Modeling the Effect of Weathering on the Evolution and Morphology of Shore Platforms

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ABSTRACT


A mathematical wave erosional model was modified to consider the effect of physical and chemical weathering on the development of shore platforms. Severe weathering was represented by a 75 percent reduction in rock strength at the mean high water spring tidal level, and moderate weathering by a 25 percent reduction. Rock strength was reduced at other intertidal levels by amounts proportional to the time of exposure of the platform surface to subaerial conditions. Each of the one hundred model runs was repeated for conditions representing no weathering, moderate weathering, and severe weathering conditions. Platform gradient decreased and width increased, at a declining rate, through the model runs, as the simulated platform profiles trended towards states of static equilibrium. Weathering increased the ability of the waves to continue eroding the cliff base and the upper portion of the platforms, and it therefore required more time for weathered than unweathered platforms to attain equilibrium. Platform width increased with the degree of weathering. The greatest proportional increase occurred on fairly narrow platforms (< 125 m wide) in resistant rocks, where, in some cases, weathering is essential in order for wave erosion to take place, whereas the greatest absolute increases occurred on wide platforms in weak rocks. Most equilibrium profiles in unweathered rocks were slightly concave, but they became more linear with increasing amounts of weathering. There was no relationship between the elevation of the cliff-platform junction and the degree of weathering. Because high waves break in deeper water than lower waves, and therefore dissipate more of their energy in crossing wide surf zones, the relationship between weathered and unweathered platform morphology and exposure to strong wave action is complex. The model suggests that the role of weathering is generally secondary to mechanical wave erosion, although its importance increases with weathering intensity and the resistance of the unweathered rock.

ADDITIONAL INDEX WORDS: Rock coasts, geomorphology.

INTRODUCTION

Much of the century old debate on the origin of shore platforms was concerned with the relative roles of mechanical wave erosion and weathering. Whereas most workers have accepted that mechanical wave erosion is the main erosive mechanism on the gently sloping shore platforms of the North Atlantic, some workers have attributed the formation of quasi-horizontal platforms in Australasia, Japan and Hawaii to chemical or salt weathering (BARTRUM, 1916, 1935; WENTWORTH, 1938; BIRD and DENT, 1966; SANDERS, 1968; HILLS, 1971; SUNAMURA, 1992; STEPHENSON and KIRK, 1998). Nevertheless, although quasi-horizontal platforms have been attributed to cliff weathering or the modification of sloping, wave-cut ramps by weathering, most theories accord an important role to the erosion and removal of weathered material by waves (TRENHAILE, 1987). Other workers have discussed

LIST OF SYMBOLS AND ABBREVIATIONS

C—coefficient to represent differences in the force exerted at the waterline by plunging, spilling or surging-collapsing breakers
E,—amount of submarine erosion over the iteration interval
E,—amount of intertidal erosion over the iteration interval
E,—wave force at the breakers
g—acceleration due to gravity
h—water depth
h,—breaker depth
H,—breaker height
H,—deep water wave height set consisting of five wave heights
H,1 to H,5
k—surf attenuation factor related to bottom roughness
L—deep water wavelength
M—coefficient (6.5 x 10^-10) to convert the excess surf force into the amount of intertidal erosion during each model iteration
MHWN—mean high water neap tidal level
MHWS—mean high water spring tidal level
MLWN—mean low water neap tidal level
MLWS—mean low water spring tidal level
MT—mean tidal level
Q—a cliff-foot protection factor related to the amount and persistence of the debris at the cliff foot
s—submarine erosion depth decay constant
S,—surf force at the waterline
S,—threshold erosional strength of the rocks
T—wave period
T,—tidal duration factor, the number of hours each year in which the water level is at each intertidal elevation
T,—spring tidal range
W—hourly number of waves of each of the five deep water heights
W,—surf zone width
δ—initial surface gradient
p,—unit weight of water
the relative importance of mechanical wave erosion, sea ice and frost weathering in producing shore platforms and strandflats in high latitudes (NANSEN, 1922; GUILCHER, 1974; DAWSON, 1980; TRENHAILE, 1983a, 1997; MATTHEWS et al., 1986; ROBINSON and JERWOOD, 1987a,b; DIONNE and BRODEUR, 1988).

