COASTAL CLIFF LINE STABILITY AND REGRESSION IN THE NEWCASTLE REGION

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ABSTRACT

The cliff areas along the Newcastle coastline comprise an inter-bedded sequence of sedimentary rocks with layers of variable strength, weathering susceptibility and defect intensity that exert a strong control over cliff morphology and erosion. Coastal cliff line instability in the Newcastle region is predominantly a surface related phenomenon associated with ongoing erosion and degradation processes rather than a deep-seated instability problem. Risk is primarily associated with toppling failure of undercut sandstone blocks, fretting/sloughing of less resistant tuffaceous, shale and coal horizons and erosion of accumulated soil deposits (talus). Sandstone and conglomerate rock falls are predominantly associated with loss of support due to preferential erosion of weaker less durable materials and the presence of occasional low angle joint surfaces. This natural process has been going on for thousands of years and typically results in localised small scale instability problems.

The paper discusses three documented rock falls that have impacted on coastal infrastructure in the last 5 years and outlines the failure mechanisms involved, in particular the role of low angle joints.

Cliff regression along the Newcastle coastline is a process associated with long term slope degradation and erosion as well as periodic localised rock fall events. The paper assesses the rate of long term cliff line regression from literature review, analysis of historical photographs, direct survey and geological interpretation.

1 INTRODUCTION

The coastline of the Newcastle and Lake Macquarie region includes numerous pocket beaches and rocky headlands. This section of the coast trends in a general south-west to north-east alignment and is fully exposed to open ocean wave conditions with a relatively narrow and deep continental shelf.

The active cliffs that we now observe along the Newcastle coastline have assumed their present form only since the Holocene marine transgression brought the sea to its present level within the last 6500 years. In general the cliff sections of the coastline are characterized by a high tide shore platform (Bird, 1976) that typically comprises high strength, durable sandstone.

The overall slope of the coastal cliffs from toe to crest ranges from about 45° to 75° with localised flatter benches associated with the more erodible siltstone, tuff and coal materials and steeper scarps associated with the more resistant sandstone and conglomerate materials. Maximum height is in the order of 70 m.

The climate along the Newcastle coastline is typified by a maximum average temperature of about 25°C in summer and a minimum in winter of about 9° to 10° with average yearly rainfall of about 1100 mm (Bridgeman and Oliver, 1995).

The coastal cliffs of the Newcastle area occur in a dynamic coastal environment where exposure to the harsh marine conditions results in erosion and cliff regression. The coastal morphology is a product of both marine erosion and sub-aerial processes with the propensity for erosion of rock materials and associated cliff regression related to rock mass lithology and structure.

Cliff line instability is primarily a surface phenomenon related to ongoing erosion and degradation processes rather than deep-seated instability. Risk is primarily associated with toppling failure of undercut sandstone blocks, fretting/sloughing of less resistant shale/coal horizons and erosion of accumulated soil (talus). This natural process has been going on for thousands of years and typically results in temporal, small scale and localised instability.

2 GEOLOGY

The rocks exposed in the coastal cliffs in the Newcastle and Lake Macquarie are Permian Age (approximately 260 million years old) sedimentary rocks of the Newcastle Coal Measures.

The main structural feature is the Macquarie Syncline comprising a broad open fold with a north west curvilinear axis. To the south of the Shepherds Hill area, the cliff sections occur on the eastern flank of the Macquarie Syncline with gentle dips of typically 1° to 3° to the south west (into the cliff). A smaller structural feature, the Shepherds Hill Anticline, influences the dip of rock strata in the Newcastle to Bar Beach area. The anticline strikes north west with dips of typically 1° to 3° to the south west and north east (parallel to the cliff line). In general the rock strata exposed in the cliffs is near to horizontally bedded with some localised variations associated with faulting and depositional erosion features (washouts and slumps).

A feature of the Newcastle region is the frequency of near vertical orthogonal joints trending generally northwest and northeast with a maximum about 300° - 320° and 020° - 045° (Moelle et al., 1986). The northwest direction is parallel to the major faults and dykes. These joints occur on a regional basis but there is significant local variation in joint directions. The alignment of the coastline follows the general strike of the dominant 020° - 045° joint set.

