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THE ROLE OF MASS-MOVEMENT IN SHORE PLATFORM DEVELOPMENT ALONG THE GISBORNE COASTLINE, NEW ZEALAND

R. F. McLEAN
University of Canterbury
Christchurch

C. F. DAVIDSON
Karamu High School
Hastings

Abstract

Tidal shore platforms form a conspicuous part of the coastal scenery north of Gisborne, New Zealand. Some of these platforms are being extended landward under present-day conditions. Present widening results primarily from cliff-retreat by mass-movement. The coincidence in distribution of areas of wave convergence, mass-movement and shore platforms suggests a genetic connection between these marine and subaerial process and response elements. Various types of mass-movement are involved in cliff-retreat, notably slumps, flows, debris slides and soil and rock falls. While the products of such mass-movement forms are removed by wave action, extensive boulder fields on some shore platforms indicate that removal is not always complete. Not all of the shore platforms on this coast are being widened at present. Widening has ceased where active mass-movement is not occurring.

INTRODUCTION

Shore platforms are distinctive features of many erosional coastlines. They have been reported from many parts of the world and the English literature alone includes many papers about their description, formation and geomorphic interpretaation. Significant contributions to this literature have been made by workers around the Pacific region including California (Emery, 1946; Shepard and Grant, 1947), Hawaii (Stearns, 1935), Japan (Mii, 1962), Australia (Jutson, 1939, 1940, 1950, 1954; Bird and Dent, 1966), and New Zealand (Bartrum, 1916, 1926, 1935, 1938; Gill, 1950; Wright, 1967). Interest in these areas has often centred on: (1) the existence of platforms as indicators of recent eustatic shifts of sea level (Russell, ed. 1961); (2) the level(s) at which marine planation takes place (Cotton, 1963); and (3) the processes of platform formation and modification (Hills, 1949). These topics are obviously inter-related and contributions in any one of them have application in the others.

The term "shore platform" lacks precise definition. It is, however, generally understood as a descriptive term which applies to the horizontal or near-horizontal benches, generally much less than 0.5 miles wide, which are found around about tide level on many rocky shores. Shore platforms can be regarded as morphological responses to a variety of processes which occur about the land-sea interface. Their existence and preservation is essentially dependent on the fact that cliff retreat above sea-level is greater than that below sea-level. But, there is no single explanation for their development. Instead, because they are located at the junction between the subaerial and marine environments, a variety of processes, partly subaerial and partly marine must be expected. These processes are decidedly complex and include numerous mechanical, biological and chemical agencies.

Furthermore, these processes are working at different rates and in different areas of the shore platform, some being dependent on other erosional processes and others independent of such processes. Despite this multivariate nature of shore planation processes, and despite the problem of ascertaining the relative importance of the various processes in the development of particular platforms, it has often proved valuable to isolate a single process element and consider its role with reference to platforms of a specific area. Thus, certain shore platforms have been viewed in terms of wave action (Edwards, 1951), chemical solution (Wentworth, 1939), water-layer weathering (Wentworth, 1938), sub-aerial weathering (Bartrum, 1926), gastropod erosion (Emery, 1946), and other erosional processes. The role of mass-movement, however, has not hitherto been considered explicitly.

Mass-movement is an important process in the erosion of some rocky coasts. As coastal slopes are subjected to the same stress conditions as inland slopes, they exhibit the same tendency towards equilibrium and move towards the development of more stable forms, modifying their slopes by mass-movement. If such slopes are unaffected by other geomorphic processes they may maintain an essentially stable form and mass-movement will be reduced to slow soil creep. These conditions appear to have been reached in New Zealand by many ancient sea cliffs whose bases are now out of reach of storm waves or are separated from the present strand by raised beaches, beach ridges, dunes or wide berms. However, where cliffs are within the reach of waves, the removal of material from their bases sets up further stress conditions causing increased movement of slope materials. Thus, the removal of basal talus by wave action ensures that many coastal slopes are unlikely to reach conditions of stability for any lengthy period of time. It is, however, only in recent years that mass-movement has been studied as a coastal erosional process. Notable contributions have been made by Dicken (1961), Emery (1960), and Byrne (1964) whose studies in Oregon and California indicate that mass-movement is a major cause of coastal change, and that lithology and structure are the most important factors influencing coastal mass-movement. However, these studies contained no reference to the role of mass-movement in shore platform development.