Mathematical models have been used to study the effect of submarine erosional processes in tideless seas (FLEMING, 1965; HORIKAWA and SUNAMURA, 1967; SCHEIDEGGER, 1970; SUNAMURA, 1976, 1977, 1978). Only a few models have considered the effect of mechanical wave erosion on the evolution of shore platforms in the intertidal zones of macro- to micro-tidal environments (TRENHAILE and LAZZELL, 1981; TRENHAILE, 1983b, 1989; TRENHAILE and BYRNE, 1986), however, and none have attempted to model the combined effects of weathering and mechanical wave erosion.

**PHYSICAL AND CHEMICAL WEATHERING**

The characteristics of freeze-thaw cycles and the amount of time available for a rock to absorb water are determined by the tidal regime and by the rock’s position within the intertidal zone. Tidally induced frost action occurs in the intertidal zone when rocks freeze when exposed to air by the falling tide, and thaw when covered by the rising tide. Laboratory experiments demonstrate that rock temperatures rapidly increase when inundated in sea water, but they also indicate that they decline very slowly when exposed to air (LAUTRIDOU, 1971; ROBINSON and JERWOOD, 1987a). This suggests that freeze-thaw cycles are most frequent in the upper portion of the intertidal zone, which is exposed to air for the greatest amount of time. This part of the platform also experiences most of the cycles related to air temperature fluctuations, as well as those which are induced by tidal ebb and flow. Tidally induced frost action was simulated in the laboratory using air and water temperatures measured in the field in southern England. Field and laboratory results suggested that there was a fairly strong relationship between the proportion of the platform surface that experienced the effects of surface frost action and the degree of exposure of each section of the platform during tidal cycles (ROBINSON and JERWOOD, 1987a,b).

Salt weathering plays an important role in the disaggregation of rocks in the intertidal and supratidal zones. The absorption of water by hydration causes salt crystals to swell and to exert pressures against the constraining walls of rock capillaries. The alternate hydration and dehydration of entrapped salts can occur many times in a single day, and the process is probably most effective where changes in temperature and humidity cause the entrainment thresholds to be crossed most often. The crystallization of salts from supersaturated solutions can also exert disruptive pressures within rocks. In the coastal zone, wind facilitates salt weathering, but several days of strong evaporation without rainfall or spray are necessary to crystallize solutions within rock capillaries (EVANS, 1970). Supersaturation and crystallization may also be a result of changes in temperature. Salt hydration and crystallization weathering are therefore related to the degree of exposure of the platform surface, and they are probably most effective in the upper intertidal zone which experiences the greatest variations in temperature and moisture content.

BARTRUM (1916) proposed that shore platforms, a little below the high tidal level, are formed in sheltered locations by weak waves, which wash away the chemically weathered debris above the level of permanent sea water saturation. Shore platforms are also lowered, smoothed, and levelled by weathering processes collectively referred to as ‘water layer leveling’, that operate around the margins of rock pools. Water layer levelling is induced by alternate wetting and drying and several workers have therefore proposed that the processes operate down to the elevation at which the rocks are permanently saturated with sea water (BIRD and DENT, 1966; SANDERS, 1968; DAVIES, 1972; TAKAHASHI, 1977). Field and laboratory work has demonstrated that there is a gradual transition in the water content of rocks from the high to the low tidal levels, however, which suggests that there is also a gradual downward decrease in the intensity of chemical weathering and water layer levelling within the intertidal zone (TRENHAILE and MERCAN 1984).