Jointing is more intense in the weaker finer grained sedimentary rock (claystone, shale, siltstone and coal) and becomes more widely spaced with increasing grain size. Joint spacing in the sandstones is typically 0.5 m to 1.0 m and several metres to tens of metres in the conglomerates. The influence of joint systems on rock mass instability in the Newcastle region has been described by a number of authors (Delaney, 1985 and Moelle et al., 1996).

Joint infilling of grey clay material has been found by Adamson et al. (1987) commonly in sandstone. The clay infill can occur up to 50 mm thick and include intruded igneous materials (basalt and tuff). The clayey infill material can contribute to slope failure (Adamson and Moelle, 1988).

The regional stress field is characterised by high horizontal stress with respect to depth. Stress measurements from underground mining operations indicate high to very high horizontal stresses with respect to depth and a relatively balanced horizontal stress field, which are indicative of overburden removal by erosion. Coal rank studies have indicated that up to several kilometres of overburden materials have been removed by erosion in the geological past. This in conjunction with the region's relatively high horizontal stress field is a factor in the widening of existing rock mass joints along the coastal escarpments.

As well as variable strength, the rock types exhibit a highly variable durability. The sandstone and conglomerate rock types are the most resistant, however they undergo surface spawling of grains (sand and pebbles). The finer grained siltstone and shale rock types are less resistant and, on exposure, undergo fretting involving the breakdown into small blocky units which accelerates the rate of clay weathering. The tuffaceous claystone rock types typically have a high percentage of swelling clay and on exposure often weather to a highly plastic clay material.

Soil profiles are poorly developed along the cliff sections and usually involve a thin cover of clayey soil weathered from the underlying rock or an accumulation (wedge) of transported clayey and gravely materials on lower angle slopes or bench features. Some small scale localised rotational instability (slumps) can occur in these soil deposits, particularly in association with heavy rainfall.

3 COASTAL PROCESSES AND MORPHOLOGY

Coastal processes occurring along the cliffs involve a balance between erosive forces and resistive forces. The erosive forces are controlled by the weathering breakdown of the exposed rock materials with the principal agent of erosion being wave action, wind, rainfall and marine aerosol, spray and splash. The resistive forces are related to rock strength and structure.

Weathering involves both chemical and mechanical processes usually operating in conjunction. Chemical weathering involves the processes of hydrolysis (clay mineral formation), oxidation (formation of iron oxides) and solution (removal of carbonate minerals). Mechanical or physical weathering involves the following mechanisms: thermal stress, salt crystallization, swelling and shrinkage of clay minerals on wetting and desiccation.

Salt crystal growth in rock interstices can lead to stresses. The evaporation of sea aerosol, spray and splash in the interstices of porous rocks like sandstones and conglomerates can lead to granular disintegration (spawling) of the rock surface.

The inter-bedded sequence of sedimentary rocks, in which layers of variable strength, weathering susceptibility and defect intensity occur in the cliff face, exerts a strong control over cliff morphology and erosion. The principal mechanisms involved in the formation of the existing cliff morphology are:

- preferential erosion by sub-aerial or wave action of less resistant layers (siltstone/shale, claystone, coal) resulting in undercutting and loss of support for the more resistant higher strength sandstone and conglomerate layers which form blocks along existing defects.
- fretting/sloughing of less resistant shale, claystone and coal horizons

- accumulation and erosion of soil deposits (talus) along bench features.

Undercutting of resistant rocks by erosion of underlying softer beds and layers is a major erosional process that creates very rugged cliff profiles and contributes to rapid regression of cliffs. The variation in rock types over short vertical distances and their contrasting mechanical and chemical properties are responsible for this type of erosion, which is very prevalent in the Newcastle region (Moelle and Dean-Jones, 1995). Undercutting and removal of support also occurs in sandstone and conglomerate units through erosion of weathered materials by salt crystallisation and wind blown sand, resulting in angular and irregular rock overhangs and opening of joints.

Siltstone, where exposed, undergoes preferential weathering resulting in a surface layer of fretted and loosened material generally in the order of 100 mm to 200 mm thick.

The presence of loose blocks results from the opening of rock joints associated with stress relief, joint infill expansion, salt crystallisation and root growth and the removal of support by preferential weathering of underlying siltstone or weaker layers or general erosion of the rock mass.

