the build-up of sand on the northern bank appeared to be a long term trend as older sand ridges occur inland at and north of the caravan park
- It was postulated that these indicate an ongoing process where sand is accumulating along the northern estuary shore
- The 1950 aerial photos show significant sand in the estuary south of Townsends Bluff but there is still an exposure of shore platform there
- Aerial photographs of 2000, 2006, 2009, 2013 and 2017 do not show significant change in sand cover or shore platform exposure at Townsend Bluff
- There is a small net northward migration of the tidal channel south of Townsends Bluff since 1950 to the present

5.4.1 Comment

- The northern banks of Anderson Inlet between Point Hughes and Townsend Bluff show a longer term trend of accumulation with a number of evolving sand spits
- The configuration of the coast at Townsend Bluff and the extent of sand immediately adjacent in the inlet appear to have changed little over the past 70 years
- This observation plus the consistent location of the channel over many years suggest this is a relatively neutral point for change within the system.

5.5 Preliminary Estimates of Sand Volume - Gains and Losses: Flat Rocks to Point Hughes:

- Using data from recent studies (GHD 2018) and construction of shore-normal profiles (ASMiner Geotechnical 2019,) **an approximation** of the volumes of sand involved in the coastal changes between Flat Rocks and Point Hughes has been calculated
- GHD (2018) showed that at the western end of the beach near Toorak Road the coastline has retreated 36 m over 7 years, with an average rate of 5 m/yr and a maximum rate of approximately 10 m/yr
- Using vertical aerial photograph comparisons of shoreline position, Water Technology (2014 and 2017) and GHD (2018) showed that from 2006 to 2018 the middle part of the beach near the Surf Life Saving Club (SLSC) has retreated by 43 m over the seven years 2012 - 2018 with an average rate of 6 m/yr and a maximum rate of approximately 10 m/yr (GHD 2018).
- Tony Miner (ASMiner Geotechnical) used the data from the above reports combined with beach profiles derived from 2007 coast LiDAR (DNRE 2007) to calculate and compare the areas and volumes of sand removed from the areas of shoreline recession with the area and volumes of sand in the areas of accretion north of Point Norman between 2009 and 2017).
- The calculations take into account (a) the recession of the high water mark and (b) lowering of the beach profile in the intertidal area.
  - The area of recession (loss) of backshore dunes (above HWM) between Flat Rocks and Point Norman from 2009 to 2017 was determined to be 48,000 m^2 (28,000 m^2 Flat Rocks to Wreck Creek and 20,000 m^2 Wreck Creek to Point Norman)
  - The area of intertidal beach between Flat Rocks and Point Norman that experienced beach lowering between 2009 and 2017 was calculated as between ~76,000 m^2 and 102,000 m^2
  - The height (thickness) of beach loss across this area averaged 1.5 m
  - The area of accumulation (gain) between Point Norman and Point Hughes was determined to be 356,000 m^2
  - Using GHD (2018) profiles and checking with Propeller, the average height of the backshore dune recession (loss) between 2009 to 2017 was 3.5 m at Ozone St and 5.5 m at the Surf Club
  - Using the bathymetry (LiDAR) and some data from the Propeller project the accumulation (gain) of sand in front of Ayr Creek lagoon occurred in an average of 2.5 m depth of water (but up to 5.0 m deep in places)

- The present average AHD of the accumulation area was estimated at 1.5 m

From these models the following **very preliminary** volumes of sand movement are suggested

- **Loss of Backshore by Dune Recession: Flat Rocks to Point Norman = 28,000 x 3.5 + 20,000 x 5.5 = 208,000 m^3 (maximum)** (The amount would be less because the height of dune is lower at either end)
- **Loss of Beach by Surface Lowering: Flat Rocks to Point Norman = (between) ~114,000 m^3 and 154,000 m^3**
- **Total Loss of Sand (Beach and Backshore): Flat Rocks to Point Norman = (max) 208,000 + 152,000 = 360,000 m^3**
- **Gain: Point Norman to Point Hughes = 365,000 x (2.5 +1.5) = 1,460,000 m^3**
- An approximate figure might be **360,000 m^3 loss** compared with a gain of **1,400,000 m^3 gain** or a **factor of at least FOUR times** more sand gained than removed from the beach and backshore. We could at a later stage compare the 2007 LIDAR with the Propeller DSM but we cannot export the DSM out of the current access we have for Propeller
- **In summary, although the figures shown here are preliminary and based on limited data, it is concluded that significantly more sand has arrived in the area between Point Norman to Point Hughes between 2009 and 2018 compared with the potential loss from the backshore from Flat Rocks to Point Norman over the same period**
- Figures 34 and 35 (based on aerial photograph) show changes over the periods 2009 to 2018 and 1968 to 2018