**THE MODEL**

TRENHAILE (2000) used a wave erosional model to study the development of wave-cut shore platforms under stable sea level conditions; as with all previous attempts to model platform evolution, this study did not consider the potential effects of weathering processes. The present paper reports on a modification of the model to investigate the role of weathering processes, and how they affect the complex interactions that exist between wave dynamics, tides, and shore platform morphology. The derivation and structure of the model are discussed in detail elsewhere (TRENHAILE, 2000), and to avoid repetition only a fairly brief review is provided here.

Most mechanical wave erosion on sloping shore platforms is accomplished by broken waves, and the model was based on the assumption that most of this erosion, by water hammer and the compression of air in rock cavities, occurs at the water surface, at the surf-rock interface where there are alternations of air and water (TRENHAILE, 1987). The possible effect of shallow water abrasion in the swash zone and in the surf zone seawards of the waterline was not considered in the model because of the computational assumptions that would have been necessary and because abrasion is not an important process on most shore platforms. Nevertheless, the model is not, in its present form, applicable to those situations where there is significant platform abrasion by sand and gravel in the surf and swash zones.

The model considered tidal range ($T_t$) and the tidal duration factor, the number of hours each year in which the water level is at each intertidal elevation ($T_{i}$). Tidal duration values were obtained for the mean tidal level (MT) and the mean high water spring (MHWS), mean high water neap (MHNWN), mean low water spring (MLWS) and mean low water neap (MLWN) tidal levels for macrotidal Swansea, Wales, and mesotidal Burnie, Tasmania, using the data provided by CARR and GRAF (1982). Other variables included deep water wave height ($H_o$, two sets of incident waves were used, each con-
sisting of five heights, H1 to H5), the hourly number of waves of each deep water height category (W1 to W5), deep water wave length (L) and period (T), breaker height (Hb) and depth (hb), the force exerted by different types of breaking wave (C), surf zone width (Ws), a surf attenuation factor related to bottom roughness (k), the gradient of the submarine slope, the water depth (h), the threshold erosional strength of the rocks (Sfmin) and a factor related to the amount and persistence of the debris at the cliff foot (Q). The linear initial surface had a gradient (δ) of 30°, representing a previously unplanated surface. Most other variables were assigned one of two possible values in each model run (Table 1).

According to the C.E.R.C. (1984), the wave force at the breakers (Fb) is given by:

\[ Fb = 0.5\rho_w h_b \]  

where \( \rho_w \) (1025.22 kg m\(^{-3}\)) is the unit weight of water. Waves break when:

\[ H_b = 0.78h_b \]  

Therefore, from (1) and (2):

\[ Fb = 0.5\rho_w (H_b/0.78) \]  

According to KOMAR and GAUGHAN (1972), the height of the breakers can be determined using the expression:

\[ H_b = 0.39g^e/(TH_s)^{0.4} \]  

where \( g \) is the acceleration due to gravity. A decay function was used to approximate the force of the surf force reaching the waterline (Sf):

\[ S_f = 0.5\rho_w(H_b/0.78)e^{-kW_s} \]  

The resistance of the rocks was represented by a threshold minimum surf force term. Surf which generated forces lower than this minimum value at the waterline, because of the height and type of breaker and wide and irregular surf zones, was unable to erode the rocks. Therefore, for each broken wave, the excess surf force available for rock erosion was given by:

\[ 0.5\rho_w(H_b/0.78)e^{-kW_s} - S_{fmin} \]  

Incorporating the tidal duration value and the number of waves over the iteration interval provided an equation for intertidal erosion at the head of the surf zone (Eg):

\[ E_g = M \sum_{W=1}^{5} (T_5W(512.61C(H_b/0.78)e^{-kW_s} - S_{fmin})) \]  

where 0.5\( \rho_w = 512.61 \text{ kg m}^{-3} \), M is a coefficient (6.5 \times 10^{-10} ), and Eg is the total erosion for W = W1 to W5, for each deep water wave height category, at a specific intertidal level. This calculation was repeated at the end of each iteration for each of the five intertidal levels. During a model run, erosion could occur at a particular time and place with all or none of the five wave height categories, or with only some of the waves in the wave set.

