

RISK MANAGEMENT OF COASTAL CLIFF HAZARDS – A CASE STUDY FROM THE SURF COAST, SOUTHWEST VICTORIA

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ABSTRACT

Coastal cliffs pose a significant and unpredictable landslide hazard to users of coastal areas. The surf coast region of Southwest Victoria encompasses more than 50 km of coastline from Torquay to Lorne. The region is a world-class surfing destination and attracts hundreds of thousands of visitors each year, from all over the world. The coastline is variable, with low-lying sand dunes juxtaposed with large sea cliffs. From Torquay to Aireys Inlet, cliffs comprise variably cemented Paleogene aged sediments of very low- to low strength sandstone, calcarenite and limestone with soil horizons, transitioning to the Cretaceous rocks of the Otway Basin around Lorne. This combination of unstable cliffs and the popularity of the area for coastal users presents a challenge to manage the geotechnical risk whilst preserving public amenity. This case study looks at how GHD aided the Great Ocean Road and Parks Authority (GORCAPA) in understanding the hazard and risk posed by coastal cliffs and how GORCAPA moved away from traditional reactive management methods to a more proactive approach. Part of this involved identifying “hotspot” areas where resources could be better targeted to monitor and mitigate risks. A key aspect was development of a Trigger Action Response Plan (TARP) and integration with the wider Coastal and Marine Management Plan (CMMP). The TARP allows GORCAPA staff to understand the actions that need to be undertaken following certain events and, tied to the CMMP, aids in a more proactive response to developing cliff risks. The reality of risk management for this area, with multiple hazards meant that only the consequences of the hazard could effectively be reduced. Restricting access to large expanses of popular beaches in the region is not feasible, therefore other strategies were deployed, including education programs in local schools, improved hazard signage and improved communication of hazards with the public via social media streams. The implemented approach has mitigated the likelihood and severity of potential casualties. An effective risk management program is essential to keeping users of the coastline safe and informed about hazards posed by cliffs.

1 INTRODUCTION

Southwest Victoria boasts a varied and rugged coastline with towering sea cliffs, sea stacks, offshore platforms, reefs and caves to low lying sandy beaches and dunes. The Surf Coast area, comprising more than 50 km of coastline extending from Torquay to Lorne, has an abundance of these geomorphic features. The varied nature of the coastline and the underlying geology are the reason for the world-class surfing environment in this region. The combination of natural beauty and coastal activity/amenity brings millions of visitors each year – with 5.5 million visitors to the Great Ocean Road Region in the 12 months to September 2024 (Tourism and Events Victoria 2024).

The coastal environment presents a number of potential geotechnical hazards, the most common being landslide hazards associated with coastal cliffs including rockfall and slide/flow-type mechanisms. With large numbers of visitors to the area every year, hundreds of thousands of people may be exposed to these hazards, possibly without understanding the risk posed by coastal cliffs. In 2021/2022, a 30-m-high cliff face collapsed near Bells Beach, part of the Surf Coast. A group of six people were sitting under the cliff face at the time, with three people struck by falling debris, leading to one person being killed with the other two sustaining injuries as a result (ABC News 2021). This highlights the risk to the public posed by coastal cliff hazards in the region.

According to the Guidebook to Public Land Management in Victoria (CJC & GCLS 2023), under the *Crown Land (Reserves) Act 1978, (Vic)*, it is the responsibility of local land managers/authorities, such as local councils and other state authorities appointed by the Department of Energy, Environment and Climate Action (DEECA), to manage the land and to protect the coastline. This includes understanding the risk posed by coastal geotechnical hazards, managing risk and effectively communicate this risk to the public.

This case study focuses on the risk management strategy implemented for an area of coastline between Torquay and Aireys Inlet (shown in Figure 1A, 1B below), managed by the Great Ocean Road Coast and Parks Authority (GORCAPA), a Victorian State Government entity (known as the Great Ocean Road Coast Committee, or GORCC, prior to December 2020). GHD were first engaged by GORCC/GORCAPA to undertake a baseline geotechnical risk assessment between Torquay and Aireys Inlet in 2012, with a review and update of the risk assessment undertaken in late 2019 and early 2020.