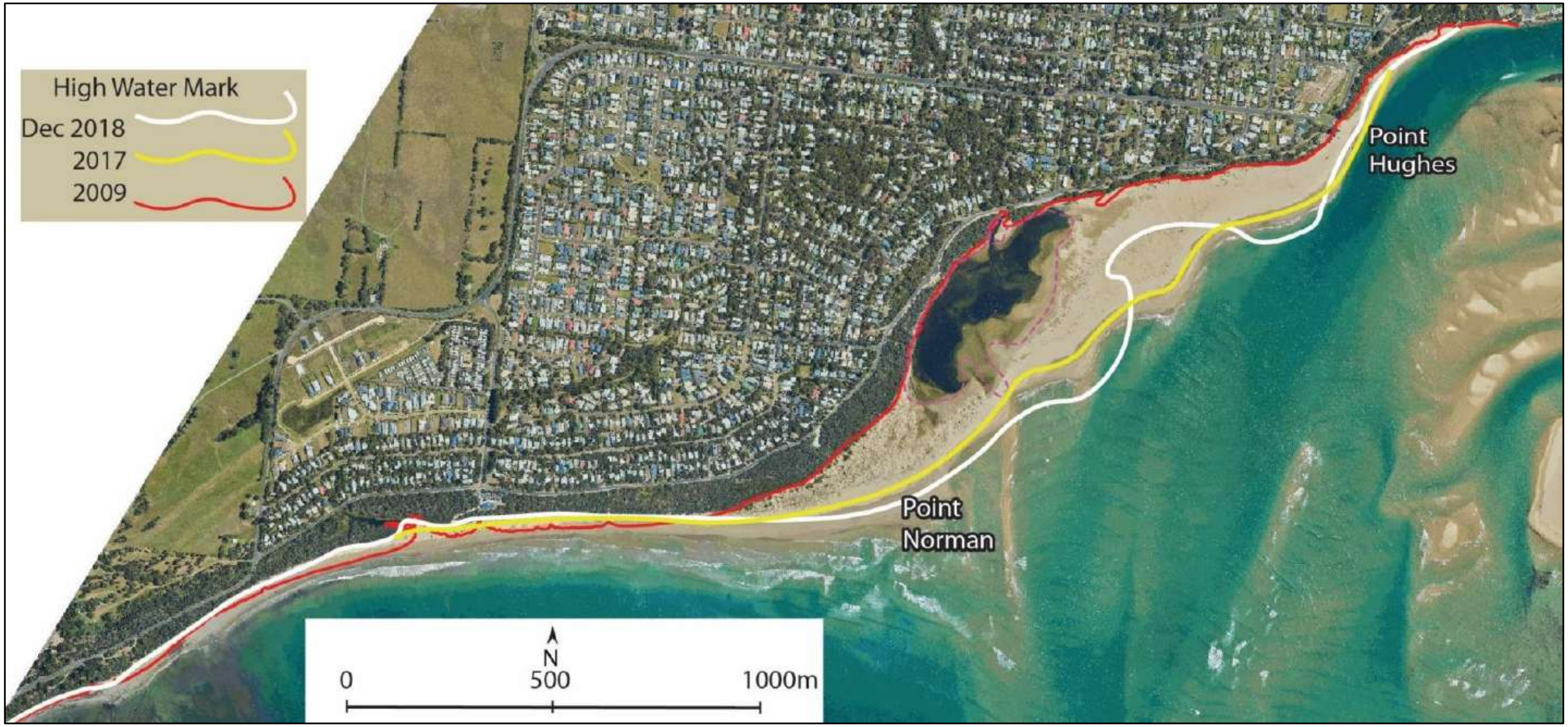


Figure 34. Changes in backshore position between 2009, 2017 and 2018. (2009 and 2017 from aerial photograph, 2018 Google Earth).

- Figure 31 shows the obvious visual (albeit superficial) comparison between the areas of loss and gain (it does not show the thickness/height of beach and backshore sand removal east of Flat Rocks nor the depth of infill and surface elevation of the accumulation area between Point Norman and Point Hughes.

Figure 35. Backshore position in 1969 (red line on both images) between 1968 and 2018. (1968 from aerial photograph, 2018 Google Earth)

5.6 Sources of Sand for Ayr Creek Barrier

- Shoreline recession between Flat Rocks and Point Norman is certainly a substantial source of sand for the Point Norman-Point Hughes foreland but cannot account for all of the rapid and substantial increase of sand accumulation between there and inside Andersons Inlet
- Other potential source(s) of the sand accumulation can be:

- On-going/accelerated discharge of Tarwin River

(Least likely source - insufficient stream discharge and sediment from Tarwin is silt rather than sand)

- Alongshore sources west of Flat Rocks

(This is unlikely as these are platform beaches isolated in embayments and there is no evidence of sand movement across the rock platforms)

- Stores inside Andersons Inlet closer to the entrance

(Possible that some has been reworked from the ebb-tide delta)

- Point Smythe beaches

(Probable source for eastern side of entrance rather than transferred west across entrance to Point Norman)

- Offshore sources - S, SE, SW

(Most likely sources are from the south to southeast - but see comments below)

- The nearshore region of Venus Bay includes shallow near-shore reefs and extensive areas of subtidal sandy sediment and patchy low-profile reef (Barton *et al.* 2012)
- In deeper water (>10 m) low-profile reef with sand sheets occurs and in 30+ m waters there is extensive rocky seafloor interspersed with sand sheets (Barton et al. 2012)
- Bare reef (without biota) extends across the mouth of Andersons Inlet as a sand-covered ledge sloping from 5 m to 15 m water depth (Figure 36)