Submarine erosion, from the MHWN tidal level to a depth of 0.5 L below the MLWS tidal level (Ee) was calculated using a decay function of the form:

\[ E_e = E_g e^{sh} \]  

where: s is a depth decay constant.

The function of frost, salt and chemical weathering is to reduce the resistance of the rocks, making them more susceptible to wave erosion and transportation. Weathering cannot, by itself, produce shore platforms. If weathered materials retain enough strength to resist wave erosion, or if the

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Table 1. The value of the variables and constants used in the model runs (S.I. units). Each column is independent of the others, and no horizontal correlation is implied between them.

<table>
<thead>
<tr>
<th>Tr</th>
<th>k</th>
<th>s</th>
<th>Q</th>
<th>Sfmin</th>
<th>T</th>
<th>δ</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>H4</th>
<th>H5</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.01</td>
<td>1</td>
<td>0.2</td>
<td>20</td>
<td>3</td>
<td>30</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>9</td>
<td>0.1</td>
<td>2</td>
<td>1</td>
<td>100</td>
<td>20</td>
<td>20</td>
<td>0.4</td>
<td>0.9</td>
<td>1.4</td>
<td>1.9</td>
<td>2.4</td>
</tr>
</tbody>
</table>

A high k value represents irregular surf zones with high rates of attenuation, whereas a low value represents a smooth surf zone with low attenuation.

The fastest rate of submarine erosion occurs when \( s = 1 \). When \( Q = 1 \) no debris accumulates at the cliff base. When \( Q = 0.2 \), debris accumulation reduces erosion at the cliff base by one-fifth. Wave heights H1 to H5 occurred for 40, 30, 20, 7 and 3 percent of the time, respectively, in both incident wave sets. Wave period was the same (either 20 or 3 s) for each of the five wave heights in the two wave sets.
waves are too weak to remove the weathered debris, platforms cannot develop or continue to evolve. As the model assumes that the erosion and removal of weathered material are dependent on the forces that are applied by wave action, it may not be applicable to situations where weathering produces very fine material which is removed in suspension.

In the model the effect of weathering was considered by reducing rock strength \( (S_{\text{frnin}}) \) according to the degree of subaerial exposure of each portion of the intertidal platform surface. Two weathering conditions were used in the model. To represent severe weathering, the strength of the rocks at the mean high water spring tidal level was reduced by 75 percent, and more moderate weathering was represented by a 25 percent reduction in rock strength. The strength of the rock at the other intertidal levels was then made proportional to the degree of exposure, using the data of Carr and Graff (1982) for Swansea and Burnie (Fig. 1, Table 2).

To compare the development of platforms in the absence of weathering with their evolution under severe and moderate weathering conditions, one hundred model runs were repeated for each of the three weathering conditions, using the same values for each of the other variables. The runs were made for one million iterations; this cannot be converted into real time units because of the influence, and uncertainty over the value of the constant, \( M \). This constant was used to convert the force exerted at the surf-rock interface into the intertidal erosion accomplished during each iteration. The value of the constant controlled the rate of erosion and profile modification during model runs, but not the form of the simulated equilibrium profiles. In the absence of any relevant field or experimental data, equation (7) was used to determine a value for this coefficient which provides rock erosion rates that are reasonably consistent with field measurements.
RESULTS

The gradient of the simulated platform profiles progressively decreased and the width increased, at a declining rate, in the model runs (Figs. 2 and 3). Faster erosion at the mean low water spring tidal level, which experiences alternations of air and water, than in the subtidal zone, produced a wide, gently sloping, shallow submarine surface. Waves therefore broke further from shore at low tide than at high tide, and this caused wave erosion to decline more rapidly at the low tidal level than at the cliff base (Fig. 4). Declining intertidal and submarine gradients eventually caused the simulated platforms to attain a state of equilibrium, with no further increases in width; in most runs this required at least 300,000 iterations. All equilibrium was static. It occurred when, because of decreasing slope gradients, the wave-induced force at each point in the intertidal zone became too weak to continue eroding the rock (Fig. 4).