The role of the existing vegetation cover (in particular Bitou Bush) in providing slope stabilisation along the cliff lines is critical, particularly across the flatter bench areas where the more erodible materials are exposed. The roots and lower branches of the Bitou Bush provide a dense mat that effectively binds the loose superficial soils (fill, talus and fretted siltstone / coal) and provides catchment and retention of rock fall materials. Where vegetation cover is not present, active erosion occurs. Bitou Bush is registered as a noxious weed, however its removal from the coastal cliff sections of the Newcastle coastline could have a major impact on cliff erosion.

4 CLIFF LINE INSTABILITY

Slope instability in the Newcastle regions is usually associated with the presence of thin low shear strength tuffaceous claystones layers that are inter-bedded with coal seams that often act as aquifers. Sliding usually involves translational movement along the sub horizontal claystone bedding planes. The cliff sections do not appear to be generally influenced by this form of slope instability as they are generally well drained and the rock materials behind the face are not significantly weathered.

Mass movement occurring along rocky coasts is of four primary types: falls, topples, slides and flows. The occurrence of these types of instability depends on geological factors such as rock type and structure and geotechnical factors such as rock strength and durability.

Modes of mass movement identified along the coastal cliffs of the Newcastle area comprise:

- Toppling failure of competent sandstone and conglomerate blocks due to erosional undercutting of weaker strata and / or adversely orientated (low angle) joints. The size of potentially detachable sandstone and conglomerate blocks is variable, ranging from about 0.1 m to 5 m in size.
- Shallow rotational / planar sliding in weak rock strata (claystone, siltstone) where the exposed surface has weathered to a soil strength veneer.
- Rotational sliding and flow of soil and debris deposits accumulated along flatter sections or benches of the cliffs.

There is a strong correlation between high rainfall events and the above forms (particularly the last two) of coastal instability in the Newcastle area.

The above modes of instability are surface phenomena related to ongoing natural erosion and degradation processes in the harsh coastal environment rather than a deep-seated instability problem. No deep seated instability has been documented in relation to the coastal cliff lines, however deep seated translational sliding has been documented by Fell (1995) at number of locations in the Newcastle – Lake Macquarie area where massive conglomerate units overlie coal and tuffaceous claystone materials. So this mechanism of instability cannot be discounted along the coastal cliff sections where this sequence occurs. The author has noted features suggestive of past large scale translational (block) sliding in areas where high conglomerate cliff sections overlie claystone and coal at or near sea level (Catherine Hill Bay and Redhead areas).

The dominant form of cliff line instability is toppling failure of sandstone / conglomerate blocks. As the cliffs are undercut, high tensile stresses develop in the overlying rock mass eventually leading to surface cracking or the dilation of existing joints behind the cliff face. After further weathering and softening of the undercut layers, commonly following a period of intense rainfall, the centre of gravity of the overhanging mass shifts, joint water pressures build up and eventually block toppling occurs.

Evidence of past instability in the form of rock fall debris can be observed at the base of all coastal cliff lines of the Newcastle region. There are a number of specific cases of cliff instability that have been documented and three of these are discussed in Section 5. In general the documented cases of cliff instability occur in areas of relatively high public exposure and not along the undeveloped cliff sections. Whilst such incidents may be observed by rock fishermen, the evidence is generally removed by storm events.

To the author's knowledge, no cases of cliff instability were documented as a result of the 1989 Newcastle Earthquake (5.6 Richter scale).

5 ROLE OF LOW ANGLE JOINTS IN ROCK FALL INCIDENTS

Rock falls along the Newcastle coastline occur in the more competent jointed sandstone and conglomerate rock units which are generally defined by near vertical orthogonal joints and sub-horizontal bedding surfaces.

This paper highlights the occurrence of adversely orientated and often hidden lower angle (i.e. 45° to 70°) joint defects that occasionally occur along the Newcastle coastal cliff lines. Whilst these "rouge" joints are likely to be infrequent, they can have a localised detrimental effect on the stability of rock faces as illustrated in the three case studies presented below.

As the location of these joints cannot be reliably predicted or observed, a conservative approach is required in assessing the stability of rock slopes.