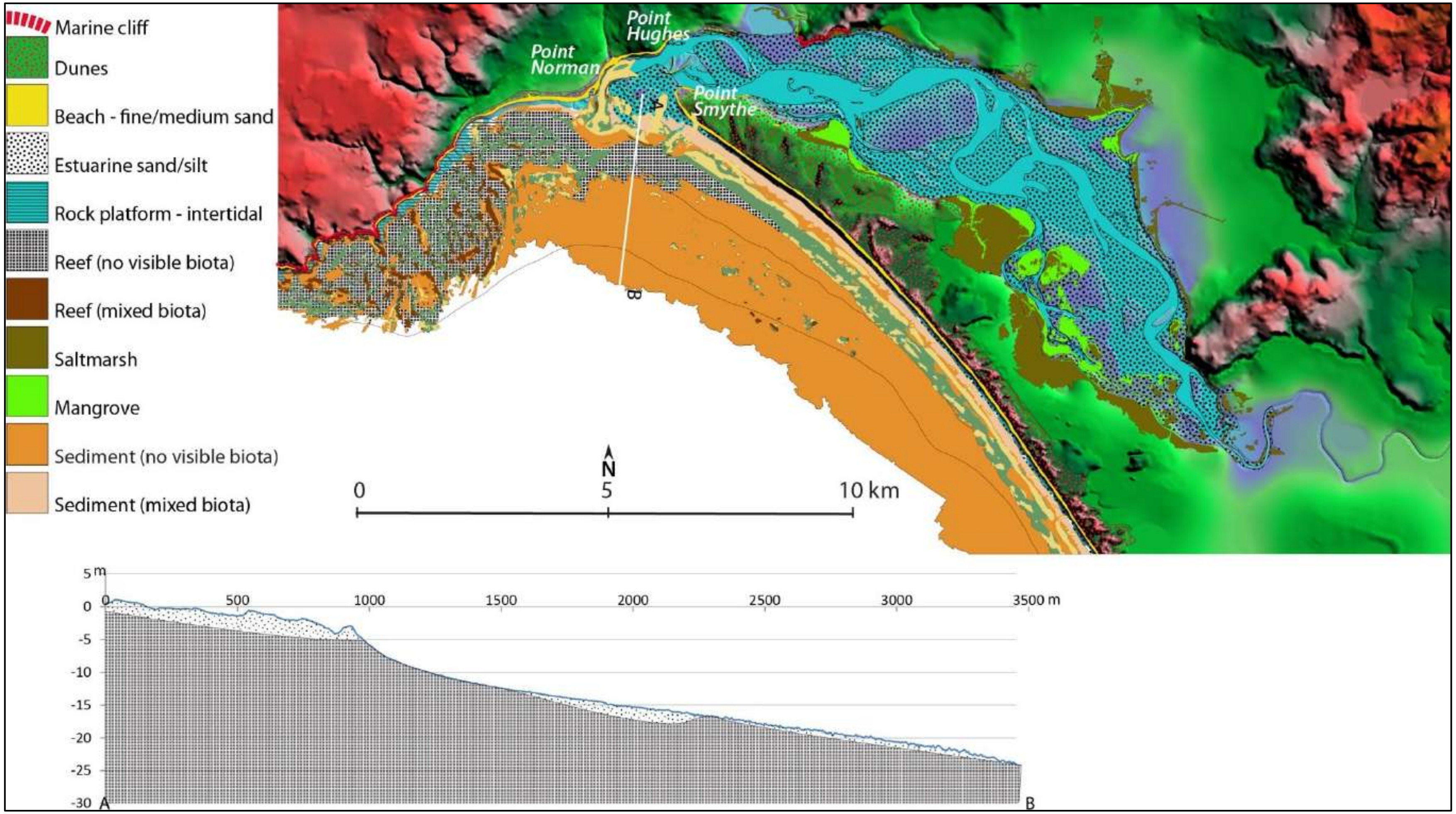


Figure 36. Seafloor materials (map and profile) northern Venus Bay. (Source: Deakin University)

6 FACTORS CONTRIBUTING TO SHORELINE CHANGES

A further key task in this study as outlined in the study brief from SGCS is to:

Identify the range of factors (including metocean conditions) that contribute to [shoreline] changes

6.1 What Shoreline Changes Have Occured at Inverloch?

6.1.1 Change of Beach Thickness Recorded by Profile Changes

- Beach profiles (thickness) change as sediment is transferred up and down and along/across the beach by waves, currents and wind
- This dynamic profile is referred to as the sweep zone
- Minor changes may occur between successive high and low tides but result in little net change over longer term
- Individual storms may cause rapid short-term recession followed by short-term accretion, leading to negligible net change over time scales of a few weeks-months
- Chronic or on-going lowering of part of the beach profile and backshore recession indicates a substantial change in beach and nearshore sediment dynamics
- Sand degraded from the beach by rip currents and strong backwash may be moved into deeper water and transferred alongshore
- Depending on local morphology, some of this may be returned alongshore or moved offshore and become detached from the local onshore-offshore transport system
- Sand moved from the beach by onshore wind is deposited backshore beyond wave action and becomes part of a foredune
- Lower beach profiles allow stronger wave and swash at high water potentially degrading/eroding the backshore
- As outlined above (Section 5.5 pages 56 -58), reduction in beach profile of ≥1.5 m has been recorded along Main Beach at Inverloch since 2012
- By comparison, beach profiles have thickened considerably at and north of Point Norman on the accreted coastal sectors.

6.1.2 Change in Position of High Water Mark (Sandy Backshore)

- Landward migration of the high water mark or swash limit is shoreline recession (commonly called "erosion") and seaward or horizontal migration is shoreline accretion (progradation)
- Recession occurs when sand at the high tide swash zone is removed either seaward or alongshore
- The most direct indication of recession is cliffing of foredunes and collapse of vegetated slopes and ridge crests
- As outlined in Section 5 of this report, rapid and sustained recession of a long sector of backshore east of Flat Rocks has occurred since 2012
- By comparison (see Section 5 above), coalesced spits have produced a wide prograded foreland between Point Norman and Point Hughes

6.2 Is Shoreline Change at Inverloch Unusual in Regional and Global Context?

- The changes to this system since 2010—namely the movement of sediment between shore sectors on the coast and within Anderson Inlet, and the changes occurring in the position of the ebb and flood channels at the entrance to Anderson Inlet—represent the most rapid recession and accretion events recorded on the Victorian coast in European historical times and are significant on a global comparison
- Accelerated recession of sandy shorelines is not a newly recognised phenomenon on a global scale as it has been apparent for over 30 years (Bird 1985)
- The (then) Commission on the Coastal Environment (now Commission on Coastal Systems) of the International Geographical Union (IGU) reported in a qualitative study (quoted in Bird 1985) that 70% of the world's sandy shorelines were receding
- Based on 33 year period (1984 - 2016) of global satellite data, the 70% erosion figure quoted by the IGU has been questioned/revised by (Mentaschi *et al.* 2018 Luijendijk *et al.* 2018)
- Luijendijk *et al*. (2018) recorded 24% of the world's sandy beaches as persistently eroding over that period at a rate exceeding 0.5 m/yr with 27% accreting and 49% stable
- On the Luijendijk *et al*. (2018) analysis Australia recorded net erosion (recession) of all beaches over that period of 0.20 m/yr

- Recession of Inverloch beaches is therefore not unusual on a regional, continental or global scale
- However, the recession rates over the past 7 years at Inverloch are at the high end of the scale by global comparison and on the Luijendijk *et al*. (2018) scale are classed as *severe to extreme*.