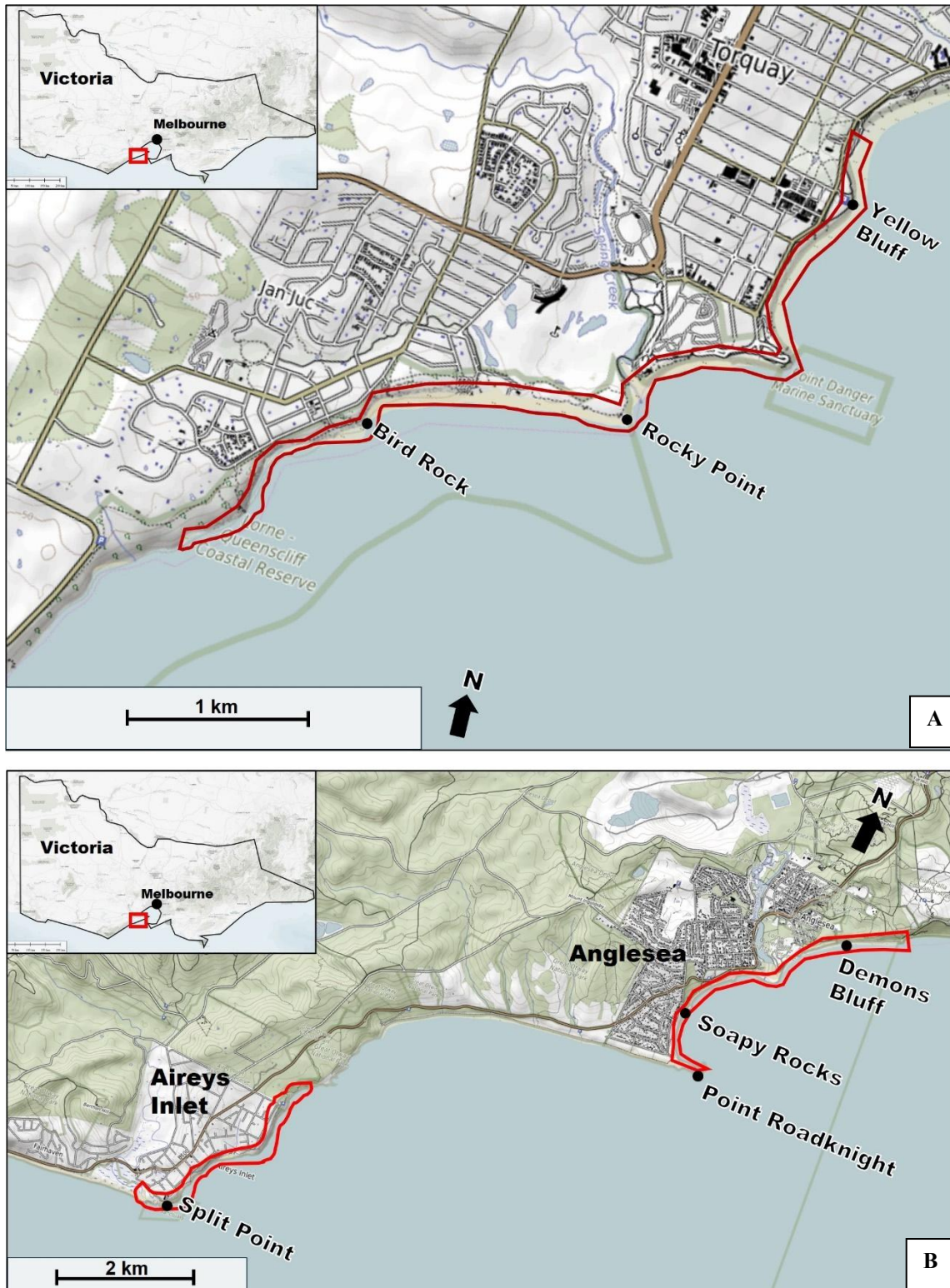


Figure 1: Area location maps. A: Torquay and Jan Juc areas. B: Anglesea and Aireys Inlet areas. Red outlines indicate the coastline that was assessed in GHD 2012 and GHD 2020. Map overlays from OpenTopoMap

As a part of the risk assessment and review process, GORCAPA were keen to identify areas of particularly high-risk cliff areas (“hotspots”), develop erosion trigger points and setbacks for clifftop amenities, undertake an audit of cliff risk signage and a review of the current cliff monitoring methodology and recommendations for improvement. The report and its findings would provide a basis for input to GORCAPA’s Coastal and Marine Management Plan (CMMP). In 2023, the Victorian Government through the Department of Energy, Environment and Climate Action (DEECA) released its

long-term coastal framework and guidelines for coastal risk management and guidelines – Victoria’s Resilient Coast. Coastal risk management activities undertaken by land managers is now also expected to align with this framework.

2 GEOLOGICAL SETTING

This case study uses the geological stratigraphy initially used in the GHD 2012 study, to allow for continuity. This is based on the 1:63,360 geological map produced in 1968 and the work of Abele (1979). The author is aware that the geological stratigraphy was updated in 2014 as part of the Victorian Seamless Geology project and geological mapping is now available in 1:50,000 scale.

The geology of the coastline from Torquay to Aireys Inlet is dominated by two major Paleogene to Neogene aged formations/groups of rocks – the Oligocene to Eocene aged Demons Bluff Formation (Te) and the Miocene to Oligocene aged Torquay Group (To). The Paleogene and Neogene rocks are folded into a series of gently dipping anticline and synclines with a gentle south-east plunge. Recent deposits comprising alluvium (Q1, Q2) swamp/lake deposits (R2) and recent sand dunes (R3) overly or abut the older rock units.

2.1 TORQUAY AND JAN JUC

The coastal cliffs in the Torquay and Jan Juc areas comprise the Torquay Group (To), as shown in Figure 2. The Torquay Group comprises two main formations – the Jan Juc and Puebla formations, with three defined limestone members within each formation (Point Addis and Waurm Ponds limestone Members in the Jan Juc Formation and the Zeally Limestone Member within the Puebla Formation). These formations are described in detail by Abele (1979) in several measured coastal cliff sections. The Point Addis Limestone Member is not encountered in this part of the project area and is described in the Anglesea and Aireys Inlet sections below.