5.1 SHORTLAND ESPLANADE – SOUTH NEWCASTLE BEACH

A rock fall occurred on 28th October 2002 at about 6 am during a dry weather period. No-one directly witnessed the fall and no-one was injured. The large joint defined rectangular sandstone block was estimated at 8 m^3 to 10 m^3 in volume and approximately 20 tonnes. The block comprised moderately weathered sandstone of estimated medium to high strength. The block came to rest on the footpath and roadway at the crest of a 7 m high seawall leaving an impact crater about 2.5 m by 2.5 m in area and 0.5 m deep in the road pavement and cracks in the asphalt pavement extending each side from the crater a distance up to 10 m.

The rock fall originated in a sandstone unit located half way up the cliff face, about 15m in elevation above the roadway with an overall slope angle of about 50° from the rock fall zone to the roadway.

Inspection of the rock fall area from an elevated work platform noted that the sides of the failure are defined by two planar side joint planes dipping at 75° to 80 ° with clay infill 10 mm to 30 mm thick. The rear joint surface is an irregular to curviplanar plane dipping down out of the cliff face, with the upper half of the surface dipping at approximately 80° and the lower part at about 50° to 55°. The rear joint surface has localised zones of clay infill and extremely weathered rock up to 100 mm thick.

Photograph 1, 1a: Rock fall at Shortland Esplanade and source zone.

A siltstone layer occurs at the base of the sandstone block with fretting of the outer 100 mm forming a dry crumbly soil material. The base area of the sandstone rock that was bearing on the siltstone layer appeared to have been about 2.9 m wide by 0.5 m to 1.1 m deep. Erosion of the siltstone has undercut the sandstone scarp up to 0.7 m in depth in the adjoining sandstone block to the north.

The rock fall mechanism appears to have involved toppling (rotation) failure. The key contributing factors are the presence of an adversely orientated hidden joint surface inclined at about 50° to 55° at the rear base of the block that significantly decreased the base area of the sandstone block that was supported on the underling siltstone layer and the progressive erosion and fretting of the siltstone. This mechanism is illustrated in Figure 1.

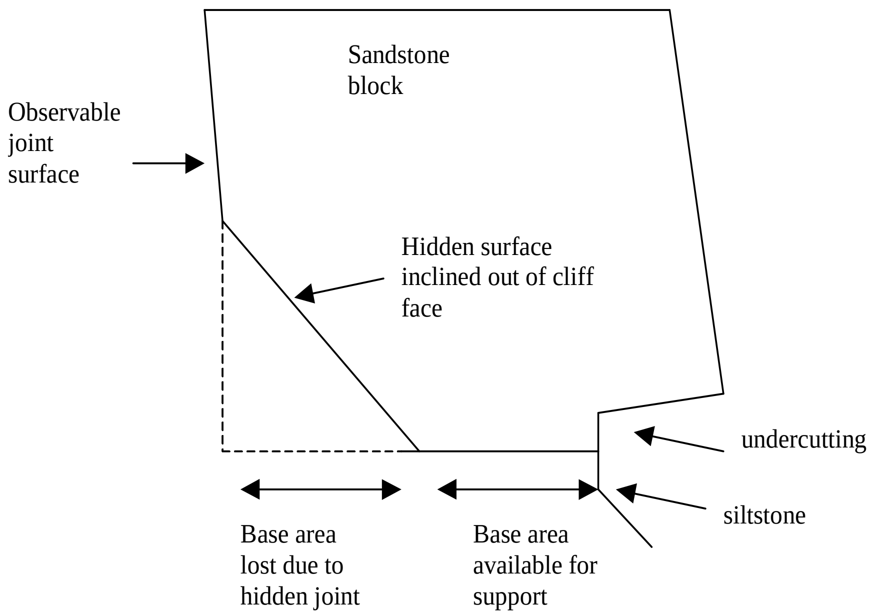

Figure 1: Sketch Illustrating Effect of Hidden Joint on Block Base Area.

It is considered that the block had been present in the cliff face with a factor of safety close to unity for years and that only minor erosion / crumbling of the siltstone base was necessary to upset the balance.

The presence of similar large sandstone blocks can be observed in the surf zone below the seawall, suggesting that large rock falls at this location are not an uncommon occurrence in the geological time scale.

5.2 BOGEY HOLE ROCK FALL – KING EDWARD PARK

A rock fall occurred overnight on the 18th to 19th September 2003 during an extended period of dry weather. No-one directly witnessed the fall and no-one was injured. The rock fall originated in a sandstone layer near the crest of the south-east facing slopes located directly above the Bogey Hole (convict excavated baths in the coastal rock platform). The slopes are up to 20 m to 25 m in height with a variable sloping / stepped gradient with localised steeper near vertical faces in the upper sandstone unit.