6.2.1 Is Shoreline Change at Inverloch Cyclical?

- GHD (2018) interpreted shoreline changes at Inverloch as "cyclical", with periods of erosion lasting several years corresponding to periods of increased storminess, and periods of "recovery" during more settled years (Water Technology, 2016)
- We are not in agreement with the concept of "cyclical" changes as the period of clear record is too short (~100 - 150 years) to interpret such rhythmic and reoccurring events
- It is preferable to use the term "periodical" as this does not imply a recycling or repetition of events and responses
- The "recovery "cited includes increase of beach thickness, progradation of the HWM and incipient foredune development with pioneer species of grass and some woody shrubs
- On top of these periodical [cyclic] changes there may also be a trend of long term recession due to sea level rise and sediment loss which means that the backshore and beach surface does not fully recover after each erosion event
- The current situation is at the extreme end of erosion recorded over the last 150 years
- It is possible more erosion will occur before the "recovery" begins (if it does)
- Geomorphic evidence suggest Point Smythe has migrated to the NW as transgressive parabolic sand ridges during the Holocene
- The present trend is for recession to the SW eroding vegetated dunes and releasing further sand into the inlet system
- More sand within the inlet system may be the cause of accumulation on the northern shore of Andersons Inlet

6.3 Potential Causes of Shoreline Change at Inverloch

- The 1984 IGU study recognised 21 potential causes of sandy shore/beach recession (not all of which would apply at Inverloch)
- The potential causes at Inverloch can be grouped as:

- Metocean factors: sea-level rise, changes in wave energy and/or direction of wave approach; increased storminess; changes in tide regime, accelerated removal of beach sediment by wind and/or runoff
- Geological- sediment factors: tectonic subsidence of the coastal region; reduction in sediment supply from alongshore and offshore (sediment supply from cliffs and fluvial sources is not relevant at Inverloch); replacement of coarse sediment sources with fine sediment and reduced retention rates on beaches; rise in the beach water table reducing cohesion of beach sediments
- There is insufficient data and/or beyond the scope of the present study to identify the specific factors in the above bullet points that may better explain the ongoing changes at Inverloch (See Section **8.1 Recommendations for Future Research** (Page 80) for details
- No engineering or other human interference factors (sea wall, dredging, seafloor mining) along the ocean coast at Inverloch have been identified as contributing to recent backshore recession
- Along the Gippsland coast including Inverloch, the continuing trend of increase in significant wave height, the spacing, duration and intensity of storm sequences in the Southern Ocean, rising global sea-level and changes in wave direction may be triggering the rapid changes noted on sandy coastlines

6.3.1 Metocean Conditions

The Water Technology (2016) analysis of metocean conditions noted (paraphrased below):

- *"The frequency of storm wave events is reflected in shoreline erosion along sandy coastlines*
- *63 years of hindcast wave conditions for the Gippsland coastline (1950-2011) showed a clustering of storm events, with periods of heightened wave storminess identified as: 1950-1956, 1964-1967, 1974-1978, 1984-1987, 1995-2001; and 2007-2011*
- *These approximate periods identified corresponded well with documented periods of significant storminess and coastal hazard impacts on the NSW coastline (Hanslow & Gissing, 2007)*
- *These phases or erosion and recovery have occurred in the past, as shown in the images from 1968 and 1981. However with the movement of much of the eroded sand alongshore and predicted ongoing sea level rise the longer term recovery of the dune is less certain"*

- There is no specific reference by Water Technology 2016) to the period post-2013 when rapid recession Flat Rocks to Point Norman occurred
- It is not known (and beyond the scope of the present phase of this values study) if the 2012 - 2016 period has been another "stormy period" using the methodology of Water Technology 2016)- or if there have been abnormal conditions
- The backshore from Flat Rocks to Point Norman is susceptible to recession when impacted by waves as it is backed by a vegetated (but unconsolidated) sandy dune
- Previous (pre-2012) colonisation of the accreting foredune has been short-lived before a rapid recession which removed all the accretion and is now cutting back into the older vegetated dunes.
- Water Technology (2016) state that storm events in 2014 and 2015 resulted in erosion of the dunes along the main beach area and loss of coastal vegetation
- However the onset of recession occurred between Jan 2012 and Jan 2014 (Phillip Heath *personal communication* Jan 2018) so it is possible erosion/recession processes were well in place before the 2014 and 2015 storms
- Estimates of the volume of sand lost from the backshore between Flat Rocks and Point Norman and the volume of sand gained in the formation for Ayr Creek lagoon and the prograded spit indicate significantly more sand is needed to account for the volume of accumulation compared with the volume available only from the backshore
- Young and Ribal (2011) showed a general global trend between 1985 and 2008 of increasing values of wind speed and, to a lesser degree wave height, with the rate of increase being greater for extreme events
- This research was recently updated (Young *et al.* 2019) for a longer period and confirmed the trend noted in the earlier findings

6.3.2 Wind Analysis Pound Creek Weather Station

- Wind data for Pound Creek Weather Station (north shore of Andersons Inlet near the mouth of Tarwin River) was obtained for the period Jan 1 2011 to Jan 1 2019)

- The data comprised extracts of continuous observations of wind velocity and direction based on hourly summaries of the conditions of the previous 60 minutes
- Data of hourly observation of average wind speed (m/sec) was plotted for all observations (24 x no of days each month) for all months 2011 to 2018 inclusive (Figure 37 is an example of January 2011 to 2018). Figure 38 shows all months for 2011 to 2018.

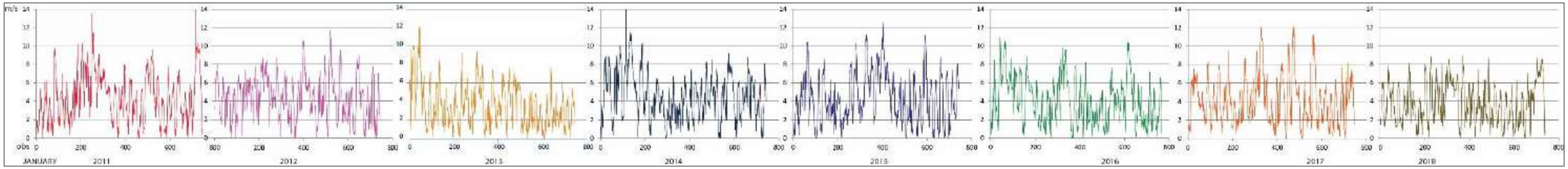


Figure 37. Average wind speed of previous 60 minutes all records January 2011 to January 2018.