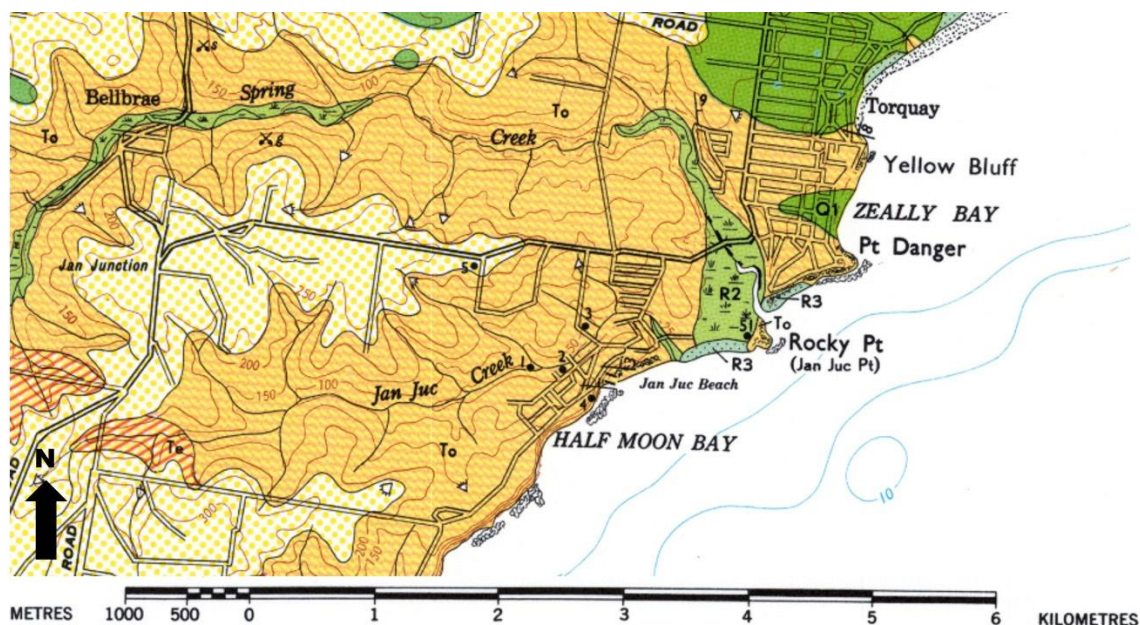


Figure 2: Surface Geology of coastline of interest - Torquay to Jan Juc (Extract from 1:63,360 Anglesea map sheet, Geological Survey of Victoria, 1968). Q1 = alluvium, R2 = swamp/lake deposits, R3 = sand dunes, To = Torquay Formation

The Jan Juc Formation generally comprises silty glauconitic marl and clayey sandy calcarenite, noted to be highly friable. The calcarenite layers are more strongly cemented, more ferruginous and more resistant than the marl beds (Abele 1979), leading to an irregular weathering pattern on cliff faces, as shown in Figure 3A. The Jan Juc Formation is exposed in the lower part of the cliffs from Bird Rock to Fisherman’s Steps beach.

The Puebla formation overlies the Jan Juc Formation and is the main component of the cliffs from Bird Rock to Yellow Bluff. The rocks of the Puebla formation comprise grey, yellow-grey-brown to grey, orange clayey silt and silty clay, commonly calcareous, with thin cemented limestone and calcarenite interbeds. Calcareous concretions are present either in layers or scattered throughout the unit. The upper beds are commonly strongly weathered and ferruginous (Abele 1979). Typical outcrops of the Puebla Formation are shown at Yellow Bluff, Figure 3B, 3C. The Zeally Limestone Member is an intermediate layer within the Puebla Formation and outcrops in coastal cliffs from Jan Juc beach, Rocky Point, to Point

Danger and just south of Yellow Bluff. The unit comprises grey, orange to pale orange sandy bryozoal calcarenite. The calcarenite has a rubbly texture due to the differentially cemented nature of the rock. This texture is well illustrated in a cliff section at Rocky Point, Jan Juc (Figure 3D).