In all model runs, platforms required longer to attain equilibrium as the degree of weathering increased. In runs with moderate amounts of weathering, simulated platforms frequently required about 100,000 more iterations to attain equilibrium than in runs with no weathering, whereas 400,000 or more iterations were needed in runs with severe weathering. In the absence of weathering, as platforms become more gently sloping, the waves break further from shore and consequently lose more of their energy in crossing wide surf zones. Weathering weakens the rocks at the high tidal level, however, and despite increasing wave and surf attenuation as platforms become wider, the reduced erosional threshold allows wave erosion to continue for much longer at the cliff base. Therefore, where there is severe weathering, equilibrium cannot occur until the strength of the surf at the high tidal level has become less than the weathering reduced rock erosional threshold.

The effect of weathering on the attainment of equilibrium conditions was most marked on narrow platforms (< 50 m wide) which developed in runs with resistant rocks, high k values and high breaker heights. In the absence of weathering, or with only moderate weathering, these platforms attained states of static equilibrium long before it was attained in the same runs with severe weathering (400,000 to 500,000 iterations compared with 1,000,000). High breakers are more energetic than low breakers, but they break further from shore and therefore dissipate more of their energy in crossing wide surf zones. Although the equilibrium gradients were

(see tabulations in Sunamura, 1973 and Kirk, 1977). Erosion rates are very sensitive to the M value, however, and accordingly, the model should be considered to represent time units only in a relative, rather than an absolute, sense.
fairly high on these narrow platforms (3 to 5°), the model suggests that, with a 5° slope, $k = 0.1$ and breaker heights of more than 1 m, the surf energy at the waterline decreases as breaker height increases (TRENHAILE, 2000). Consequently, the surf force generated at the waterline by high breakers became less than the erosional threshold of the rocks before that associated with low breakers, and narrow platforms therefore needed fewer iterations to attain equilibrium in runs with high breakers than in runs with low breakers.

Most equilibrium profiles were slightly concave in the absence of weathering, but they became more linear with increasing amounts of weathering. Platform gradient at all intertidal elevations decreased with increasing weathering. This is consistent with the direct relationship between platform gradient and rock strength in the field (SANDERS, 1968; TRENHAILE, 1972, 1978, 1987; KIRK, 1977), and in other mathematical models (TRENHAILE and LAYZELL, 1981). GILL and LANG (1983) proposed that the ultimate equilibrium platform profile in Victoria, Australia, is graded to the low tidal level, and they attributed the occurrence of gently sloping ramps to the lack of time for an equilibrium profile to be attained in resistant rocks; the model provides some support for this.

Figure 4. Simulated rates of erosion at the high (MHWS) and low (MLWS) tidal levels in run 64.
contention. The model also suggests that narrow (< 50 m wide) platforms in resistant and unweathered rocks can have equilibrium profiles in low tidal range environments that extend up to the mean high water spring tidal level and slope seawards with gradients of up to 6°.

There is a tendency in the field for the junction between the cliff and shore platform to be higher in areas of harder rock than in weaker rock (Wright, 1967; Trenhaile, 1972). Whereas weathering makes it easier for the lower portion of shore platforms to be extended at the expense of the higher areas, the occurrence of weaker weathered rocks in the upper parts of the platform also facilitates erosion and landward extension at the high tidal level. These two influences essentially counteract each other, and the degree of weathering therefore had almost no influence on the height of the cliff-platform junction in the model.