- A table summarising all wind speeds >10 m/sec for all months is shown below

TABLE 1: POUND CREEK WEATHER STATION: HOURS/MONTH 2011 - 2018 WITH AVERAGE WIND SPEED ≥10m/sec

MONTH	2011	2012	2013	2014	2015	2016	2017	2018
JAN	15	09	07	13	26	10	19	0
FEB	23	03	06	17	02	00	16	13
MAR	29	20	04	00	26	19**	28	25
APR	07	16	02	06	05	11	09	05
MAY	16	17	06	09	01	00	17	09
JUN	45	06	01*	06	17	20**	47	07
JLY	35	01	02	20	22	00	36	28
AUG	06	15	10	02	10	16	06	21
SEPT	06	22	19	08	07	10	44	04
OCT	10	05	38	21	02	09	12	01
NOV	08	16	13	20	16	22	09	21
DEC	00	15	08	13	14	23	00	07
TOTAL	**200**	**144**	**117***	**135**	**148**	**140**	**243**	**132**

* 15 days of record missing ** 3 hrs>16 m/s

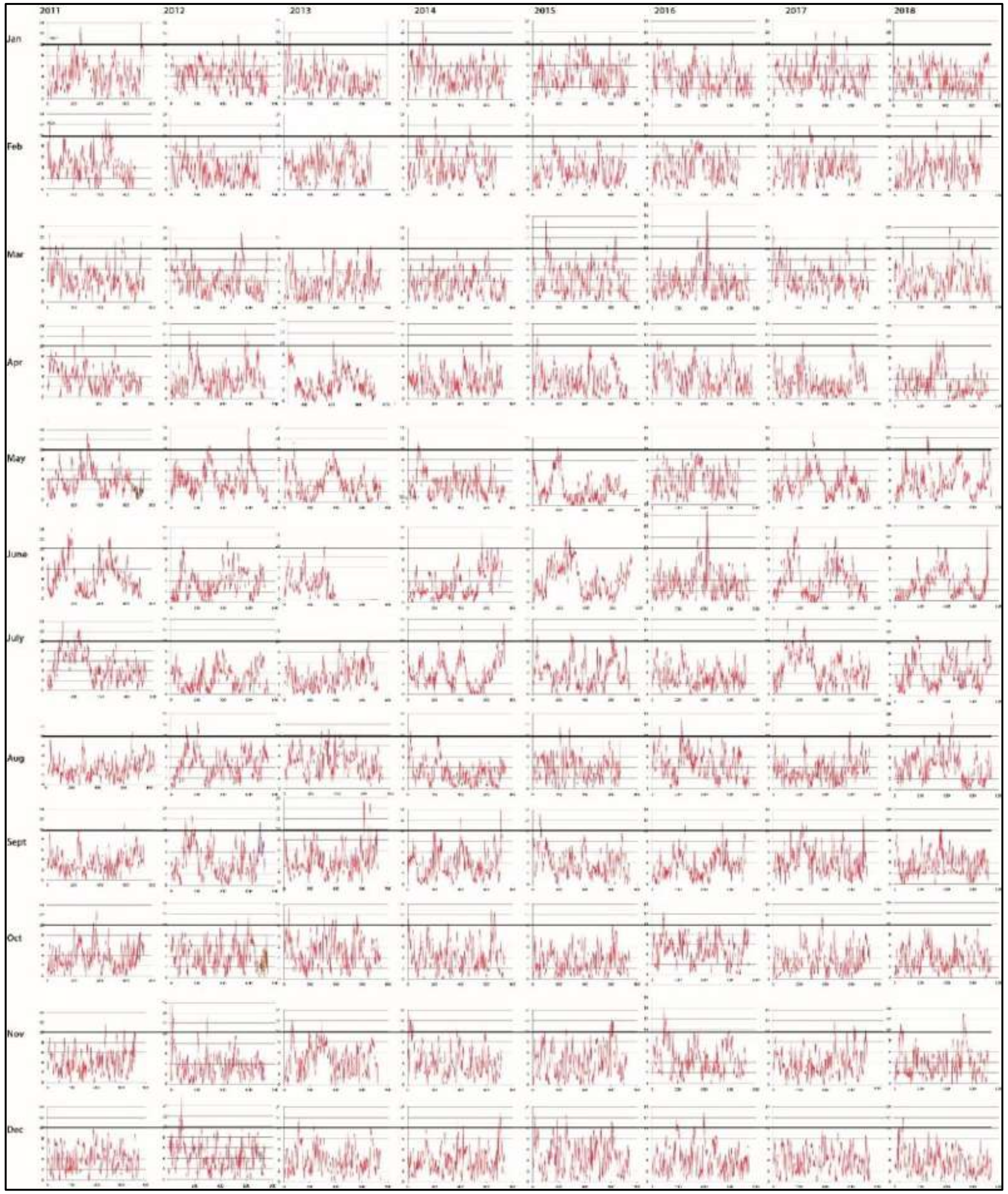


Figure 38. Average wind speed of previous 60 minutes all months January 2011 to Dec 2018. Heavy black line shows 10 m/sec to allow comparison of wind strength across the period of record.

- The table shows that years 2011 and 2017 had markedly higher average wind days over 10 m/sec and the periods of strongest wind (>16 m/sec occurred in March and June 2016
- To illustrate the direction and frequency of strongest winds, annual wind roses segmented with wind speed are shown as Figure 39.