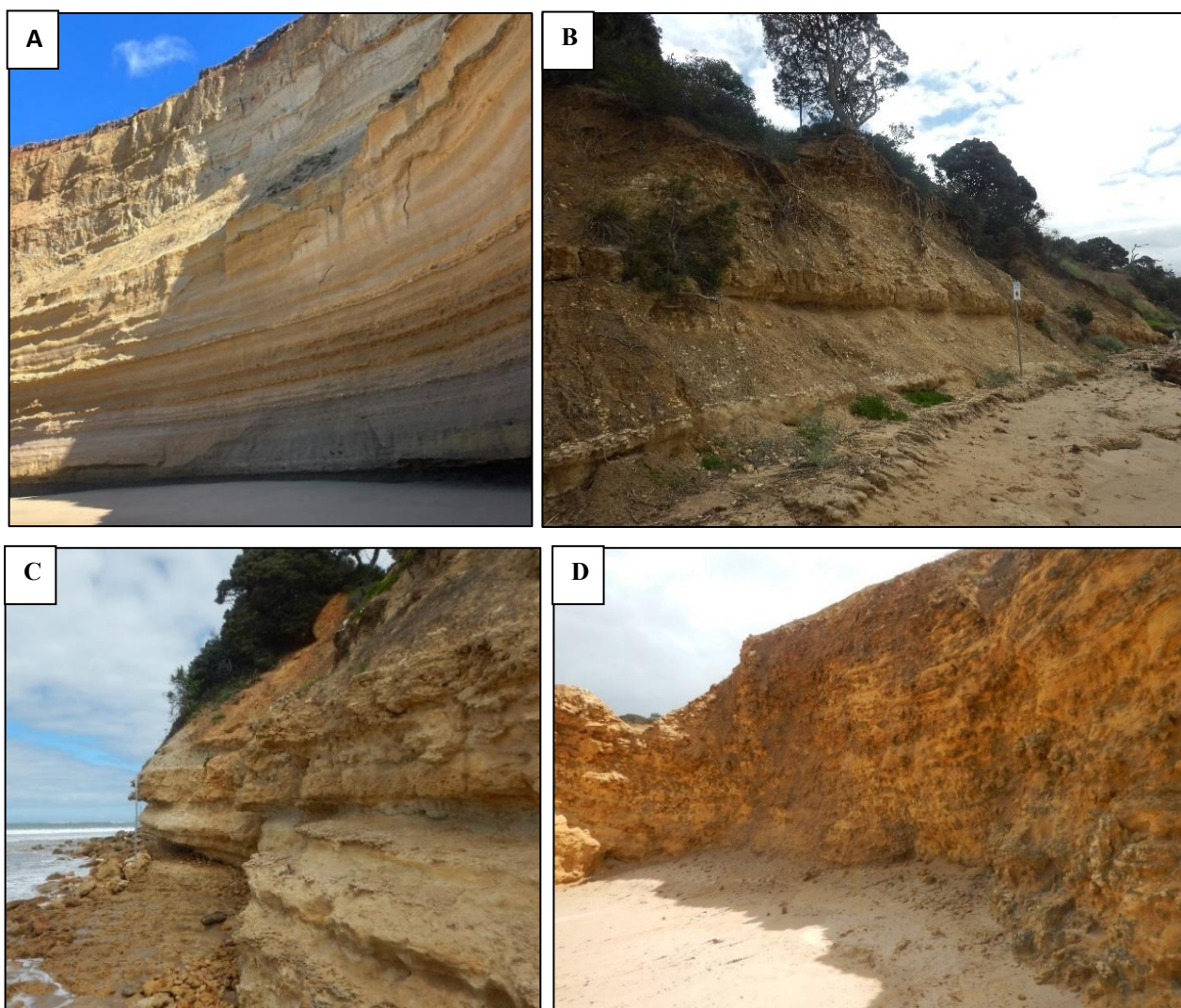


Figure 3: Typical outcrops of the Jan Juc Formation (A – Near Bird Rock GHD 2023), Puebla Formation (B and C, near Yellow Bluff GHD 2020) and Zeally Limestone Member (D, Rocky Point, Jan Juc GHD 2020).

2.2 ANGLESEA AND AIREYS INLET

The coastal cliffs in the Anglesea area comprise the Demons Bluff Formation (Te). In Aireys Inlet, the Demons Bluff Formation units are overlain by Torquay Group (To) rocks, comprising the Point Addis Limestone Member of the Jan Juc Formation. The relationship of the surface geology is shown in Figure 4.

The Demons Bluff Formation is made up of two members: the Anglesea Siltstone Member (which includes the previously differentiated Addiscot Greywacke Member) and the Angahook Member. The Anglesea Member makes up the vast majority of the Demons Bluff Formation and consists of a poorly stratified homogenous brown-black to brown-grey carbonaceous, pyritic clayey silt to fine sand and silty clay. Where intensely weathered, it presents as grey-red to pale-brown (Abele 1979). A conspicuous feature in the coastal cliffs at Demons Bluff is the abrupt change in colour of the Anglesea Member sediments from dark grey to pale brown, as is shown in Figure 5. This colour change is thought to represent a diagenetic change rather than an obvious erosional or lithological change (Abele 1979).

In contrast to the Anglesea Member, the Angahook Member is more heterogeneous/lithologically varied. The Angahook Member comprises basalt, tuffaceous sediments, tuff breccias, quartz sand and gravel, sandy clay and clay. These materials are well exposed in the Aireys Inlet area (as shown in Figure 6A, 6B), as well as near Point Roadknight and Soapy Rocks west of Anglesea. Basalt is observed at the base of the cliffs at Aireys Inlet near Split Point. Further east/north-east, the unit grades into tuffaceous sediments, poorly to well cemented, in part well laminated/bedded that

grade to more massive pyroclastic units with large boulders of basalt and other rocks. At Soapy Rocks in Anglesea, the Angahook Member is well described with laminated clay, tuffaceous mudflow, tuff breccia, tuff, tuffaceous sand and clayey silt. A 10-m-thick reddish brown and yellow ferruginous sandy clay overlies this tuffaceous succession (Abele 1979).

The Point Addis Limestone Member overlies the Angahook Member at Aireys Inlet. The Point Addis Member generally consists of grey-orange to very pale orange sandy bryozoal calcarenite, locally interbedded with silty or sandy marl. The calcarenite is poorly cemented and poorly stratified (Abele 1979)