The model has previously demonstrated that there is a direct relationship between platform width and tidal range, and an inverse relationship with rock resistance, the degree of irregularity of the platform surface (k value), the amount and persistence of the cliff foot debris (Q value), and wave period (Trenhaile, 2000). The present study suggests that platform width also increases with the degree of weathering. Platform width and absolute weathering induced increases in width tend to be greatest in high tidal range environments, but the highest proportional increases are on the generally narrower platforms in low tidal range environments. Equilibrium widths were usually 3 to 3.5 percent greater with severe than moderate weathering with high tidal range, and 4 to 4.5 percent greater in the low tidal range environment. Severely weathered platforms were frequently more than 30 percent wider than unweathered platforms in runs that produced fairly narrow platforms (up to 125 m wide). They occurred in high and low tidal range environments, in runs with hard rock and usually high k values which were not conducive to rapid wave erosion; weathering was therefore able to significantly increase the erosive efficacy of the waves. Conversely, low percentage increases in width (<10 percent) occurred in runs with high and low tidal range environments, weak rock and mainly low k values, which produced wide platforms (200 to 500 m in width). In such cases, wave erosion was able to operate efficiently in the absence of any weathering, although weathering did increase its effectiveness to a small degree. In sheltered or weak wave environments, resistant rocks are almost immune to wave erosion, and wave and surf attenuation can cause erosion of less resistant rocks to stop once a narrow platform has developed. Weathering induced reductions in the rock erosion threshold can therefore allow wave erosion to significantly increase the width of narrow shore platforms, whereas the effect of weathering on wide platforms in weak rocks in areas exposed to strong wave action is proportionately much less.

**DISCUSSION**

Micro-erosion meter measurements suggest that weathering is the dominant process on subhorizontal shore platforms in low tidal range environments in Australasia (Stephenson and Kirk, 1998). Waves presently dissipate much of their energy in crossing gently sloping shore platforms, however, and assessments of the relative importance of the formative processes cannot be based on contemporary measurements of erosion rates within very small portions of the platform surface. Modeling represents one of the only ways to determine the relative roles of mechanical wave erosion and weathering, integrated over long periods of time, in determining contemporary platform morphology. The model demonstrates that wave and surf zone energy is increasingly dissipated in crossing shore platforms as they become more gently inclined and trend towards an equilibrium state (Trenhaile, 2000); under such conditions, wave erosion essentially ceases and weathering must then become dominant.

Shore platforms can only be in dynamic equilibrium if the rate of erosion at the high and low tidal levels are equal. Erosion rapidly decreases and eventually ceases at the low water spring tidal level because of the gentle slope produced by fairly rapid erosion in the intertidal zone and slow erosion in the submarine zone below (Fig. 4). The erosion rate at a depth of 1 m was less than half the erosion rate at the waterline, for the most rapid rate of submarine erosion considered in the model (the depth decay constant, s = 1). Increasing the relative efficacy of wave induced submarine erosive processes would delay the attainment of an equilibrium state, but more gentle submarine gradients, in comparison with the intertidal zone, would still prevent the rate of erosion at the low tidal level from becoming equal to that at the high tidal level, and it could not prevent the submarine gradient from eventually becoming so low that wave erosion at the low tidal level would stop.

The model suggests that weathering influences the width, gradient, and other elements of the morphology of shore platforms. In general, however, even severe weathering, which reduced the strength of the rocks at the high tidal level by 75 percent, only played a secondary role in platform development. In 53 percent of the model runs, for example, the introduction of severe weathering conditions increased the equilibrium width of unweathered platforms by less than 20 percent. The model therefore suggests that the morphology of platforms that are cut by waves that are powerful enough to erode severely weathered rocks is determined more by wave and tidal conditions than by weathering. Weathering was of greater importance in runs with resistant rocks in weak wave environments, however, and equilibrium platform width was more than 40 percent greater under severe weathering conditions than with no weathering in 29 percent of the runs. It is conceivable that platforms can only develop in rocks that are severely weathered in environments that are less conducive to effective wave action than were considered in the present study. In such cases, the role of the weak waves would be essentially limited to removing the weathered debris, and weathering would therefore play an important role in determining platform morphology. This conclusion is consistent with some elements of Bartrum’s (1916) Old Hat theory, although there is no evidence that this type of platform is associated with a permanent level of saturation within the intertidal zone.