The rock fall appeared to have involved dislodgment of a sandstone wedge up to 1.5 m in size from a single location. The block split into three main rock fragments (0.5 m to 1 m in size) during the fall trajectory with fragments coming to rest near a picnic table, half way down the stairs to the baths and in the middle of the baths.

Inspection of the rock fall source area was undertaken with the rock fall comprising a wedge defined by the following joint surfaces (as looking at cliff face):

- Right side – planar joint striking 90° and vertical with clay coating / infill.
- Left side –irregular to curviplanar joint striking approximately 150° and dipping at about 50° down out of the cliff face with clay infill.
- Base surface at the junction of the above two joints of less than about 0.3 m thick.

Photograph 2, 2a: Rock fall at Bogey Hole, slope overview and rock fall fragment.

The rock fall wedge occurs in the middle of the sandstone layer and does not appear to be associated with weak siltstone / tuff materials. Localised opening of sandstone rock joints can be observed along the crest of the cliff.

The rock fall mechanism appears to have involved toppling of a wedge formed along intersecting joints. The primary causative factors are:

- Open joints with clay in-filled surfaces (common stress relief feature),
- Adversely orientated joint surfaces in particular a low angle joint surface inclined at 50° and
- Loss of base support through progressive erosion of the sandstone.

The rock fall appears to be a natural cliff erosion process associated with the presence of a sandstone wedge formed along an inclined intersecting joint surface that has progressively lost base support through erosion of the sandstone.

5.3 SUSAN GILMORE BEACH

Access to Susan Gilmore Beach was via a concrete pathway with wooden stairs leading down to the beach. A rock fall from the cliff face in May 2001 during a period of heavy rainfall resulted in rock fall debris demolishing the stairway as shown in Photograph 3.

The rock fall involved toppling failure of sandstone rock estimated at about 10 m^3 from the cliff face about 5 m above the top of the stairs. The rock fall debris ran out about 10 m onto the gentler slopes below the base of the cliff.

The sandstone layer comprises moderately weathered rock with sub-vertical joints typically spaced at about 0.5 m to 1 m with a slope gradient of about 60° that overlies inter-bedded siltstone and coal associated with the Dudley Coal seam and sloping at a gradient of about 45° above the pathway and stairs.

No evidence of erosional undercutting was noted along the base of the sandstone layer in the adjoining cliff sections and no evidence was noted in a photograph of the cliff taken in 1998 (Photograph 3b).

Access to the rock fall source area was not available. It is considered that the rock fall can be attributed to:

- The presence of a limonite stained planar rock joint surface that is inclined down out of the cliff face at about 60° and orientated sub-parallel to the cliff face.
- Water pressure within the rock joints during heavy rainfall.
- Progressive loss of rock mass strength associated with long term coastal weathering processes.

No irregular drainage features or concentration of surface catchment were noted in the area above the failure.

Photograph 3, 3a: Rock fall at Susan Gilmore Beach. Rock fall and source area on left (2001) and area before failure above (1998).

6 CLIFF LINE REGRESSION

Long term erosion and cliff line regression is the cumulative result of both ongoing breakdown and erosion of the soils and rock together with small scale temporal instability events such a rock falls and slides. The hazard from long term cliff erosion is in relation to the progressive loss of utilizable property, loss of public amenity and risk of rock falls.

Cliff regression is essentially an episodic and localised process associated with both long term slope degradation / erosion as well as short term storm induced erosion and instability associated with wave, rain and wind action. The actual erosion rate is the average value of the recession distance over a short period of time during which the actual erosion is actively occurring. The actual erosion rate is usually significantly greater than the long-term erosion rate where the length of time under consideration is typically 10 to 100 years. Erosion rates documented or recorded in sedimentary rock from around the world are presented in Table 1 and show a wide range of long term erosion rates. These values are averaged over periods ranging from 1 to 6000 years and over a certain long shore distance of coast.

Table 1: Recorded Cliff Line Regression Rates in Sedimentary Rock (Sunamura, 1992).

