# TOWARDS A TYPOLOGY OF ROCKY COASTS IN THE CONTEXT OF RISK ASSESSMENT

David M. Kennedy[1], Barbara Brighton[2], Adam Weir[2], Shauna Sherker[2] **Colin D. Woodroffe**[3]

[1] Department of Resource Management and Geography, The University of Melbourne, Parkville Vic 3010, Australia.

[2] Surf Life Saving Australia, Locked Bag 1010, Rosebery NSW 2018, Australia.

[3] School of Earth and Environmental Sciences, University of Wollongong, Wollongong NSW 2522, Australia.

## Abstract

Rocky coasts occur around ~40% of the Australian margin and represent some of the most iconic landscapes. They are an important component of the natural heritage, attracting tourists to such sites as the Twelve Apostles on the Great Ocean Road or the Blowhole at Kiama, and offering recreational resources for rock fishers. However, coastal managers are becoming increasingly aware of the risks associated with people's use of these rocky coasts, as a result of significant numbers of both injuries and deaths. For example, statistics compiled by Surf Life Saving Australia indicate that 18% of all drowning deaths on the coast occurred off rocky landforms. Since records began in 2004, more than 70 rock fishers have drowned, accounting for about 70% of the drowning fatalities (which average 16 per year), and making it one of the most dangerous sports or past-times in Australia. Other activities such as rock walking, taking photographs, attempting to rescue those already in distress in the water, as well as swimming, have also resulted in drowning along rocky coasts. Rocky coasts therefore clearly represent a high risk location for drowning and one which presents significant challenges for coastal management. We report on the initial stages of a study to develop a typology of rocky coasts and to identify the factors which render some locations more dangerous than others. The approach is based on methodologies used to classify beach types and to assign them a safety index. It begins with an analysis of physical characteristics of rocky coast landforms, such as lithology, rock platform elevation and width, and the orientation and exposure of the coast. It then considers the physical processes and their modification in particular settings, combining aspects of wave climate with their transformation as a consequence of water depth and shallow seafloor morphology. We propose the development of an integrated, site-specific, risk index for rocky shores that can be incorporated into broader risk assessments of popular fishing or recreational locations. It is envisioned that this index will provide key data on which rocky coast areas are most hazardous that could ultimately be integrated with weather and tidal information to indicate the level of risk to users.

## Introduction

Horizontal rock platforms at the foot of cliffs, also called shore platforms, have been a feature of geomorphological interest for centuries. They are clearly related to sea level, but the actual processes that form them (whether cut primarily by wave action or subaerial processes) and their age (whether formed by contemporary processes or inherited from the past) remain elusive. Some of the best examples of such platforms in the world occur along the south coast of New South Wales and along the southern coast of Victoria. These platforms were the subject of descriptions by James Dana, who coined the term 'shore platform', when he visited Australia on the US Exploring Expedition (Dana, 1849).

There are prominent rock platforms at the foot of cliffs along many of the coasts of southeastern Australia. Some of the platforms appear to be related to lithology and the structural setting of the coast (Bird and Dent, 1966). However, there has been a vigorous geomorphological debate as to the extent to which such platforms are eroded directly by wave action (Trenhaile, 2002), or have been lowered by subaerial physiochemical processes acting on their upper surfaces (Stephenson and Kirk, 2000a, 2000b). Some rock platforms in the Illawarra reflect inhomogeneities in the rock associated with joints and fissures (Abrahams and Oak, 1975). The apparent elevation of several of the platforms above the highest tide level also adds support to a view that the platforms might have been formed at earlier sea-level highstands during the Pleistocene and be, at least partially, inherited features (Brooke et al., 1994). The rock platforms of southeastern Australia are particularly horizontal with a distinctive scarp at their seaward margin, in contrast to more sloping platforms (called ramps) in other parts of the world. Although there remains debate as to whether they have been eroded primarily by waves, or are the product of subaerial weathering, it seems that the platforms are formed in a narrow elevational range that is closely associated with the level of the sea. As a consequence, these rock platforms are accessible, particularly at low tide, but are also hazardous, because they are subject to overtopping and overwashing by waves.