Static equilibrium is attained when the wave generated forces become too weak to erode the rock. Platforms could
continue to evolve, however, if fine-grained, weathered material was carried away in suspension. Water layer levelling and other weathering processes could continue to flatten and lower the upper portions of the platform surface, periodically allowing renewed wave erosion at the cliff base, until, because of increasing platform width and decreasing gradient, the waves eventually became too weak. Continued weathering and suspended sediment transport would ultimately produce a gently sloping or horizontal platform at the low tidal level, below which the rocks are permanently saturated with sea water.

The model assumed that the degree of weathering is determined by the exposure, during a tidal cycle, to subaerial conditions. As previously noted, there are laboratory and field data from a number of sources to support this contention for frost action, but there is less information on the relationship between chemical and salt weathering and tidal elevation. Although the available evidence suggests that the efficacy of these processes is also dependent on the degree of tidal exposure, it is possible that they operate more uniformly over the entire platform surface. This situation occurs, albeit for entirely different reasons, on the coast of Galicia in northwestern Spain, where shore platforms were cut during the Quaternary into rocks that were previously chemically weathered in the Tertiary (Trenhaile et al. 1999). In such cases, weathering reduces rock resistance uniformly, and the morphology of the platforms would be similar to those cut into weak, unweathered rocks by wave action. These platforms have lower cliff-platform junctions and they are wider and more gently sloping than platforms in more resistant rocks (Trenhaile, 2000).

CONCLUSIONS

The main conclusions of the present study include the following:

1) The negative feedback relationship between the wave generated erosive force and the width and gradient of shore platforms causes them to trend towards a state of static equilibrium, in which their morphology remains constant through time. Platform weathering increases the ability of waves crossing wide, gently sloping platforms to continue eroding the cliff base and the upper portion of shore platforms, and weathering therefore increases the time required for platforms to attain a state of equilibrium.

2) Weathering differentially weakens the upper portion of shore platforms, and increases platform width. The greatest absolute weathering induced increases are on wide platforms formed in weak rocks, but the greatest proportional increases in platform width occur on narrow platforms where weathering may be an essential precursor to the erosion of resistant rocks. Although weathering is an important component in the development of shore platforms in weak wave environments, because large waves break in deeper water, and therefore dissipate their energy over wider surf zones, it can also be important for platform development in more exposed areas.

3) In the absence of weathering, shore platforms tend to develop slightly concave equilibrium profiles in homogeneous rocks, whereas weathering encourages the development of more linear profiles.

4) There is no relationship between the elevation of the cliff-platform junction and the degree of weathering.

5) Weathering may be the dominant influence on the development of narrow shore platforms in resistant rocks in sheltered environments, and it may be the only process able to operate on very gently sloping platforms today. Weathering plays a significant role in influencing the gradient, width and other aspects of platform morphology, and in determining rates of platform development. Nevertheless, the model suggests that the overall morphology of shore platforms is normally determined by tidal control of the distribution of wave energy within the intertidal zone. Any portion of a shore platform consisting of weaker rock than other portions of the platform is eroded more rapidly, and it becomes wider and more gentle sloping, which, in turn, eventually reduces the rate of erosion. Therefore, although weathering reduces rock resistance and facilitates rapid wave erosion, its influence is limited by the controlling negative feedback relationship between platform gradient and rates of wave and surf attenuation.

LITERATURE CITED


SUNAMURA, T., 1973. Coastal cliff erosion due to waves—field investigations and laboratory experiments. *Journal of the Faculty of Engineering, University of Tokyo*, 32, 1–86.


