

## MASS MOVEMENT\* IN TANGOIO CONSERVATION RESERVE NORTHERN HAWKES BAY

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### Abstract

In a random sample of 52 valley-side profiles at Tangoio, mass movements are shown to occur preferentially on profiles with a northerly aspect, which are long, or steeply sloping.

Detailed measurements of 27 debris slide and two slump scars dating from a storm in May 1971 enable an estimate of the rate of erosion of loess and volcanic ash from valley-sides to be made. Valley-side slopes are changing from a convexo-concave equilibrium form under the original forest towards a new, more rectilinear equilibrium form under grass.

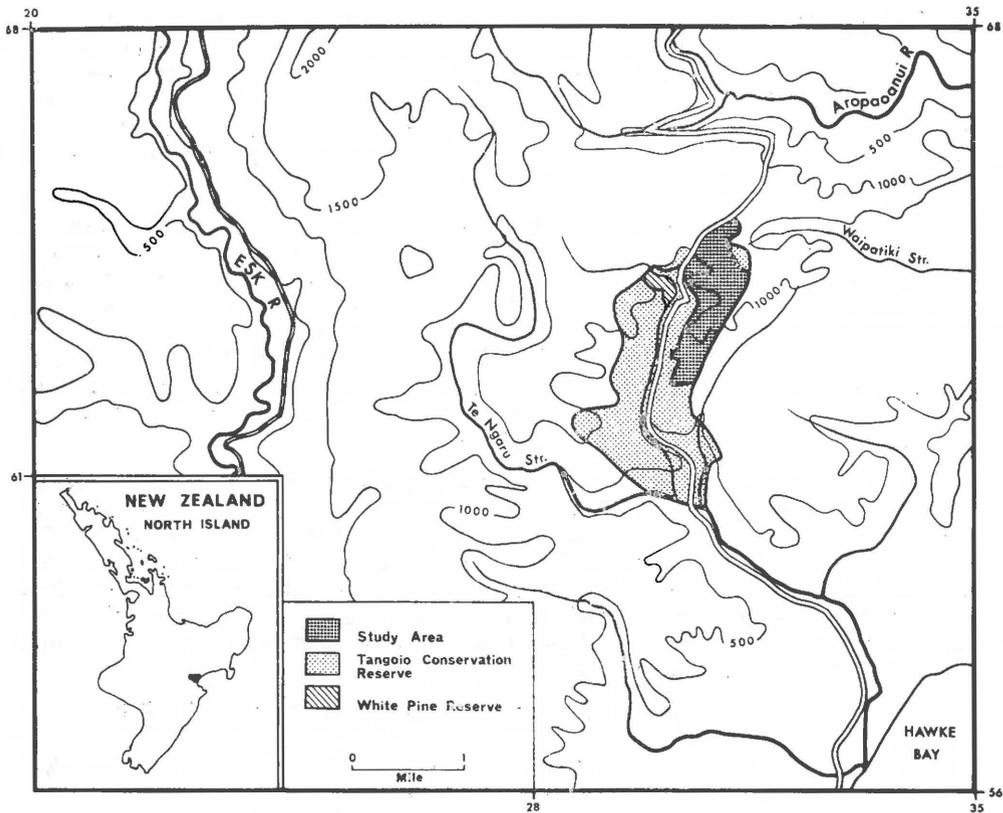


Figure 1 Location of the 162 hectare portion of Tangoio Conservation Reserve which forms the study area. Topographic details, including the generalised 500 foot (152m) contours, are from NZMS 1, Sheet N124.

\* Defined as any sudden movement of material from an area of valley side; this excludes soil creep.

## INTRODUCTION

This paper is a preliminary report on studies being conducted by the writer, in conjunction with staff of the Ministry of Works, Napier, into processes of erosion affecting 162 hectares of the Tangoio experimental farm (Figure 1). This is part of the Tangoio Conservation Reserve, an area of 639 hectares adjoining 9km of the Napier-Wairoa main road which was badly disrupted by mass movement in the 1938 'Anzac storm', and acquired by the Soil Conservation Council in 1946. Four hundred and fifty seven hectares bordering the highway have been planted in trees while the remaining 182 hectares form the experimental and demonstration farm.

The study area is in, and can be considered representative of, the Tangoio hydrological region (Toebes and Palmer, 1969), an area of 1334km<sup>2</sup>, mainly on Lower Pleistocene marine sediments which dip toward Hawke Bay. In the Tangoio Reserve these are represented by strata of limestone, conglomerate, sandstone and siltstone which range in thickness from two to thirty feet and which dip at about 10° to the southeast. These strata vary markedly in resistance to erosion, and the limestones, in particular, frequently outcrop on valley sides, buttressing and preserving weaker material on the slopes above. Late Pleistocene and Holocene volcanic ash of at least four showers, and loess several metres thick, are preserved on ridge crests, further complicating the soil and erosion patterns.

The northern boundary of the study area is on the divide between the Wai-patiki and Te Ngaru Stream systems and a secondary divide between Rauwirikokomuka and Kareara drainage runs northeast to southwest through the centre of the farm (Figures 1 and 2). There are considerable relief contrasts within the study area; summit elevations decrease from 335 to 275 metres toward the south, relative relief increases, and ridge summit convexity diminishes toward the south, east and west boundaries.