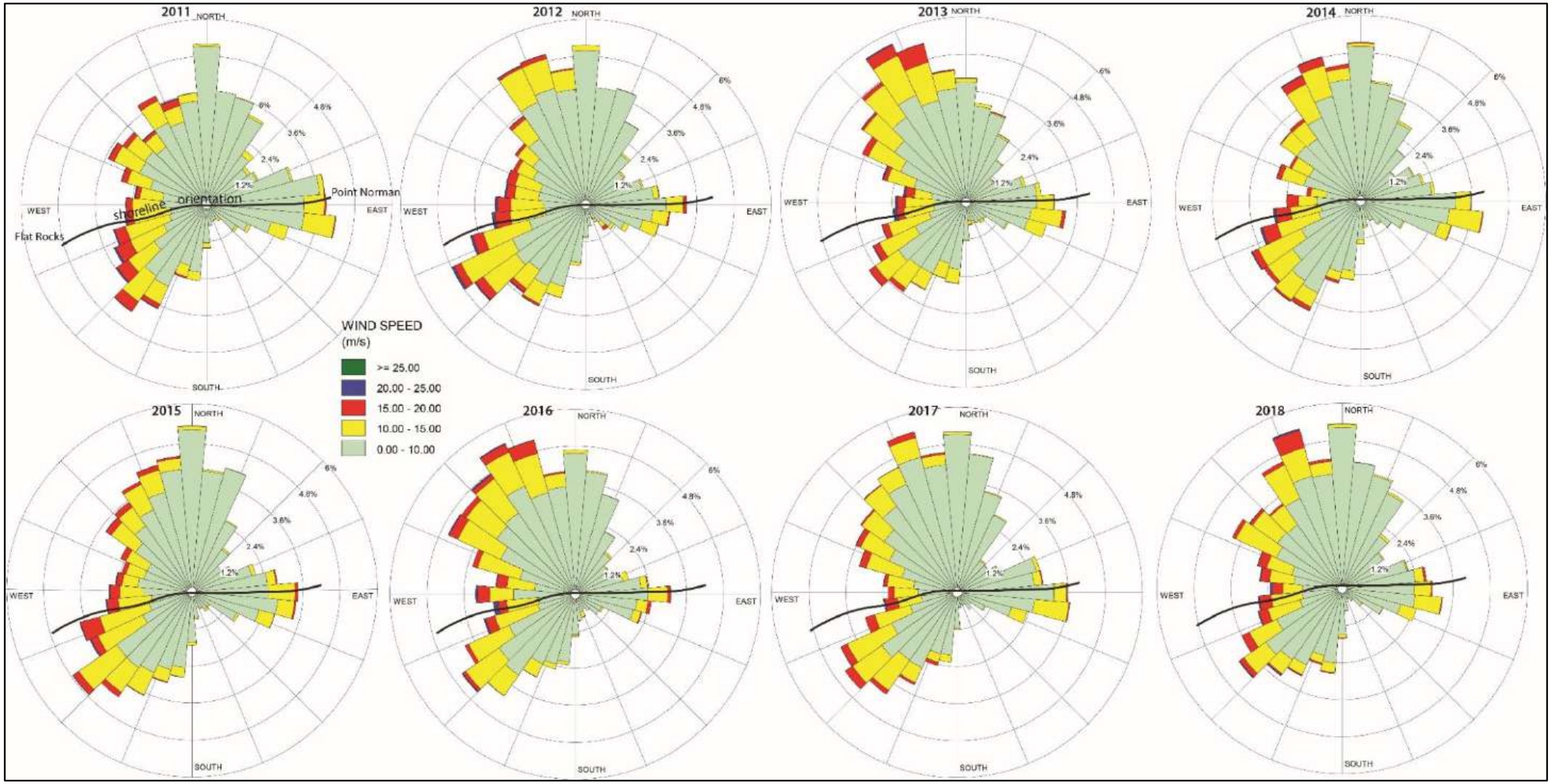


Figure 39. Annual wind roses of direction and wind speed at Pound Creek 2011 to 2018 and shoreline orientation between Flat Rocks and Point Norman. (Data from Bureau of Meteorology and processed using WPLOT View)

- Figure 39 shows that the most frequent winds are between N and WNW and are offshore between Flat Rocks and Point Norman

- Strong and relatively frequent winds from WSW to SW are onshore and assist wave break to be oblique alongshore creating alongshore drift to the east.
- These are stronger and more frequent than waves influenced by easterly winds (Figure 40).

Figure 40. Vertical aerial photography Jan 2017 with 2013 annual wind rose overlay.

- The year 2013 (when the most rapid and extensive backshore recession and beach lowering apparently occurred) does not stand out in the wind data (see pages 56 and 57 above) as an excessively “stormy” year
- As pointed out above (page 55) it is not necessarily a single or close-spaced series of events that can generate dune shore recession at a higher rate than previously experienced.

- The most recent and significant coastline recession has occurred during storm surges when strong winds, big swells and high tides were concurrent. (These components will be analysed in more detail in a later study).

6.4 Future Configuration of Andersons Inlet Entrance

- Although characterised as an estuary, Andersons Inlet is functionally a tidal inlet as the inflow of freshwater is minimal compared with the inflow of seawater.
- The throat (entrance between Point Norman and Point Smythe) is shaped by the tidal prism that passes into (and out of) the inlet body
- The entrance configuration is therefore responsive to changes in sediment availability for distribution by flood tide currents
- The present form (width-depth-shorelines) of the entrance to Andersons Inlet is determined by the complex interaction between the following processes:
    - Movement of sediment into the inlet on flood tide and wave derived currents
    - Dispersal and settling of that sediment on the shore and sub-tidal floor of the estuary
    - Entrainment and transfer back to the entrance and potentially offshore by ebb tide currents
    - Episodic augmentation of ebb discharge by river flooding and a rise in the water level of the inlet allowing outflow at all tides
    - Reduction in the capacity of the inlet due to sedimentation (aided by vegetation spread - in this case mangroves and *Spartina*)
    - Development and dynamics of the ebb and flood tide deltas
    - Position of the ebb-flood channels in relation to the shoreline either side of the entrance
- Currents in ebb tide channels function as a hydraulic groyne and this may the case at Point Norman
- Ebb channel current velocity is increased by the forcing pressure from easterly winds that blow directly down the centre of the inlet and are a significant component of the annual wind regime (see Figures 32 and 33)
- The accumulation of sediment at Ayr Lagoon may in part be a function of the interruption of eastward longshore sediment transport by strong ebb tide currents (and associated hydraulic groynes function) increasing sedimentation in the ebb-tide delta in shallow water

- Subsequent flood tide currents augmented by swash currents from southwest waves breaking directly into the entrance carry sand into the entrance at Point Norman