SHORE PLATFORMS AND CLIFF RETREAT

From evidence around Auckland, first recognised by J. D. Dana in 1840, Bartrum (1916, p. 134) hypothesised that high-water rock platforms "are due not so much to wave-attack upon a definite zone of weathered rock as to the destruction of cliff-faces by subaerial erosion and the removal of the resulting waste by weak wave-action." Unfortunately, neither in this report nor subsequent papers (Bartrum, 1926, 1935, 1938) did Bartrum specify whether or not mass-movement was included in his term "subaerial erosion". However, our observations suggest that if mass-movement is included, and if "weak wave-action" is replaced by "wave action" the Bartrum hypothesis is applicable, in general terms, to *tidal* shore platforms on the Gisborne coastline. Thus one of the objectives of the present preliminary study is to indicate that current shore platform development on the Gisborne coastline results primarily from the destruction of cliff-faces by mass-movement and removal of the resulting waste by wave action.

As previously mentioned, shore platforms result primarily from cliff retreat. Davidson (1965) has shown that on the Gisborne coastline this retreat is mainly caused by the interaction of mass-movement and oceanic processes. While wave action is important in the removal of talus from the base of coastal cliffs it is less important as a *direct* erosional agent. Instead mass-movement is the primary process by which material from the upper slopes, behind shore platforms, is brought within the reach of wave action. A second objective of the present investigation is to evaluate the relative contributions of the various types of mass-movement to shore platform development. This necessitated classifying the mass-movement landforms. The system of classification used here is that of Rapp (1960) who distinguished three types of movement: (1) falls; (2) slides and (3) flows. Descriptive ratios of mass-movement features, such as the length : depth ratio were also used. They proved most useful in ascertaining the amount of erosion following landslides.

DESCRIPTION OF GISBORNE COAST

The area distinguished as the Gisborne coast in this study extends northward from Gisborne city for about 15 miles to Pouawa (Fig. 1). This is an appropriate coastline to investigate the role of mass-movement in shore platform development because of: (1) the known susceptibility of the coastline to mass-movement

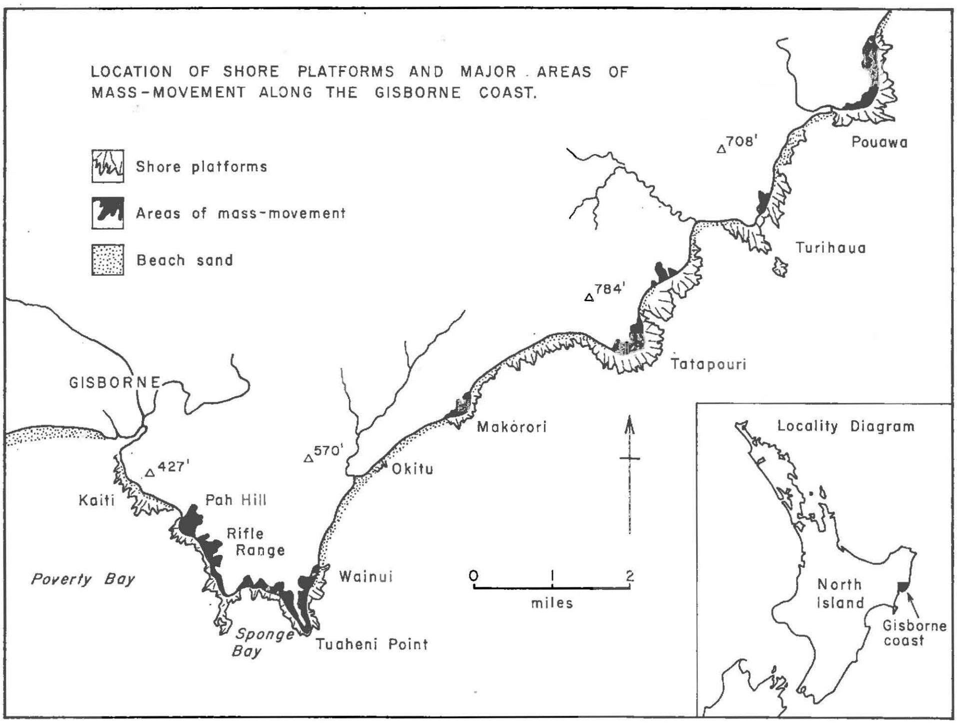

Figure 1. Location of shore platforms and major areas of mass-movement along the Gisborne coast. Sources: N.Z.M.S. 1 Sheet N 98, aerial photographs and field survey. *Inset:* locality diagram of Gisborne Coast.