This paper describes some of our preliminary results from studying different platforms, and a program of research that we believe will enable a clearer understanding of the morphology of platforms and the processes to which they are exposed. Our pilot program of research has involved surveying and sampling of several platforms along the Illawarra coast, as well as comparative studies of rock platforms along the coast of Victoria (Figure 1). It is aimed at providing a clearer set of guidelines that can underpin risk assessment on these platforms in an effort to reduce the number of drowning incidents on rocky coasts.

## Risks associated with rock platforms

Rock platforms are dangerous environments. In Australia 113 people lost their lives on rocky coasts between the 2004/5 and 2010/11 summer seasons, accounting for 18% of all drowning fatalities on the coast (SLSA, 2011). People are washed off the platforms into the sea by waves; such fatalities could be reduced if there was a clearer understanding of how waves interact with the rocky shore and the physical factors that make one stretch of coast more hazardous than another. We hypothesise that the chance of being washed into the sea is likely to be a function of the morphology of the platform and how large the waves are.


**Figure 1. Location of rocky coasts discussed in this paper.**

We are initiating a program of research that aims to build on knowledge of the geomorphology of rocky coasts to develop a better understanding of risk in order to focus effort on reducing drowning. The approach follows that which was used in the Australian Beach Safety and Management Program (ABSAMP) which has contributed to a reduction of incidents of drowning on beaches (Short, 2006), which underpins all beach safety programs in Australia and has been successfully adapted for use in New Zealand and the United Kingdom. The ABSAMP program evolved through a series of stages, comprising: i) detailed description of the morphology of a series of ‘beach types’ in NSW, ii) focused research on the relationships between wave processes and beach response (morphodynamics) at key sites, iii) extension of the morphodynamic classification of beaches around Australia, and iv) development of a hazard assessment scheme in conjunction with Surf Life Saving Australia (SLSA).

A similar approach could be applied to rocky coasts. Although these do not undergo morphological adjustment as beaches do in response to incident wave conditions, the degree of risk on platforms of different morphology is generally a function of wave and tidal conditions and their change through time. ABSAMP provides the model for our approach to assessing risk on rocky coasts, involving: i) description of the morphology of the rocky coasts of southeastern Australia, ii) examination of wave processes at key sites, iii) extension of classification to other rocky coasts, and iv) incorporation of these principles into SLSA risk assessment procedures.

***Morphological characterisation of rock platforms***

The morphology, and hence elements of risk associated with platforms, differs from place to place. Rocky headlands, or continuous stretches of rocky coast, as occur along the Great Ocean Road, need to be systematically described in terms of morphological parameters, such as elevation of the platform, its width and slope, and the shape of its seaward edge, each of which is likely to be important in contributing to the risk of drowning. Lithology is also an important factor that influences the type of platform that can develop (Figure 2).


**Figure 2. The influence of lithology on the morphology of rocky headlands illustrated with examples from NSW. a) A horizontal platform developed at Warden Head, Ulladulla cut into the Wandrawandian siltstone; b) Resistant essexite at Bawley Point maintains a domed topography with minimal bench development at sea level, and c) Latite at Kiama Blowhole.**

Highly resistant rocks, such as basalt, generally comprise prominent rocky headlands. Often they form plunging cliffs, on which steep, near-vertical cliffs continue beneath the water line, with little if any notch or bench formed at sea level. Where platforms have formed in such hard rocks they tend to occur at higher elevations than those in softer rocks (Thornton and Stephenson, 2006). The significance of lithology can be seen along the NSW south coast, and is particularly apparent in the area around Kiama, where there are several near-horizontal platforms that appear to have a close relationship to sea level. For example, south of Kiama a horizontal platform occurs in the relatively resistant Westley Park Sandstone member of the Late Permian shallow-marine Broughton Formation (Shoalhaven Group), forming a prominent platform on the headland. The sandstone underlies the Blow Hole Latite, a potassium-rich type of basalt, and although the lithological boundary is tilted, the platform is eroded to form a horizontal surface that clearly truncates the structure of the rocks, implying that it has been cut by the sea and is not simply formed along a bedding plane.