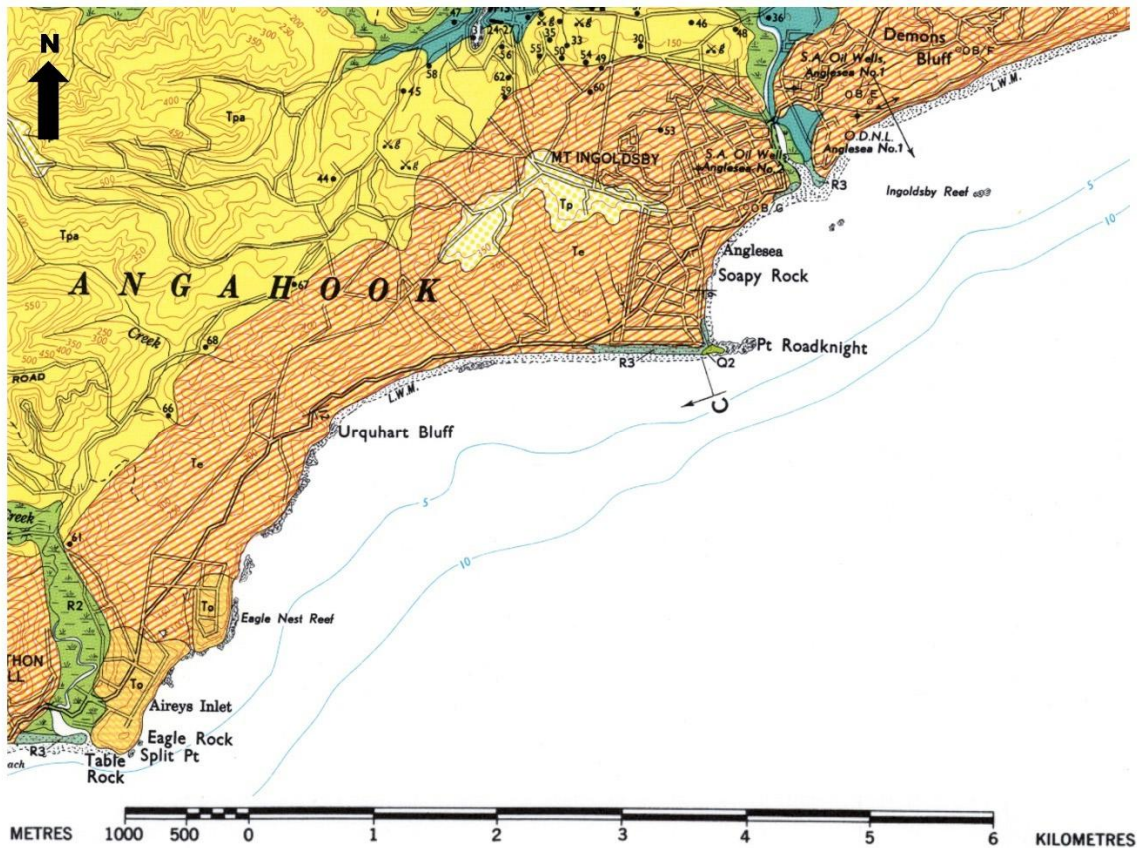


Figure 4: Surface geology of the coastline of interest – Anglesea to Aireys Inlet (Extract from 1:63,360 Anglesea map sheet, Geological Survey of Victoria, 1968). Q1, Q2 = alluvium, R2 = swamp/lake deposits, R3 = sand dunes, Te = Demons Bluff Formation, To = Torquay Formation.



Figure 5: Drone capture showing typical outcrop of the Anglesea Member, in the Demons Bluff cliffs, Anglesea (Provided by GORCAPA)



Figure 6: Typical exposures of the Angahook Member at Aireys Inlet, showing lithological diversity from basalt/basaltic sediments (A) to tuffaceous sediments and pyroclastic sediments (B). Photo B shows the contact of the Point Addis Limestone Member and the Angahook Member (GHD 2020)

2.2 GENERAL REMARKS

The geological make-up of the coastline of interest is lithologically varied, although one key property is shared between all the rocks which comprise most of the cliffs: they are all poorly or variably cemented. This poor induration means that the rocks are very-low-to low strength and soil strength in part. The cliffs that have formed are mostly near vertical, and this is reflective of dynamic and active coastal processes of recession under current sea levels. Therefore, the cliffs are more susceptible to erosion and stability issues compared with higher strength rocks.

3 HAZARD AND RISK ASSESSMENT

GHD were first engaged by GORCC/GORCAPA to undertake a baseline geotechnical risk assessment between Torquay and Aireys Inlet in 2012, with a review and update of the risk assessment undertaken in early 2020. The risk assessment methodology employed is briefly described in the following sections.

2.1 2012 AND 2020 ASSESSMENT

The initial baseline risk assessment by GHD (2012) included the following elements.

- Definition of hazard types observed during site visit (Based on AGS (2007a) terminology, see Table 1)
- Hazard zoning for each of the identified danger types, based on the estimated frequency of each danger type occurring (Table 2), for the coastline of interest (areas split and numbered 1 to 17). Frequency of each danger type was estimated utilising aerial photography, photo comparisons of the same geographic areas against previous report photos, anecdotal evidence of previous failures and general literature for similar failure types.
- Qualitative/semi-quantitative risk assessment was undertaken for cliff top property (paths, lookouts, car parks and other infrastructure) following the guidance in AGS (2007c)
- Quantitative risk assessment for risk to life was undertaken for cliff top users and beach users.

The risk to life for the individual most at risk was calculated using the method from AGS (2007c).

$$R_{(loI)} = P_{(h)} \times P_{(s:h)} \times P_{(t:s)} \times V_{(d:t)} \quad (1)$$

where:

- $R_{(loI)}$ is the risk (annual probability of loss of life (death) of an individual).
- $P_{(h)}$ is the annual probability of the hazardous event occurring.
- $P_{(s:h)}$ is the probability of spatial impact on the beach area.
- $P_{(t:s)}$ is the spatial temporal probability, i.e. the probability of the individual occupying the beach area at time of the event.
- $V_{(d:t)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).




The initial estimates of risk to life showed annual probability of death for the person most at risk to be significant. This was assessed to be due to the uncertainty involved with estimating user numbers and the frequency of events accurately. Due to the number of assumptions required, the decision was made to reduce the calculated risk by an order of magnitude for each area.

The GHD (2020) risk assessment update included

- Review of the 2012 risk assessment methodology
- Updated risk assessment, utilising updated user numbers provided by GORCAPA
- Identification of “hotspot” areas for targeted increased surveillance and assessment
- Hazard signage audit
- Review of GORCAPA coastal management plan
- Initial development of a Trigger Action Response Plan (TARP) to aid GORCAPA in coastal risk management.