(evidenced by the periodic disruption of roads, and threat to housing at Wainui Beach), and, (2) the presence of unusually wide shore platforms. Furthermore, the Gisborne coastal strip is representative of the greater part of the whole East Coast region.

The Gisborne coast consists essentially of a series of cliffed headlands separated by bays and beaches. Much of the shore is fringed by shore platforms which are widest, about 0.3 miles wide, and most clearly developed around the headlands. The headlands, shore platforms and beach hinterlands are composed mainly of banded mudstones and banded mudstones and sandstones, of variable thicknesses (Stoneley, 1964; Kingma, 1965). On the whole these Tertiary sediments break down readily, and lithology and structure are important considerations in dealing with shore platform erosion. This fact has been noted by others working in this area including Gill (1950, p. 67) who stated that "the nature of the country rock is the most important factor in the formation of these wide platforms . . ." The lithologic units found along the Gisborne coast are included in Groups V and VIII of O'Byrne (1967), both of which are subject to many different types of mass-movement, especially flow, slump and gully erosion. Both O'Byrne (1967) and Davidson (1965) have found that the rocks most susceptible to mass-movement are the bentonitic mudstones. These outcrop on the shore just south of Sponge Bay.

The shore platforms are, however, well developed in all the different rock types although there are variations in microtopographic features on their surfaces, which can be accounted for by structural and lithogical variations. Some of these have been documented by Gill (1950).

DISTRIBUTION OF SHORE PLATFORMS AND MASS-MOVEMENT

Figure 1 shows the location of shore platforms and active mass-movement areas along the Gisborne coast. A general correspondence in distribution can be seen. This distributional data indicates that in most instances areas of active mass-movement are located on the slopes behind shore platforms. It is in these areas that cliff retreat is resulting in an extension of the inner edge of the shore platforms.

However, Figure 1 also shows that some shore platforms such as at Kaiti and between Makarori and Tatapouri, are not associated with areas of active mass-movement. It is suggested that these platforms are not being widened under present-day conditions. Instead, the inner edges of these platforms are covered by beaches of variable width and material or by ancient colluvium which protects the basal cliff slopes.

Field observations also suggest that where shore platforms are free from debris, that is the residual products of mass-movement, planation is limited to processes other than mass-movement (biological, chemical and wave erosion). This, however, is not always the case. Where shore platforms have a large amount of rubble, including boulders and sand on their surfaces, landward extension of platforms by mass-movement is continuing.

TYPES OF MASS-MOVEMENT

Mass-movement forms located landward of shore platforms have been classified as (1) falls; (2) slides; and, (3) flows. The volumes of material involved in these mass-movement types, and length/depth ratios for slides and flows are given in Table 1. This data has been compiled from air-photo and field measurements.

(1) Rock and soil falls

These may be defined as the more or less free falling of rock and/or soil particles of various sizes from cliffs. They can be divided into three groups: (1) pebble falls, (2) boulder falls, and (3) soil falls.

Pebble falls were not measured but the constant rattle of falling rock fragments reported also by other workers (Henderson and Ongley, 1920; Gill, 1950) indicates that they are actively contributing to coastal erosion. Pebble deposits were found at the base of most mudstone cliffs backing shore platforms. This material would easily be transported from the inner edge of shore platforms by wave action.

Boulder falls on the other hand are more easily observed. A survey carried out in January 1965 indicated at least 23 areas where boulder falls had recently taken place. Boulders varied in size, the largest ones with diameters in excess of five feet, being associated with the bentonite cliffs, backing the shore platform between Pah Hill and Sponge Bay. At the base of many predominantly mudstone cliffs, groups of boulders were found which appeared to have fallen together. They had a fresh angular appearance which set them apart from the more rounded boulders comprising the beach itself.

Soil falls occur at the toes of the major slides, and many were noted along the coast. As much of the material in soil falls is less than sand size it is easily removed by wave action, and preservation cannot be expected for any length of time.