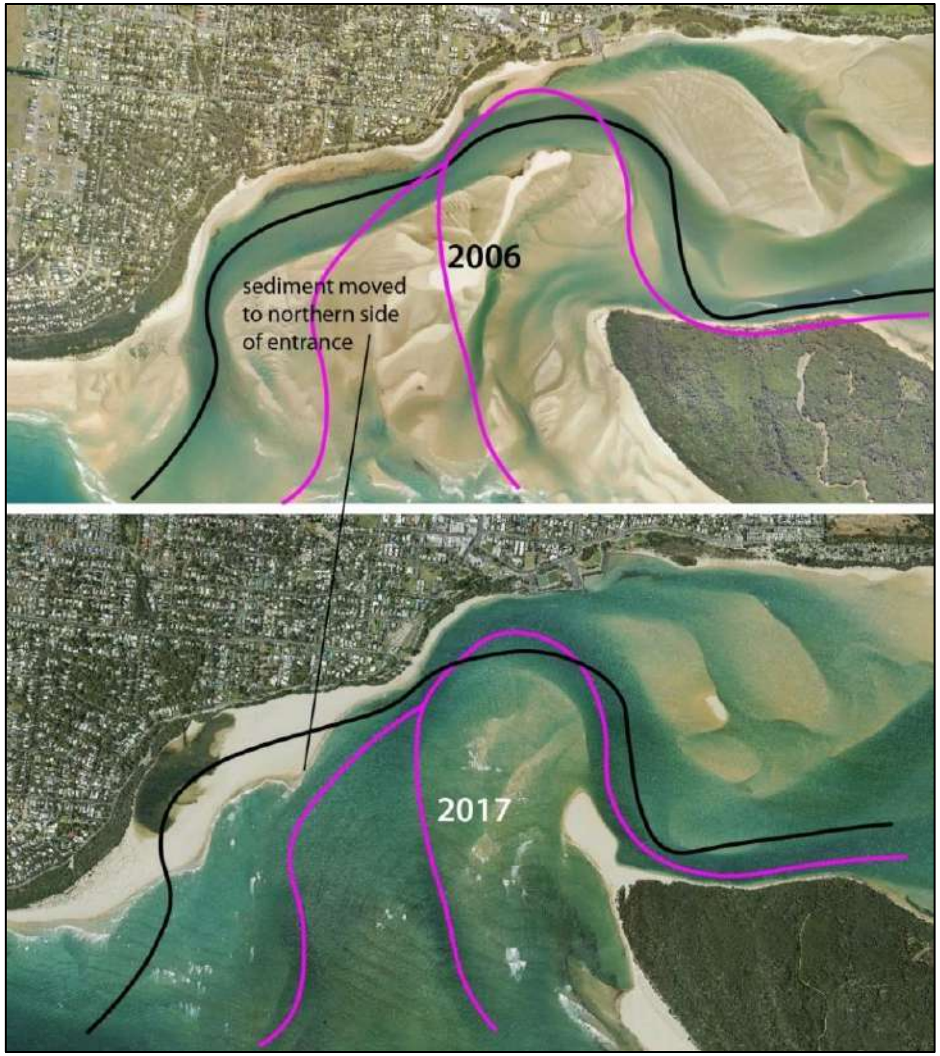


Figure 41. Migration of tidal channels and associated accretion (Point Norman to Point Hughes and recession Point Smyth

- Reduction in wave and tidal current transport capacity inside the entrance leads to deposition and extension of the Point Norman spit and foreland

- As a result the tidal channel effectively moves east (towards Point Smythe) leading to further shallowing of the area between Point Norman and Point Hughes and recession of the northern and northwest shoreline of Point Smythe (Figure 38)
- Associated with the migration of the ebb tidal channel is an exaggeration of the meander geometry moving from the southern to northern side of the inlet (Figure 41)
- Further extension of the ebb delta will be at the centre and to the eastern side of the entrance
- The trend of geomorphic changes noted above suggest that short term (±5 years) are likely to be:
    - Continued accretion and infilling (by overwash) of the Ayr Lagoon
    - Dune accretion on the Point Norman to Point Hughes foreland
    - Narrowing and deepening of the entrance ebb-flood channels leading to further recession of the northern shore of Point Smythe
    - Alternating episodes of accretion and recession on the western shoreline Point Smythe
    - The intertidal and subtidal morphology of Andersons Inlet throat will continue to change rapidly
    - The Point Norman - Pt Hughes coastal foreland will likely continue to extend/widen along the northern shore of Andersons Inlet
    - These changes will at times include a narrowing and shallowing across some of the entrance - however tidal and wave current ventilation will be sufficient to maintain an open entrance
    - It is highly unlikely that a continuous sand (or other sediment) barrier could be developed and maintained across the ocean opening of Andersons Inlet between Point Smythe and Point Norman.
    - Sand accumulated in the Point Norman - Point Hughes foreland can only be removed by a westward (shoreward) migration of the ebb-tide channel eroding the new shoreline
    - The complex hydrodynamic and sedimentological factors that may trigger and maintain this migration are beyond the scope of the present study.

7 GEOMORPHOLOGICAL VALUES OF THE INVERLOCH COAST

- A complex dynamic system of great interest for historical and on-going studies of coastal landform evolution
- The changes since 2012 are one of the most rapid recession and accretion events recorded on the Victorian coast
- ***However, there is evidence in the landscape and from historical maps and aerial photographs that substantial relocation of shoreline position has occurred over both historical and geomorphological time frames***
- <u>**Key geomorphic values that make the area a site of State Geoscience Significance:**</u>
- Transition from active coastal cliffs and platforms to a stranded marine cliff now a coastal bluff
- Preservation of backshore sand ridges between the bluff and the youngest Holocene dunes
- Exchange of sediment between adjacent shore sectors both inside and outside Andersons Inlet
- Substantial changes occurring in the position of ebb and flood channels across the entrance to Andersons Inlet.
- Processes of shoreline change and the rate and mechanism of foredune initiation and subsequent development
- The relationship of different vegetation species and associations in determining the morphology of coastal dunes

7.1 Geological and Geomorphological Values of the Bass Coast Shire

- A previous inventory that included parts of the (now) Bass Coast Shire (Rosengren 1984 identified a range of geological and geomorphological values (geoscience sites) on coastal and inland areas
- These sites were included in a Environmental Significance Overlay in the Bass Coast Planning Scheme in order to "protect and conserve sites of geological and geomorphological significance from development"
- The current revised planning scheme no longer includes this specific provision for geoscience sites
- It is recommended that an inventory of the Bass Coast Shire be commissioned to identify geoscience sites across all of the Shire and protection of such sites be included in the planning scheme.