The Kiama region is composed of Late Permian interstratified lava and sedimentary sequences. The Kiama Blowhole is a particularly famous example of a blowhole, which is a crack or fissure in coastal rock through which air and spray are expelled when waves break on the shore (Figure 2c). The effect of trapped air is clearly audible where waves converge into cavities or sea caves. The Blowhole at Kiama was initially described by George Bass in 1797; it appears to have lost some of its force in recent years. A smaller blowhole occurs at Little Blowhole at short distance to the south. The Blowhole occurs in a distinctive igneous lithology called the Blow Hole Latite, but which would now be described as shoshonitic basalt, a basalt with olivine and augite phenocrysts (Carr and Jones, 2001).

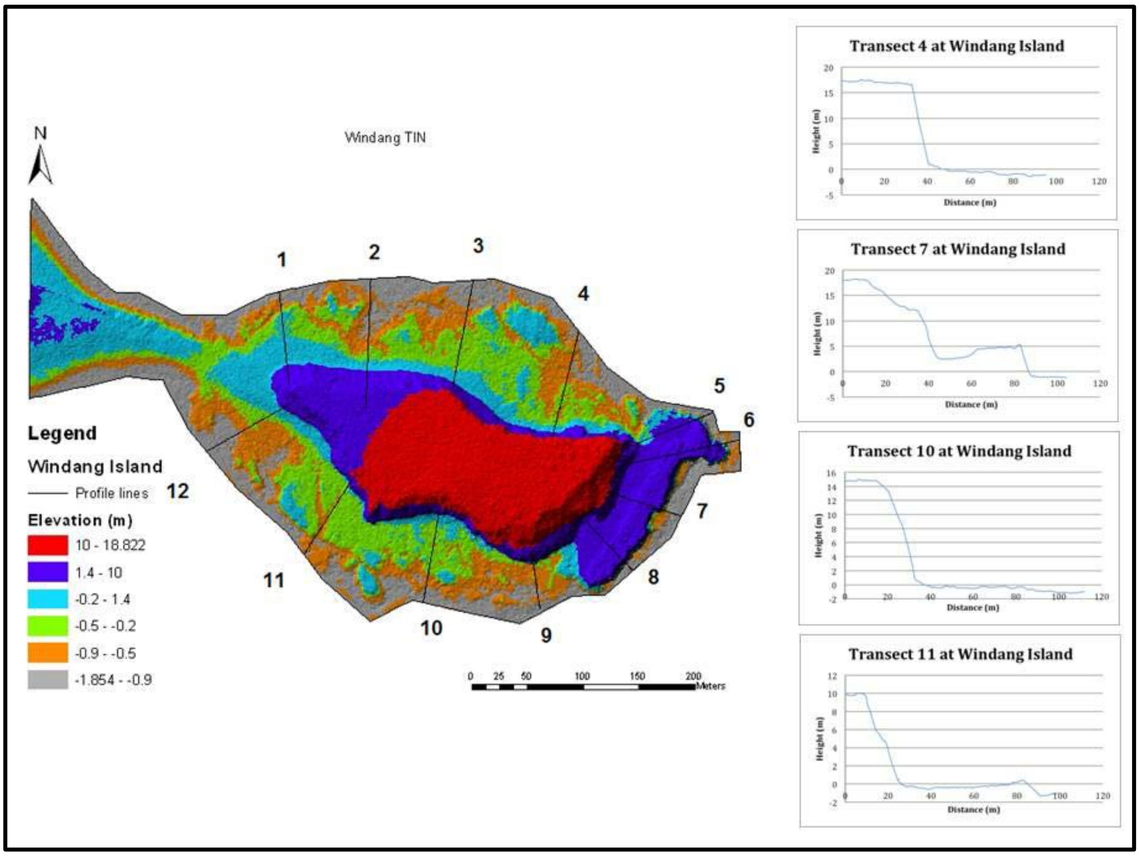


**Figure 3. Topography of Windang Island, showing the rock platform that surrounds the island. The Digital Terrain Model (DTM) is a Triangulated Irregular Network (TIN) derived from LiDAR. Transects illustrating the topography are shown at the right, indicating that in places the platform is gradually sloping, elsewhere it is near horizontal and on the eastern end of the island it has a prominent rampart.**