(2) Slides

Slumps and debris slides were the most common type of landslides, both types being recorded on each headland. Length/depth ratios were calculated for these landslides and compared with average length/depth ratios from various sources (Ward, 1945; Varnes, 1958; Roth, 1959; Todd, 1959). Average ratios for slumps on the Gisborne coast were 4.6 and for debris slides 16.7. These figures compare with the average ratios of 5.5 and 20.0 found by other investigators. A probable reason for the length/depth ratios on the Gisborne coast being lower than those calculated from the literature is the removal of slide toes by waves crossing shore platforms at high water and during storms.

Table 1. Length/Depth Ratios and Volumes of Different Mass-Movement Types.

Type of mass-movement and location	L/D ratios	Volume (Cub. yds)
1. Falls 1		
Boulder falls (n = 31)		9,185
Soil falls (n = 22)		814
2. Landslides		
(a) Slumps 2		
Pah Hill	3.4	366,444
Rifle Range	4.5	73,800
Sponge Bay 1	4.1	117,166
Sponge Bay 2	4.1	28,750
Wainui 1	4.8	146,286
Wainui 2	4.5	94,979
Wainui 3	4.1	1,512,592
Wainui 4	4.5	75,555
Wainui 5	3.5	73,656
Makarori 1	4.7	54,964
Makarori 2	4.2	15,848
Tatapouri	3.1	10,540
(b) Debris slides 3		
Pah Hill	19.1	7,751
Sponge Bay A	10.1	3,780
Sponge Bay B	18.1	7,066
Tuaheni Point A	18.5	11,450
Tuaheni Point B	19.5	6,558
Makarori	14.4	5.866
3. Flows		
Rifle Range earthflow	65	60,208
Turehau earthflow	63	36,203
Rifle Range mudflow	66	47,666

NOTES:

1 Total volume calculated by average fall volume X number of falls (n).

2 Volume calculated by length X width X 1/3 depth in feet, divided by 27.

3 Volume calculated by length X width X depth in feet, divided by 27.

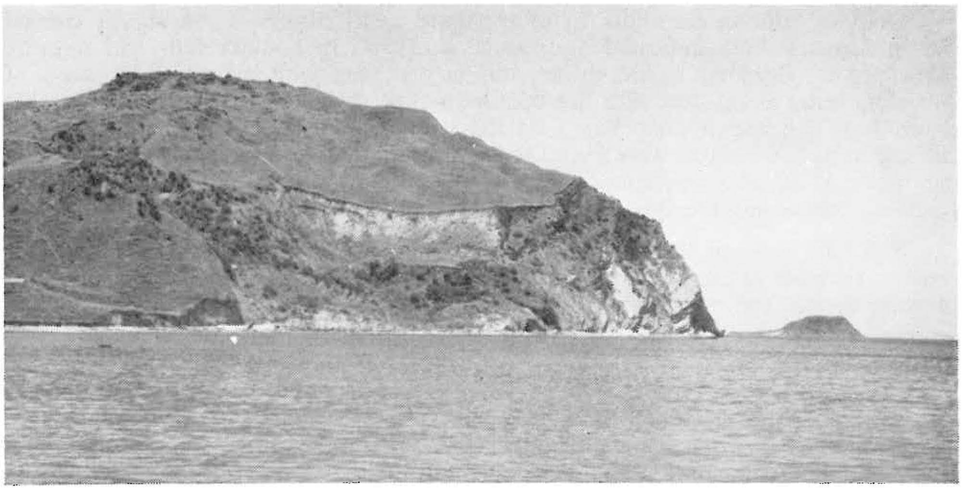

Figure 2. Large slump complex on south side of Pah Hill. Major movement of this slump took place in 1955 and since then there has been considerable trimming back of its seaward edge which rests on a shore platform. The summit of Pah Hill is about 420 feet high. A debris slide can be seen immediately to the left of the headland. Photograph taken at high water when the shore platform is completely covered by water. Tuamotu Island, Sponge Bay is in the right background.

Slumping along the Gisborne coast is a complex phenomenon. At any one locality often more than one slump is found. Slumping is a continuous process and, as shown in Table 1, involves large amounts of material. One slump complex involving over 350,000 cubic yards is illustrated in Figure 2. While this is larger than all but one of the other slumps, its characteristics are representative. Typically large blocks slump seaward leaving arcuate scarps or scars at the rear, and fan-like tongues of debris at the toe. Wave erosion of the toes results in removal of much of the unconsolidated material and leaves a field of boulders covering the shore platform surface as remnants.