The revised risk assessment also noted risk levels to be significant, similar to that assessed in 2012. Again, this was thought to be due to the uncertainty in assumptions and estimations made for user numbers and hazard frequency, such as a blanket 4% increase year on year in visitor numbers with few/no physical counts being undertaken and general lack of information related to landslide frequency. Due to this, the assumptions behind the calculations were essentially the same as those in 2012 and produced conservative risk level estimates. A general recommendation was made that GORCAPA look to improve the recording of landslide events (i.e. build a landslide inventory) and look to improve data on user numbers for cliff top and beach amenities.

Table 1: Slope Stability Danger Classification (GHD 2012)

Classification	Danger Type	Description	Example From Site
A	Small rotational and translational slides	Less than 1000 m ³ displaced material. Initial failure is likely to be rapid. Example: Failure of infilled sinkhole, Aireys Inlet	
B	Large rotational and translational slides	Larger, generally deeper, slides than those in 'A' above, involving greater than 1000 m ³ displaced material. Example: Soapy Rocks Landslide, Anglesea	
C	Minor falls/topples	Failure of less than 1 m ³ of material from cliff face. Failure likely to be extremely rapid. Example: Rock fall, Yellow Bluff, Torquay	



D	Major falls/topples	As in 'C' above, with greater than 1 m ³ of failed material. Example: Cliff failure, Demons Bluff, Anglesea	
E	Rill and gully erosion	These are often ephemeral features and are formed by erosion of the land surface by flowing water. Example – Rills/Gullies adjacent to Anglesea SLSC	

Table 2: Descriptors for hazard zoning, adapted from AGS (2007a) (GHD 2012)

Hazard descriptor	Falls, topples and small slides on natural cliffs (Danger classes A, C, D)	Large slides on natural slopes (Danger class B)
	Number/annum/km of cliff	Annual probability of active sliding
Very High	>10	10 ⁻¹
High	1 to 10	10 ⁻²
Moderate	0.1 to 1	10 ⁻³ to 10 ⁻⁴
Low	0.01 to 0.1	10 ⁻⁵
Very Low	<0.01	<10 ⁻⁶

2.1.1 Hotspots

As part of the 2020 Cliff Risk Assessment Review (GHD 2020), GORCAPA were keen to identify particularly high-risk areas to focus monitoring resources on. Termed “hotspots”, these were defined as areas of the coast where risk ratings (for risk to life and risk to property) were classified as Very High, High or Moderate. These areas were recommended to be prioritised for increased surveillance to improve understanding of the frequency of hazards and the number of users in order to improve assumptions made. The following areas were identified as hotspots

- Zone 1 – Yellow Bluff
- Zone 3 – Rocky Point
- Zone 6 – Bird Rock
- Zone 7 – Jan Juc: Sparrows to Boobs/Steps
- Zone 8 and 9 – Anglesea East (Demons Bluff/Demons Bluff to Anglesea River Estuary)
- Zone 10 – ASLSC to Soapy Rocks
- Zone 11 – Anglesea West
- Zone 12 and 13 – Soapy Rocks and Point Roadknight
- Zone 14 and 15 – Aireys Inlet – Sunnymead Beach to Sandy Gully Beach

2.1.2 Signage Audit

A signage audit was undertaken along the coastline of interest. This was completed by taking a GPS-located point at every hazard/warning sign encountered during the site walkover of the coastline areas of interest. Signs were then classified based on type, with nine different varieties of signage identified. The signs were then assessed based on their compliance with relevant Australian standards – AS1319:1994 (Safety signs for the occupational environment) and AS2416.1:2010 (Water safety signs and beach safety flags). Essentially, hazard signs fall into one of two classes: Warning or Danger sign types, with each having specific criteria as per the standards. Warning signs typically should have a black pictogram which has a simple depiction of the hazard, on a yellow background in a diamond shaped black bordered box. Danger signs should include the words “Danger” and include red, black and white colouring to highlight the importance of the information.

The signage audit found five different styles of warning sign (three types shown in Figure 7A, 7B, 7C) depicting the same hazard – unstable cliffs. Some had accompanying text in English, others had only the pictogram with no words. Spatial distribution was generally quite random, with some areas having more signs than others for no obvious reason. With so many varieties of the same sign, communication of the hazard could become confused/unclear.



Figure 7: Cliff hazard signage examples from the signage audit. A, B and C – sign examples as observed by GHD in 2020 in the GORCAPA managed areas, three different varieties of sign all communicating the same hazard. D, E – Signs from Parks Victoria managed areas, communicating the hazard posed using words, pictograms, colour and photographs of the actual hazard to clearly communicate the hazard and risks, including contact details/places to obtain further information as required.

Example signage from other land management agencies, such as Parks Victoria, were used to compare against those found in the GORCAPA managed land area and showed what could be achieved. For example, at popular sites along the Great Ocean Road, Parks Victoria had combined Warning signage compliant with the Australian standards with a photograph of similar hazard/failure, in order to visually communicate the risk. Signs observed are shown in Figure 7.

2.2 TARP DEVELOPMENT

Following completion of the risk assessment update, signage audit and review of GORCAPA monitoring plan, GHD recommended development of a TARP. TARPs are used extensively within mining settings in relation to pit stability, intrinsically linked to detailed monitoring of slope stability, to document clear actions and responsibilities associated with geotechnical failures of differing scales. Parallels can be made with mining pit slopes and coastal cliffs in terms of geotechnical failures of varying scale. The underlying idea behind the proposal of a TARP for the coastal environment

was to avoid implementing a complex system of various trigger points and setbacks for each individual cliff area/hazard, essentially making it more practical for GORCAPA coastal reserve staff to implement. The initial TARP proposed by GHD included

- Triggers related to the cliff slope conditions, for beach users, cliff top assets >5m to the edge of the cliff and cliff top assets <5 m to the edge of the cliff.
- Triggers rated from low to very high, with green, yellow, amber and red alert levels, based on the potential failure size/potential for failure to impact on public paths and lookouts
- For each trigger/alert level, a corresponding response level was nominated, containing the person responsible and the actions required to be undertaken.