The topography that develops on rock platforms varies along the coast. LiDAR (Light Detection and Ranging, also called airborne laser scanning) offers a hitherto unprecedented opportunity to look in considerable detail at the morphology of sometimes otherwise inaccessible platforms (Palamara et al., 2007). In this preliminary assessment of the potential to describe the morphology of prominent headlands, an Illawarra example, Windang Island, has been examined using LiDAR to investigate the overall morphology of the platform and its apparent height in relation to sea level. This analysis is used as a guide to the process that may currently affect each platform, and those that may have contributed to their formation. It might be anticipated that platform width is related to wave energy (Abrahams and Oak, 1975); LiDAR offers a means of testing this without the need for prolonged field surveys. Combining this morphological analysis with wave modelling can then allow the development of a safety index that can be applied more generally along the coast of southeastern Australia, and then subsequently applied more widely, without having to physically visit every shoreline. The example selected in this exercise was tragically the scene of a recent drowning when a teenager was swept from the rocks in September 2010; it has been chosen because the rock platforms around the island are exposed on each of their northern, eastern and southern sides.

In Figure 3, the many LiDAR points are compiled into a Digital Terrain Model (DTM), called a Triangulated Irregular Network (TIN). The prominent rampart that runs along the seaward margin of this island is clearly visible, reaching in places more than 5 metres above sea level. Numerous transects can be derived from the LiDAR, showing the morphological detail of Windang Island where platforms are eroded into the tuffaceous sandstone. On this island the platforms on both northern and southern side are horizontal and appear of similar width on both the southern side which is more exposed to the prominent southeasterly swell, and the northern side which is more sheltered.

***Investigation of wave processes on platforms***

The impact of waves on the rocky coast has long been a subject of debate. Their impact has been difficult to resolve because of the inaccessibility of such platforms during extreme storm events, and even under calmer conditions. In the early literature such features were called ‘wave-cut platforms’, but it has increasingly been realised that there are other processes at work, and that similar platforms occur even in environments where wave action is limited (Kennedy, 2010). With the advent of modern instrumentation and computing, it is becoming possible to investigate wave interactions with shore platforms (Ogawa et al., 2011). Wave energy distribution and dissipation across a platform has recently been shown to be strongly influenced by such key morphological elements as the shape of its seaward edge, and its elevation and slope. However, it remains a challenge to identify exactly where waves will break and the hazard they pose to users such as rock fishers. In order to quantify the wave hazard on rocky coasts our project will adopt a range of methods to try to relate morphological and process elements to identify which areas are most dangerous. The morphological approach offers the opportunity to incorporate other evidence, such as the presence of wave-deposited boulders on platforms, and evidence of their movement during large storms (Saintilan and Rogers, 2005).

Incidents of drowning can occur during periods of relatively calm weather or be associated with ‘rogue waves’ which are difficult to measure. It has also been recognised that at-risk groups such as rock fishers underestimate rocky coast hazards and often overestimate their ability to cope with waves (Moran, 2008). In order to produce a risk assessment process which has applicability to the real-world and is able to input into existing management frameworks of SLSA, interviews and surveys will need to be conducted with users of the rocky coast in order to assess their perception of hazard. In this way both actual and perceived hazard will be investigated in order to produce an integrated risk model.

## Changing conditions on rock platforms

Although rocky coasts appear unchanging across geological time scales, they clearly do respond to environmental conditions. In this section we discuss the rates at which the platforms themselves change, gradual changes of boundary conditions such as sea level, and the day-today variations in tide and wave conditions which are the most conspicuous components of the proposed integrated risk model.

### *Platform erosion*

There have been several attempts to date the time of formation of rock platforms. Those in the northern Illawarra have been considered to be related to former Pleistocene sea-level highstands, based on the age of overlying sandy deposits (Brooke et al., 1994). One component of our program involves exploring whether cosmogenic dating can provide insights into when the platforms were truncated, and another involves longer-term monitoring of lowering rates along the Victorian coast.