Debris slides have a greater length/depth ratio than slumps but do not possess the large-scale dimensions of the slumps. However, they are still important mass-movent forms on the Gisborne coast. Debris slides involve the movement of weathered material (regolith) down very steep slopes. The slide plane is the boundary between bedrock and weathered material, but combinations of both bed-rock and regolith are transported. Debris slides made up of large blocks of rock embedded in a jumbled mass of fines are typical. At the toes of such slides boulder beaches composed of the larger size products of former slides are common.

(3) Flows

This type of mass-movement is the continuous plastic deformation of material along a shallow surface. Two earthflows and one major mudflow were distinguished on the Gisborne coastline. Their dimensions are given in Table 1. The length/depth ratios for these three flows are all close to 65, which is about one-half the average of 120 found by other investigators. These flows form trough-like depressions, have a distinctly hummocky surface with wide tension cracks and clearly defined boundaries. The toes of the flows are much lower than the adjoining slopes. They extend beyond the cliff edge and spill out on to the inner edge of the shore platform. Wave erosion subsequently truncates the toe and cuts the flows back to cliff level. This probably accounts for the low length/depth ratios. With continual flowage and removal of material, cliff retreat is inevitable and shore platforms are extended landward.

WAVE ACTION AND MATERIAL REMOVAL

While structural, lithological and climatic (especially high intensity rainfall) factors are important controls in mass-movement, the role of wave action must also be investigated in coastal situations. All of the types of mass-movement outlined previously deposit material on the inner edge of shore platforms. In most cases this material, be it individual rocks from rock or boulder falls or large masses of mud or earth from flows, comes within reach of normal high water level or storm waves, and is removed wholly or partly by wave erosion or carried away in suspension by currents.

Wave action is the major transportational agency of cliff talus after it has been deposited by mass-movement on the shore platform. Although the shore platforms along the Gisborne coast are exceptionally wide, they are covered by water of variable depth at high tide. Waves cross the platforms and cut away material from their inner edges either removing it completely from the platform or else redepositing it elsewhere. As much of the bedrock is composed of soft mudstones and bentonites this material is carried away in suspension and deposited offshore, whereas the sandstones and marls break down to sand or boulders and provide material for sandy bay-beaches or the transient beaches fronting some sea cliffs and resting on shore platforms. While it has often been argued that wide platforms reduce the effectiveness of wave attack on their inner slopes, there seems little doubt that along the Gisborne coastline wave action is sufficient to transport large quantities of material from these places. In fact in many cases the intensity of wave attack