Location	**Rock Type**	**Erosion Rate (mm/year)**	**Interval (years)**	**Method**
Sturt Point, Victoria	Siltstone	17.5	6000	survey
Sturt Point, Victoria	Sandstone (arkose)	9	6000	survey
Point Peron, Perth	Limestone	0.2 – 1	9	Steel pegs
Kuji, Japan	Cretaceous sandstone	10	6000	surveys
Ngapotiki, New Zealand	Conglomerate	3500	29	Air photos
Yorkshire, England	Shale	9 - 20	1 - 60	Erosion meter, maps
Leucadia, California	Claystone and sandstone	0 - 500	5	Nails
La Jolla, California, USA	Cretaceous sandstone	0.3 – 0.6		Dated inscriptions
	Sandstone and shale	10 - 200	39	photos
Sunsets cliffs, San Diego, USA	Cretaceous sandstone siltstone	12	75	photos

Long term cliff line regression rates in the Newcastle area have been assessed based on historical records / photographs, survey records and the relationship between current cliff line morphology and the geological time scale with details presented below.

6.1 HISTORICAL REVIEW

A qualitative assessment of cliff line erosion over the past 100 years has been undertaken by comparing cliff profiles and features from historical photographs to the present. Two examples are presented below.

A photograph of Newcastle Beach taken in 1907 indicates the presence of a pathway leading down to the beach above the present skateboard park. Fence poles for the pathway can be observed on the present day cliff as well as the remains of a bitumen pathway surface. Assuming a path width of about 1 m to 2 m gives an erosion rate of about 1 m to 2 m in a period of 90 years (10 mm to 20 mm per year).

A photograph taken in 1907 in the picnic area below the vertical sandstone cliff at South Newcastle Beach shows a bracket on the sandstone rock face for wire cables. The same bracket is present today and there is a gap of about 90 mm between the bracket and the rock face where the face has eroded exposing the metal dowels supporting the bracket. This indicates an erosion rate of 1 mm per year for competent sandstone rock faces subject to sub-aerial weathering erosion. Examination of sandstone rock footings and block wall corrosion elsewhere indicates an erosion rate for more permeable sandstones of up to 3 mm per year with the higher strength less permeable sandstones as exposed on the rock platforms eroding at rates of less than 1 mm per year.

Moelle and Dean-Jones (1995) note that cliff line erosion rates indicated by undercutting of a railway line between Glenrock lagoon and a railway tunnel through the cliffs at Merewether are in the range of 1.5 m to more than 4 m over approximately 50 years (i.e. 30 mm to 80 mm per year). Shallow mine workings in the Victoria Tunnel Coal Seam with total extraction (goaf) occur in close proximity to the coastal cliffs in this area and this is likely to have an effect on the rate of cliff regression due to opening and loosening of rock joints within the angle of draw of the workings.

6.2 SURVEY ASSESSMENT

The number of old small scale survey plans in the Newcastle area that show the location of a permanent structure relative to a cliff edge is very limited. Assessment of cliff line regression based on comparing a measured set back of a permanent structure from a cliff edge relative to the distance as scaled from old maps, was undertaken at Nobby's Lighthouse and the corner of Watt and Ordnance Streets, Newcastle.

The lighthouse, signal station and original dwellings were constructed at Nobby's Headland in about 1857. An undated survey plan at a scale of 1 inch to 10 feet shows the location of the cliff edge relative to the structures. At three locations the crest of the cliff was measured to have regressed 1.0 m to 1.2 m relative to the location shown on the survey plan. A cliff regression rate of about 10 mm to 15 mm a year appears to be appropriate for the closely jointed and bedded siliceous tuff rock at this location.

The surveyor D.W. Maitland installed a road alignment post in 1864 at the corner of Watt and Ordnance Streets. A 1:475 survey plan by the Department of Lands Lithographic Branch in 1896 shows the benchmark located about 3 m from the crest of the cliff. The present cliff line is located about 0.5 m to 1.0 m from the survey mark. This suggests the cliff crest has regressed 2 m to 2.5 m in the last 100 years giving a cliff regression rate of about 20 mm to 25 mm a year in the conglomerate and pebbly sandstone material capping the crest of the escarpment.