Cosmogenic dating involves measurement of the accumulation of $^{10}Be$ in quartz grains as a consequence of exposure to cosmogenic radiation. We collected samples from the near-horizontal platform cut into the Westley Park Sandstone in southern Kiama, collecting rock from six sites on the platform or in the vertical cliff face to its rear. However, chemical digests of the rock samples revealed that there was insufficient suitable quartz in this tuffaceous sandstone to be able to derive an exposure age using cosmogenic nuclides. As a consequence, we have re-directed our sampling to a number of sites in the northern Illawarra. Samples were collected from Coalcliff, Sandon Point, and Thirroul. There are impressive platforms at these sites cut into the Hawkesbury Sandstone. Rates of lateral retreat of this prominent sandstone, a major component of the Illawarra escarpment, have been independently determined on geological and geotechnical grounds by Flentje (2012). Of the samples collected from Coalcliff, 6 were found to be suitable for cosmogenic nuclide analysis. These comprised a sequence of rock samples across the platform at increasing distances from the landward cliff face. Four samples produced Holocene ages (Figure 4), whereas another two appeared slightly older. Such ages appear to fit well with the suggestion that the platform is a landform that was shaped during a mid-Holocene highstand of the sea. The ages fall into a sequence that is older at the outer edge of the platform getting progressively younger closer to the inner margin of the platform. However, we consider it premature to infer that the platform was eroded across its entire width during the past few thousand years. Such rates are orders of magnitude faster than those proposed by Flentje (2012).

An alternative approach to determining the rate of erosion of rock platforms involves the use of micro-erosion meters, whereby stainless steel bolts are cemented into the rock, and the rock surface is measured around these at successive points over time using a specially designed micrometer. Rock platforms at Lorne, and adjacent sites along the Great Ocean Road, have been surveyed precisely and also have the distinct advantage that they contain 50% quartz suitable for cosmogenic dating. The site has been monitored for rates of erosion as a consequence of the installation of micro-erosion meters in the 1970s by Edmond Gill providing an unusually long record of lowering rate which averages around 0.3 mm/yr (Stephenson et al., 2012).