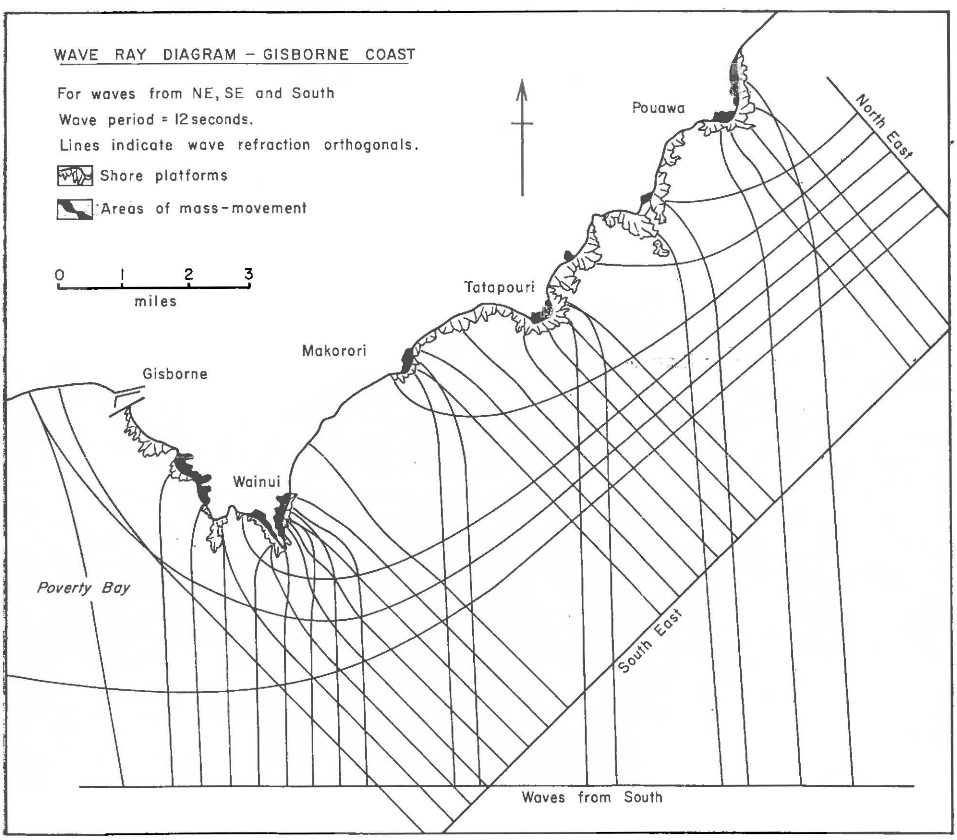

Figure 3. Wave ray diagrams for the Gisborne coast. For waves with a 12-second period and coming from various directions.

on the inner slopes of shore platforms on the headlands is greater than that in adjacent bays. This is because of the wave refraction effect, whereby energy is concentrated on the headlands, the areas where platforms are widest. Some measure of the variation in wave attack and relative wave intensity along the Gisborne coast was obtained by constructing wave refraction diagrams for waves of various periods and directions. Figure 3 illustrates wave ray (orthogonal) patterns for waves with a 12-second period emanating from the north-east, south and south-east, the main deep-water swell directions. The correspondance in location of mass-movement forms, shore platforms and areas of greatest wave convergence probably reflect a strong genetic connection. This is especially noticeable at Wainui where there is marked convergence of wave rays resulting from refraction of south and south-easterly swell around Tuaheni Point and the Tuaheni Rocks offshore. Mass-movement and shore platform extension in this particular area can be expected to continue for a long period.

That wave action is important as a transporting agent of mass-movement debris, and indirectly in the sculpture of shore platforms, appears certain. Supporting evidence is indicated by the fact that the sea reaches the base of all the mass-movement depositional forms at high tide; in some cases the toe position is two - four feet below high water level. Thus there is potential for frequent removal of material. That this potential is used is apparent from recurrent observations and measurements. Further, the rate of removal of mass-movement products from basal slopes is rapid. Measurements of one earthflow, one slump and one debris slide between January and August 1965 resulted in an average rate of toe erosion equal to 5.5 feet/year. This amount however, could readily be removed during short periods of storm seas.

BOULDERS ON PLATFORMS

While removal of large volumes of material takes place by wave action, only exceptionally high waves can transport the larger products of mass-movement. As noted previously the inner surface of some platforms is littered with boulders while in others the boulder cover is nearly complete (Figure 4). In many instances

Figure 4. Boulder-covered shore platform, south Sponge Bay, at low tide. Note large complex slumps at left and centre of hill area, and fresh steep cliffs at right. It is evident that the slumps in this area also possess certain morphological characteristics of flows. The boulders on the platforms represent remnants of extensions of numerous past and present slumps and flows.

it appears that these boulders have not been subjected to any other transportational agent than mass-movement. They are essentially deposited *in situ* and are exposed when the incompetent surrounding sediment is removed by wave action. These boulders represent the former extensions of mass-movement forms, in a comparable way to ground and terminal moraines which indicate former extensions of glaciers. A possible manner in which to estimate the amount of material removed, and hence erosion, is to compare length/depth ratios for the present slumps, with their estimated original length as indicated by relic boulders.

Length/depth ratios as measures of toe erosion

It has previously been indicated that the average length/depth ratios for mass-movement forms on the Gisborne coast are less than the average computed from various sources. This probably results from the rapidity of toe erosion. Unless measurement of the slide or flow length is made immediately following movement the length dimension will be less than the initial length because of wave trimming. However, where a boulder field is found resting on a platform in front of the mass-movement landform and its perimeter grades back to the line of the slide or flow, then it may be assumed that the boulder field represents the original extent of the mass-movement feature. Thus, the original length may be estimated by adding the length of the boulder field to the length of the present mass-movement form. This has been done for slump forms along the Gisborne coast (Table 2). The difference column in Table 2 indicates the measured length of the boulder field in front of the slumps, and has been added to the present slump length to give the estimated original length. It also represents the amount of toe erosion following the major period of slumping. Using the estimated extrapolated length, original length/depth ratios can be derived. The resulting ratios, given in the last column in Table 2 are surprisingly close to the average slump ratios (5.5) obtained from the literature.