6.3 GEOLOGICAL ASSESSMENT

The Newcastle coastline is characterised by horizontal rock platforms that extend up to 80 m out from the cliff bases. The rock platforms have formed on the more resistant and higher strength sandstone layers since the Holocene marine transgression some 6500 years ago. The platforms have formed and widened where the rate of landward erosion of the cliff exceeds that of the sandstone rock platform. The erosion / regression rate of the high strength sandstone rock that forms the rock platform is likely to be significantly (at least an order of magnitude) less than the erosion / regression rate of the cliff comprising inter-bedded layers of variable strength.

Shore platforms at relatively high levels have been interpreted in various ways. Cotton (1963) notes that in south-east Australia they are only generally submerged under spring high tides or under storm waves with the width of the “storm wave” platforms a function of the relative rates of front and rear regression. Fairbridge (1961) and Flood and Frankel (1989), suggest that the shore platforms are the product of wave abrasion at an earlier phase of the Holocene marine transgression when sea levels were slightly higher than present.

The width of the rock platform beneath high cliff sections (> 30 m height) at Shepherds Hill, Bar Beach, Merewether Beach and Burwood Beach is typically 60 m to 80 m. Assuming that the platforms have formed under relative static sea levels during the last 6500 years (Thom and Roy, 1985), estimates of the rate of cliff line regression due to preferential erosion above a resistant sandstone layer can be made as follows:

- Minimum regression rate of about 10 mm per year assuming nil erosion of the rock platform.

- Maximum erosion rate of about 2 mm per year for the sandstone platform gives a maximum regression rate of about 15 mm per year for the cliff sections.

6.4 RATE OF LONG TERM CLIFF REGRESSION

Rates of cliff line regression are highly variable and actual measurements are very limited. The variability of erosion rates depends on factors such as wave exposure, effectiveness of sub-aerial weathering processes, rock type, rock structure and cliff height. The rate of long term cliff line regression for the Newcastle coastline as assessed from various methods is presented in Table 2.

Table 2: Rates of Cliff Line Regression – Newcastle Coastline.

Method	Location	Rate (mm/year)	Comment
Historical	Newcastle Beach, Bogie Hole, Merewether.	1 - 40	
	Lloyd Street	30 - 80	Mine subsidence effects?
Survey	Nobbys	10 – 15	Direct survey
	Watt Street	20 – 25	Direct survey
Geological	Rock platforms	10 - 15	High cliff areas
	Rock platforms	Up to 25	Low cliff areas
Rock surface	Newcastle Beach, Dixon Park, seawalls	1 - 5	Erosion rate of sandstone exposures

In general the correlation between the various methods is good with a long term cliff line regression rate in the order of 10 mm to 25 mm per year (1 m to 2.5 m per 100 years) applicable for the higher inter-bedded cliff sections of the Newcastle coastline.

Factors that may result in an increase in the rate of cliff line regression above the typical rates shown in Table 2 are:

- Sea level rise resulting in direct wave impact at the base of the cliffs. The cliff sections are to a large degree protected by the sandstone rock platforms, however an increase in sea level would result in greater erosion of weaker coal and siltstone / shale seams that often occur along the base of the cliffs.
- Mine subsidence features (localized).
- Scour associated with storm water discharge (localized).
- The National Parks and Wildlife Service have listed Bitou Bush as a noxious weed and its removal from the coastal escarpments in the Newcastle area could have a major impact on the rate of cliff line erosion.

It is widely accepted that a world wide sea level rise is likely to occur during this century due to global warming with a sea level rise of about 0.5 m to 1 m widely noted in the literature. This is considerably higher than the average global sea level rise of 1 mm to 2 mm per year thought to have occurred over the last 100 years (Warrick and Oerlemans, 1990).

In a geological context, the projected rise in sea level is not unusual. During the last 250,000 years, many sea level fluctuations of up to 100 m have resulted from glacial and eustatic (tectonic) origin. The most recent is a rapid rise of up to 100 m in sea level (up to 10 mm per year) during the Holocene marine transgression some 6500 years ago. Since then sea levels have remained relatively stationary, although some minor fluctuations have been recorded.

Most of the attention associated with sea level rise has focused on beaches and coastal lowlands. A sea level rise of in the order of 1 m will greatly influence rocky coasts, in particular areas such as the Newcastle coastline, which is characterised by horizontal shore rock platforms. A rise in sea level may bring about submergence of the existing rock platforms resulting in a temporary landward shift of the shoreline.

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