8 CONCLUSION

- The geomorphological values of the Inverloch coastline have been identified above as of State significance
- This high significance is a function of the present and relict landforms i.e. shore platform, abandoned seacliff, dune accumulations of Pleistocene and Holocene age and other indications of varying sea-levels
- Sites that illustrate geomorphic processes and on-going landform evolution are a critical part of geomorphic significance of some landscapes and this is certainly the case for the Inverloch and Andersons Inlet areas
- The rate and processes of landform changes clearly has implications for other landscape components and values e.g. ecological, recreational, aesthetic
- Given the shoreline changes being experienced, to maintain some of these other values at Inverloch implies engineering intervention
- This will alter ambient processes that shape coastlines and produce an artificial element to the geomorphology that reduces the inherent geomorphic values - including the rate and processes of landform evolution
- Part of the geomorphic significance of the study area is the representation of past geomorphic processes on a range of time scales—months to millennia
- Fluctuations of shoreline position along the study area are clearly expressed in the landscape and it is to be expected that given the structure, morphology and composition of that landscape that rapid and substantive changes must be anticipated
- Oscillation between recession and accumulation of different sectors of the shoreline will continue but will do so under changing metocean conditions that may force different modes and rates of change that have been recorded over the period of European occupation
- Sections of coast without a strong shore platform and or rocky substrate are prone to be more susceptible to periodic coastal erosion
- This is a function of the interbedded and faulted nature of the Cretaceous deposits
- Townsend Bluff is relatively stable point within the system and has been generally neutral to change over the last 150 years
- Point Smythe is a dynamic landform and experiences periods of loss and accumulation at different parts of the spit
- The volume of sand within Andersons Inlet that is moved around under ebb and flood tide is very large and may far outweigh contributions from recession of the coast to the west

- The worlds coastlines—as are the alpine regions—are highly responsive to climate change
- Sandy coastlines are at the high end of the sensitivity scale and respond rapidly to changed conditions determined by eustatic sea-level rise and increased energy of the principal drivers of the marine system— wind and associated waves and currents
- Sandy coastlines adjacent to and incorporating inlets are also influenced directly by changed terrestrial conditions of temperature, rainfall and runoff that alter terrestrial as well as marine ecosystems
- The present and future coastal and terrestrial geomorphology of Inverloch - Andersons Inlet will be determined by sediment transport and deposition regimes and the interface with—and response of—the biosphere - including *Homo sapiens*.

8.1 Recommendations for Research

- A key initial task is to better quantify the volumes of sediment involved in the recession and accretion sectors
- Coupled with this is the need for further sampling and analysis of beaches and nearshore areas (grain size and shape, composition, stratification) to determine the source of sand within Andersons Inlet and the sources and dynamics of sediment for the entire coastal area of Venus Bay
- A major component of a further proposed study is analysis of all available metocean (weather and wave) data (direct records and hindcasting) to identify storm events
- Studies of tidal dynamics and monitoring of tidal ventilation to determine sediment pathways on ebb and flood tides
- On-going measurement of the configuration of the entrance and the ebb-tide deltas
- On-shore drilling to determine the geomorphic histories of the Tarwin Embayment and Venus Bay Barrier
- Extension of detailed studies of temporal and spatial associations of shoreline change along the Gippsland coast
- From this data the storm events since 2012 can be compared with the long record to see if storms in this period are unusual in magnitude, frequency and direction, and therefore a major determinant of recent shoreline recession.
- The research tasks, purpose, personnel and approximate costs are shown in Table 2 below

- Tasks 1 to 4 and 7 and 8 are identified as key tasks.

Table 2. SUGGESTED FURTHER RESEARCH TASKS INVERLOCH COAST

TASK NO.	RESEARCH TASK	PURPOSE	METHODOLOGY	PERSONNEL	TIME FRAME	APPROXIMATE COST
1	**Area/volume of sediment removed from eroded area and accumulated in accreted area since 2012**	**Determine relationship between eroded and accreted areas**	**Interrogation of LiDAR, aerial photography, drone photogrammetry, ground survey**	**Coastcare, SGCS members, locals** **Consultants**	**2019**	**Volunteer** **$5,000.00**
2	**Comparison of sand character onshore and offshore**	**Define potential sources-sinks of coastal sediments**	**Sand collection from nearshore for grain size and carbonate analysis**	**Surfers, divers, boaties.** **Consultants**	**2019**	**Volunteer** **$5,000.00**
3	**Age of foredunes based on palaeosols**	**Geomorphic evolution of backshore around Surf Club**	**1. Collection of palaeosols** **2. Radiocarbon dating**	**1. Consultants** **2. Waikato University (NZ)**	**2019**	**1. $2,500.00** **2. $4,000.00**
4	**Metocean data analysis**	**To determine wave regime and storm history for period of record**	**Modelling and Analysis of Bass Strait climate and wave data**	**CSIRO Aspendale**	**2019**	**Unknown say $8,000.00**
5	Configuration of entrance Andersons Inlet	Dynamics of entrance and sediment movement	Drone photography across entrance Pt Norman - Pt Smythe	Coastcare, SGCS members, local group	2019 and ongoing	Volunteer
6	Composition and age of backshore ridges	Geomorphic evolution of Tarwin embayment	1. Geoprobe coring backshore dune ridges. 2. OSL dating selected samples 3. Ground Penetrating Radar of foredunes	1. Southwest Drilling Pty Ltd 2a. Vic. University (NZ) lab 2b. Consultants 3. Consultants	2019	1. $6,000.00 2a. $4,000.00 2b. $3,000.00 3. $5,000.00
7	**Report preparation**	**Consolidate all data**		**Consultants**	**2019-2020**	**$10,000**
8	**Geoscience heritage features Bass Coast**	**Extend existing partial inventory**	**Desktop and field studies**	**Consultants**	**2019-2010**	**$12,000.00**

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