Table 2. Present and Original Lengths and Length/Depth Ratios for Slumps.

Location	Present length (ft)	Original length (ft)	Difference (ft)	Present L/D ratio	Original L/D ratio
Pah Hill	510	810	300	3.4	5.4
Rifle Range	410	514	104	4.5	5.7
Sponge Bay 1	450	600	150	4.1	5.4
Sponge Bay 2	250	330	80	4.1	5.5
Wainui 1	387	437	50	4.8	5.4
Wainui 2	453	553	100	4.5	5.5
Wainui 3	816	1066	250	4.1	5.3
Wainui 4	272	322	50	4.5	5.3
Wainui 5	171	271	100	3.5	5.5
Makarori 1	378	438	60	4.7	5.4
Makarori 2	331	431	100	4.2	5.5
Tatapouri	156	276	120	3.1	5.5

RELATIVE IMPORTANCE OF MASS-MOVEMENT TYPES IN CLIFF RETREAT

The volume of material involved in each type of mass-movement at each site along the Gisborne coast has been given in Table 1. It is evident that slumping constitutes the most important mass-movement process in terms of amount of material involved, with flows being ranked second in importance. While debris slides are only third in volume, our observations suggest that these movements are more frequent than either slumping or flowage. Similarly, rock and soil falls are very frequent although they are ranked last in the amount of material involved. Products of soil falls and debris slides, that is the finer materials, are removed more rapidly than the larger rock fragments.

DISCUSSION

The data described in this paper indicates that mass-movement on slopes behind shore platforms involves large volumes of material. The shore platforms on the Gisborne coast have been attributed by Gill (1950) to various agencies, notably powerful sea action and rapid subaerial weathering of the weak "papa" bedrock. Little mention has been made of the role of mass-movement as a process involved in their formation. However, our data reveals that mass-movement is an important agent in bringing large, upper sections of the coastal slopes within the reach of wave action, for transportation, leading to the retreat of cliff sections in areas where shore platforms are currently being widened. The sequence of events resulting in shore platform extension can be outlined. Direct wave attack is confined to the base of unprotected coastal slopes and helps cause collapse of sections of the slope. The material from soil and rock falls is quickly removed by the sea leaving the slopes to bear the brunt of wave action at the base. Over-steepening may continue until the slope angle becomes too great for the shear-strength of the slope materials and failure occurs by slumping, debris slides or flowage. The sea then attacks these depositional forms on the inner edge of the shore platform undercutting sections to cause further rock and soil falls. Erosion is much more rapid because the deposited materials are fragmented and fines can be carried away in suspension. Slope stability is again upset and mass-movement recurs. Retreat of coastal cliffs results, leaving a platform covered with boulder and debris remnants of the mass-movement forms. Much of this debris is ultimately swept from the platform.

While shore platform extension is continuing in areas of wave convergence by constantly rejuvenating mass-movement, in other areas this process has practically ceased and the inner edge of shore platforms are covered by thick deposits of beach materials, precluding platform extension. In such cases these stranded slopes are still being modified by surface movements such as debris slides and soil creep, but not at the same rate or magnitude as those slopes still being actively attacked by the sea. Thus at certain places, e.g. Kaiti Beach and Southern Tatapouri, the platforms appear to have reached their maximum width under present energy conditions and major planation has ceased. Secondary erosion, by biological, chemical and other mechanical agents is, however, still continuing.

SUMMARY

1. In modified form the Bartrum (1916) hypothesis is applicable to the development of tidal shore platforms along the Gisborne coastline, i.e. current shore platform extension results primarily from the destruction of cliff-faces by mass-movement and removal of the resulting waste by wave action.
2. The coincidence of areas of wave convergence, mass-movement and active shore platform extension suggests a genetic connection between these processes and response elements.
3. Cliff retreat and shore platform extension is carried out by various types of mass-movements including rock and soil falls, landslides, and flows. The volume of material involved in mass-movements along the Gisborne coast is greatest for slumps, then flows, debris slides and finally soil and rock falls.
4. The products of mass-movements are removed by wave action but extensive boulder fields on some shore platforms indicates that removal is not complete. In such cases these boulders remain as evidence of the former extension of mass-movement forms.
5. Comparison of present length/depth ratios and original length/depth ratios indicates the extent of toe erosion.
6. Not all of the shore platforms along the Gisborne coast are being widened. Where active mass-movement is not occurring shore platform widening has ceased.

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