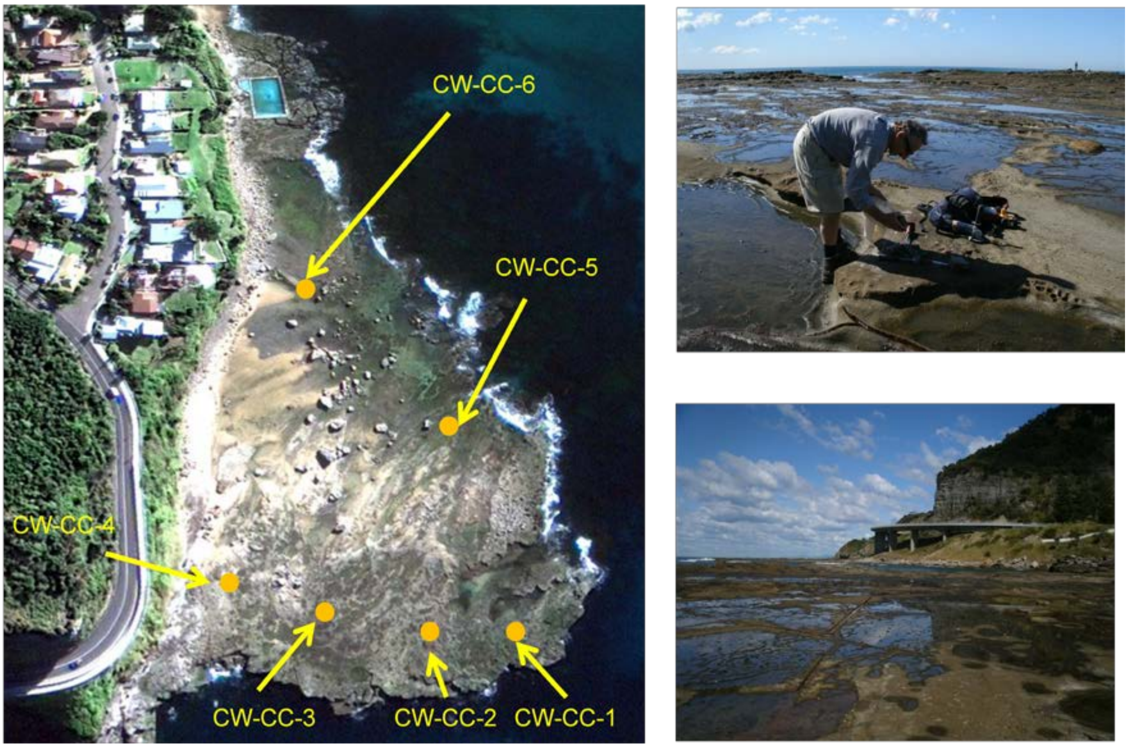


**Figure 4. Aerial image of the platform at Coalcliff with the location of the six samples for which ages can be derived marked. Collection of samples is shown in upper right, and the near-horizontal surface of the platform, adjacent to the Sea Cliff Bridge, can be seen in the lower right.**

While these are slow rates of change, it is also necessary to consider what effect observed and anticipated changes in sea level will have over coming decades. Tide gauge records indicate that the sea is increasing at all sites around Australia (Church et al., 2006). Rates in southeastern Australia appear to correspond broadly with the global average rate of sea-level rise, although in other parts of the nation greater rates of rise have been reported. Higher sea level is likely to accentuate the risks to those using rock platforms, with extreme wave events which wash across the surface occurring more frequently.

### *Tide and wave conditions*

In contrast to these long-term changes, it is the considerable variability in tidal and wave conditions which accounts for the variation in level of risk over time and from one platform to another. Tidal conditions can be predicted with great accuracy, and clearly it is important to reinforce the need for those using coastal areas for recreation to be aware of the stage and height of the tide. The greatest variability is in wave conditions, and a focus of our future research needs to be on the extent to which it is possible to forecast wave conditions in relation to particular rocky coastal sites. There are several different approaches to modelling the transformation of swell and wind waves across the nearshore. For example, numerical models such as SWAN, which simulates waves through a nested sequence of grids as they approach the coast (Hemer, 2009), provide one approach, whereas GIS-based methods based on fetch (Pepper and Puotinen, 2009) provide an exposure-based estimate. It requires further research to determine if these approaches offer insights into the likely size of large waves on rock platforms. An alternative would be to extend the surf forecasting methods already available over the internet to examine whether these provide useful information on likely wave conditions that could inform rock coast users such as rock fishers.

## Summary

Rock platforms are dangerous places, and the number of drownings on rocky coasts could be reduced if there was a greater understanding of the form of different rock platforms, the processes that operate on them, and the type of users and their pattern of use. The ABSAMP framework developed an approach that was able to quantify wave-driven sandy beach dynamics through the development of a model linking the shape of a beach and its surf zone with the size of the waves impacting that shore. This model was subsequently adapted into a drowning risk assessment and is now quite advanced and can deliver real-time information on beaches directly to mobile devices through products such as the Beachsafe App™. We have commenced a program of research which attempts to follow a similar sequence of steps to characterise rock platforms, understand the processes that operate, and develop an integrated risk model that can underpin assessments of risk on platforms and ultimately provide useful information to those who use these sections of coast. We believe that it is important to know the physical components of the system that influence wave transformation from deep to shallow water. Platform morphology is key; gently sloping surfaces will dissipate more energy offshore than those which are near-horizontal and have a seaward cliff. The elevation of the platform will also determine the degree of inundation that can occur each tidal cycle, as well as the size of waves necessary to allow water to cross its surface. Finally the depth of the seaward cliff base is also a key element as this will determine how much wave energy will impact the platform without breaking offshore. Collecting such information and then communicating it in ways that can better inform the user groups could help reduce the number of drownings and other incidents of this nature.