For example, an orange alert level (high) trigger is noted for cliff top assets >5 m from the cliff edge constituting tension cracks or failure observed between 5 and 10 m from public areas of the asset (i.e. paths or lookouts). Responsibility lies with the GORCAPA Coastal Reserve Manager (CRM) – with actions to be taken including notifying coastal staff of the alert level, preparing to close the asset, notifying stakeholders of the situation. GORCAPA operations staff then would be told to continue to monitor the situation and provide feedback to the CRM in case of worsening condition.

GORCAPA later built on the draft TARP and updated and amended it to fit their operations, as well as tie in with an updated CMMP. Figure 8 shows the triggers defined by GORCAPA (2020). It is noted that all measurements in terms of distances and volumes are estimated from a safe distance and not measured by GORCAPA staff to maintain safety.

Risk Level	Beach Users			Cliff Top User
	Potential or actual failure of cliff face (Erosion, soil/rock falls, ground displacement).	Loss of cliff crest	Tension cracks within Xm from cliff crest.	Tension cracks or failures within Xm from a public area, walking track or lookout.
Low	Volume < 1m ³	<2m	<2m	>10m
Medium	1m ³ < Volume <25m ³	2-5m	2-5m	10-7m
Significant	25 m ³ < Volume < 100 m ³	5-10m	5-10m	7-5m
High	Volume > 100m ³	>10m	>10m	<5m

Figure 8: Excerpt from GORCAPA Understanding Geotechnical Risk Manual (2020) showing the Triggers defined for each risk level/alert level.

Responses per risk level trigger, from GORCAPA (2020), include

- **Low:** On-going routine monitoring as per the CMMP
- **Medium:** CRM to assess situation, monitor, communicate with staff on the location, nature and expected conditions associated with the failure. External communication: inform public via Website and Social Media outlets). For Beach user risk: audit of local signage to ensure signs are legible and free from damage. GORCAPA Staff: avoid hazard area, report any change in conditions to CRM.
- **Significant:** CRM: same actions as Medium, but with addition of contacting a geotechnical consultant if cliff top users are at risk from the hazard/failure and preparing to close the asset/restrict access to a safe location if practicable and notify other stakeholders. For Beach users: consider temporary signage and fencing to prevent access to failure zone if practicable. GORCAPA Staff: avoid hazard area, report any change in conditions to CRM.
- **High:** CRM: same actions as Significant, but for cliff top risk close the asset and restrict access, notify stakeholders. Investigate and formulate recovery plan (formal risk assessment may be required). GORCAPA Staff: avoid hazard area, report any change in conditions to CRM.

4 COASTAL AND MARINE MANAGEMENT PLAN

This section briefly explores the implementation of the recommendations of the 2020 risk assessment in terms of GORCAPA's CMMP.

4.1 UPDATED SIGNAGE

Following the recommendations of the signage audit completed in 2020, GORCAPA committed to upgrading and improving hazard signage. Cliff hazard signs were replaced/upgraded with standardised symbology and wording along the coastline (Figure 9). In addition, GORCAPA also implemented different signage to communicate the hazards at beach and coastal path entrances, taking cues from the Parks Victoria examples in incorporating photographs of the hazard, as well as additional information available in other languages access via the website/QR codes on the sign (Figure 9).



Figure 9: Updated signage examples found at Jan Juc and Anglesea. A: Unstable cliff warning sign, showing a clear pictogram of the hazard and advice on what to do to avoid the hazard. B: Photographic sign depicting typical failures, as well as showing the correct usage of paths. A QR code also links viewers to the GORCAPA website for further information which is also in other languages.

4.2 MONITORING

Monitoring of cliff condition lies at the heart of the CMMP. The purpose of the monitoring is to

1. Assemble an inventory to assist with understanding landslide frequency for future risk assessment.
2. Reassess previously noted hazard conditions.
3. Identify imminent failures and initiate actions (in line with the TARP).

There are two scales of monitoring: regional and local. Regional monitoring covers a large area, with methods that are easily and cheaply undertaken across the area. The local scale is targeted at hotspot areas (as identified by the regional scale methods), covers a smaller area in finer detail, and may be more time consuming and expensive.

Methods employed to undertake monitoring, scale and frequency are summarised in Table 3. The monitoring plan will also allow for better quality landslide frequency data to be collected to inform future risk assessment updates.

Table 3: Monitoring methods summary (GORCAPA CMMP 2021)

Monitoring Method	Scale	Description	Capture Frequency
Aerial Imagery Analysis	Regional and Local	Assessment of shoreline and cliff top position over time using GIS software and aerial imagery captured at different points in time	Yearly
Photogrammetry ¹	Local	Elevation data obtained from drone photography	Cliff – Yearly
Geotechnical Assessments	Regional and Local	Visual geotechnical risk assessments undertaken by a consultant	Regional – 10 years Local – as required
Day to day observations by GORCAPA staff	Regional	Detailed information captured by GORCAPA staff undertaking day-to-day duties	Daily

Monitoring Method	Scale	Description	Capture Frequency
Information provided by the public	Regional	Detailed information received from the public through GORCAPA's communication channels	Daily
Cliff Assessments by GORCAPA Staff	Local	Involves the completion of a cliff risk assessment pro forma, photo capture and evaluation against GORCAPA's Trigger Action Response Plan (TARP)	After high rainfall events/storms Every 3 months

¹Photogrammetry is currently undertaken by the Victorian Coastal Monitoring Program (VCMP) run by Deakin University on behalf of DEECA at certain sites along the coast and processed through the software platform Propeller. For sites outside of the VCMP, GORCAPA has adopted drone photogrammetry using its own pilots and the software Drone Deploy.