## Acknowledgements

The preliminary cosmogenic dating results referred to in this paper were undertaken at ANSTO as part of AINSE grant AINGRA11017; we thank David Fink for the analyses. Carrie Thompson is thanked for assistance with geospatial analysis of the LiDAR data.

## References


Abrahams, A.D. and Oak, H.L., 1975. Shore platform widths between Port Kembla and Durras Lake, New South Wales. Australian Geographical Studies, 13: 190-194.

Bird, E.C.F. and Dent, O.F., 1966. Shore platforms of the South Coast of New Souh Wales. Australian Geographer, 19: 71-80.

Brooke, B.P., Young, R.W., Bryant, E.A., Murray-Wallace, C.V. and Price, D.M., 1994. A Pleistocene origin for shore platforms along the northern Illawarra coast, New South Wales. Australian Geographer, 25: 178-185.

Carr, P.F. and Jones, B.G., 2001. The influence of palaeoenvironment and lava flux on the emplacement of submarine, near-shore Late Permian basalt lavas, Sydney Basin (Australia). Journal of Volcanology and Geothermal Research, 112: 247-266.

Church, J.A., Hunter, J.R., McInnes, K.L. and White, N.J., 2006. Sea-level rise around the Australian coastline and the changing frequency of extreme sea-level events. Australian Meteorological Magazine, 55: 253-260.

Dana, J.D., 1849. Geology. Report of the United States Exploring Expedition 1838-1842, 10. C. Sherman, Philadelphia, 756 pp.

Flentje, P., 2012. Evolution of the Illawarra escarpment terrain. Australian Geomechanics, 47: 1-16.

Hemer, M.A., 2009. Identifying coasts susceptible to wave climate change. Journal of Coastal Research Special Issue, 56.

Kennedy, D., 2010. Geological control on morphology of estuarine shore platforms, Middle Harbour, Sydney, Australia. Geomorphology, 114: 71-77.

Moran, K., 2008. Rock-based fishers' perceptions and practice of water safety. International Journal of Aquatic Research and Education, 2: 128-139.

Ogawa, H., Dickson, M.E. and Kench, P.S., 2011. Wave transformation on a sub-horizontal shore platform,Tatapouri,North Island, New Zealand. Continental Shelf Research, 31: 1409-1419.

Palamara, D.R., Dickson, M.E. and Kennedy, D.M., 2007. Defining shore platform boundaries using airborne laser scan data: a preliminary investigation. Earth Surface Process and Landforms, 32: 945-953.

Pepper, A. and Puotinen, M.L., 2009. GREMO: A GIS-based generic model for estimating relative wave exposure. 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation. Anderssen, R. S., Braddock, R. D. and Newham, L. T. H. Cairns (eds.), Australia**:** pp. 1964-1970.

Saintilan, N. and Rogers, K., 2005. Recent storm boulder deposits on the Beecroft Peninsula, New South Wales, Australia. Geographical Research, 43: 429-432.

Short, A.D., 2006. Australian beach systems: nature and distribution. Journal of Coastal Research, 22: 11-27.

SLSA, 2011. Surf Lifesaving Australia Annual Report 2010 - 2011.

Stephenson, W.J. and Kirk, R.M., 2000a. Development of shore platforms on Kaikoura Peninsula, South Island, New Zealand: II: the role of subaerial weathering. Geomorphology, 32: 43-56.

Stephenson, W.J. and Kirk, R.M., 2000b. Development of shore platforms on Kaikoura Peninsula, South Island, New Zealand: I: the role of waves. Geomorphology, 32: 21-41.

Stephenson, W.J., Kirk, R.M., Kennedy, D.M., Finlayson, B.L. and Chen, Z. 2012. Long term shore platform surface lowering rates: Revisiting Gill and Lang after 32 years. Marine Geology 299-302: 90-95.

Thornton, L.E. and Stephenson, W.J., 2006. Rock Strength: A Control of Shore Platform Elevation. Journal of Coastal Research, 22: 224-231.

Trenhaile, A.S., 2002. Rock coasts, with particular emphasis on shore platforms. Geomorphology, 48: 7-22.