4.3 EDUCATION AND COMMUNICATION

In addition to the CMMP, GORCAPA have been undertaking different methods of communicating the dangers posed by the coastal cliff hazards to local users and visitors to the coastline. Communication of hazards/failures or imminent cliff failures are communicated via GORCAPA's social media streams (e.g. Facebook, Instagram), in addition to the local signage. Communication via local print media is also used to keep the local population apprised of developments with hazards or temporary closures of paths/lookouts/beaches. During the peak season, GORCAPA also implement geofenced marketing strategies, which involves targeted adverts appearing on phone apps/websites when people enter the GORCAPA managed coastal zone. The adverts highlight the coastal hazards and how to stay safe around cliffs. This demonstrates an innovative way to reach visitors who may be new to the area and have no prior knowledge of the coastal hazards. GORCAPA has also previously been involved in education programs in local schools (Environmental Education Program), helping to educate local children on coastal hazards and how to be safe around cliffs, however, this program is no longer in operation. GORCAPA has also been training coastal staff in how to identify geotechnical hazards, linked to the TARP. These workshops were run in conjunction with GHD to help GORCAPA staff be more confident in identifying potential failures and implementing the TARP.

5 DISCUSSION

This case study highlights the difficulty in managing geotechnical hazards posed by coastal cliffs in weak rocks. The geology of the cliffs in this study area makes them highly susceptible to landslide hazards but has also led to the development of reefs and submerged rock platforms that contribute to the appeal of the area for coastal amenity.

The risk assessment methodology adopted for the risk assessment was undertaken in general accordance with AGS(2007a, b, c, d, e). Previous risk assessment (prior to 2012) along the coastline of interest had included the superseded AGS (2000) method, as well as bespoke assessment methods from other geotechnical consultants. In 2020, the New South Wales National Parks and Wildlife Service (NPWS) commissioned Golder Associates to develop clear guidance for geotechnical practitioners, setting out preferred methods for calculating individual and societal risk associated with trails and lookouts within state parks, to allow comparisons with NPWS selected risk criteria for individual and societal risk (Golder Associates 2020). This methodology is based on the AGS (2007a, b, c, d, e) and ANCOLD (2003) guidelines, but presented in a user-friendly format, particularly in terms of walking paths and lookouts. This method was used for risk assessment at a cliff top path at Jan Juc beach by GHD in late 2022 (GHD 2023), and the results gave a similar risk profile to the 2020 assessment, but with better definition of societal risk. This method might be useful applied to the coastline of interest in future risk assessment updates.

However, any method for risk assessment is only as good as the input data. Good quality data such as monitoring data on landslide frequency, size/volume, runout distance, and user numbers for cliff top amenities and beaches is crucial to further refine risk assessments, reduce conservatism in assumptions and focus risk management activities.

The formalised monitoring plan within the GORCAPA CMMP is important for future risk assessment work and should lead to an improved landslide inventory to improve estimates of frequency. Some issues have been identified, particularly with drone photogrammetry data. The VCMP is generally based on the Propeller online platform, and the raw data from the surveys is processed by Deakin University and Melbourne University on behalf of DEECA and uploaded to the platform. Simple volume differencing is possible within Propeller, as well as comparing surveys over a date range to assess changes. However, there are concerns that the software cannot differentiate between vegetation and topography, leading to poor measurements/false topography. GORCAPA and other similar land managers don't have the internal capability/budget to undertake this sort of data processing/validation/correction. This is leading to valuable drone data

being under-utilised in landslide risk management. Further support from specialists will be required to aid land managers in processing this data and understanding changes occurring to cliffs and help understand if triggers are being met as per the TARP.

A key challenge identified during the risk assessment process was how to mitigate the identified risks to an acceptable level of risk. In the coastal environment, methods usually employed to reduce the likelihood (frequency) of events (such as engineering of slopes, rock bolting, rock-fall mesh, rock-fall barriers) are likely to be less effective due to the interaction with seawater and storms/wave action. These engineering solutions tend to be expensive to implement, and generally beyond the budget of most land managers. Therefore, the only other options available to mitigate the risk are those related to reducing the consequence of the hazards – reducing the chance of people/property being within the zone of influence of the failure.

The TARP, tied to the CMMP, creates a much more proactive response to cliff risk. Monitoring streams feed in to identifying potential issues early, sometimes before a failure occurs, meaning the TARP can be activated based on the risk posed and responses can be implemented. Education on how to identify geotechnical risk, for the operational staff undertaking their daily duties on the coast, is crucial in the success of the TARP process.

Effective communication of the hazard/risk posed by cliffs in the coastal environment is key. Signage alone is unlikely to be effective in communicating the hazard to all users of the coastline. Therefore, utilising different media streams (such as social media, websites and print media), with content available in different languages, to reach as wide an audience as possible is an important strategy. This aids land managers to meet their obligations in terms of managing coastal cliff hazard and risk as far as is reasonably practicable.

The implemented approach to risk management in the GORCAPA managed area of the coastline has mitigated the likelihood and severity of potential casualties related to cliff hazards.

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