Primeval forest, of which White Pine Bush Reserve (Figure 1) is a remnant, probably covered the entire district until destroyed on higher and drier areas a few hundred years ago by Maori burning (Guthrie Smith, 1921). The manuka scrub and fern vegetation cover that followed destruction of the forest was, in the latter part of last century, replaced by grass when the area was farmed as part of the 12,000 hectare Kaiwaka block. By 1946, in the absence of topdressing, this had deteriorated to a pasture of predominantly danthonia and ratstail (Campbell and Anaru, 1964). Today, with improved pasture management the sward is much denser, and contains clovers and high quality grasses.

It is not known for certain how these vegetation changes have influenced erosion rates and processes. The 1938 storm was not unique; Guthrie Smith (referring to Tutira, the block immediately north of Tangoio) wrote in 1921, "after a 'southerly buster' or a 'black noreaster' of three or four days uninterrupted torrential rain, I have counted on a two mile stretch of hillside over two hundred slips great and small, new or newly scoured out. Seven or eight times since '82 the grasses and sedges of the valleys round the lake have been overlaid by mud varying in depth from six inches to a couple or three feet".

Northern Hawke's Bay is renowned for high intensity storms (Table 1).

Table 1 Two-day rainfalls above 200mm recorded since 1952 at Tangoio Conservation Reserve meteorological station.

| Date         | Amount (mm) |
|--------------|-------------|
| March 1955   | 342         |
| July 1956    | 252         |
| October 1958 | 258         |
| June 1963    | 498         |
| August 1965  | 223         |
| June 1968    | 204         |
| May 1971     | 204         |

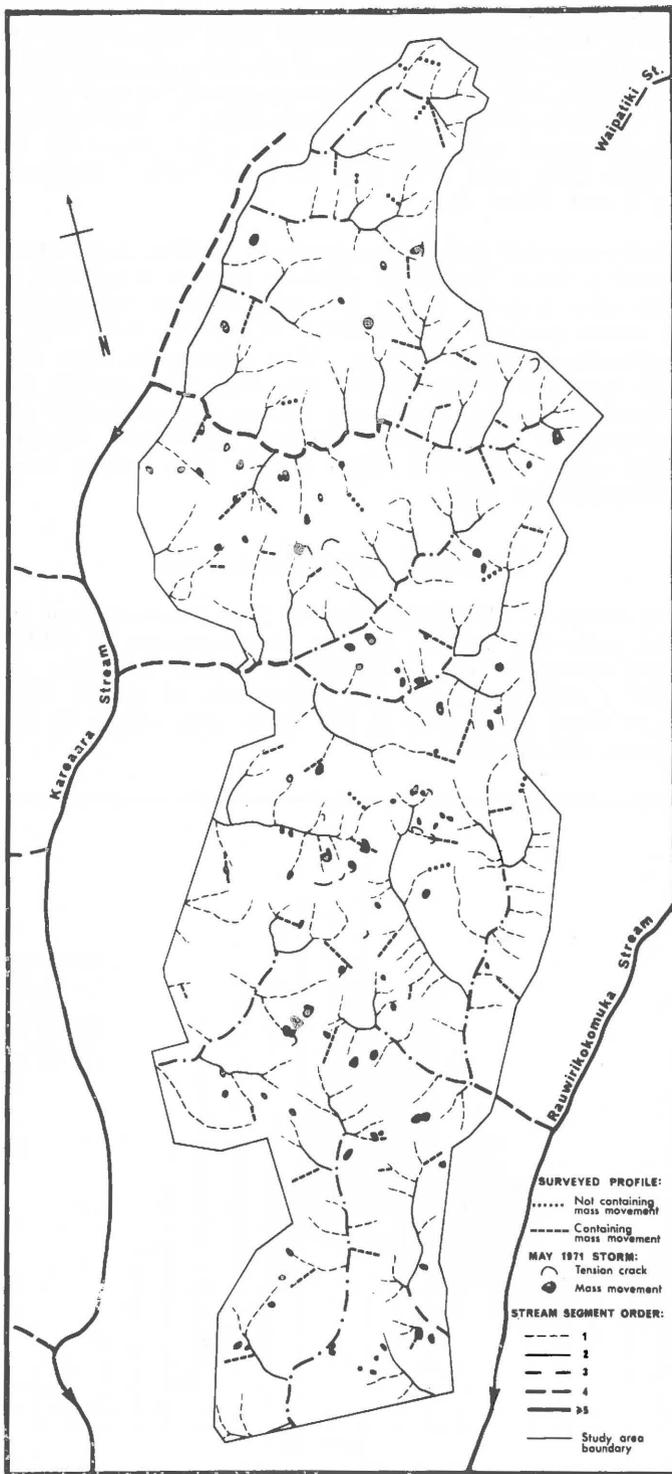


Figure 2 The study area showing the drainage pattern and stream orders, the sample of 52 valley-side profiles and mass movements due to the May 1971 storm.

There is some evidence (Grant, 1965) that intense storms have caused catastrophic erosion at least as far back as A.D. 1650, that is since the postulated destruction of the forest over large portions of Northern Hawke's Bay. At Tangoio, an area of steep slopes and generally soft rocks covered by ash and loess, the rate of erosion has probably always been relatively high. Pasture improvements since 1946 have not eliminated mass movements and in the period for which records are available, since 1960, three of the four storms in Table 1 triggered mass movements (Figure 2 and Table 3).

It is generally assumed that the frequency of shallow mass movements under undisturbed forest is lower than under scrub or pasture (Campbell, 1945). Some support for this view is given by the fact that no mass movements occurred in the May 1971 storm, and only several minor slips in the June 1963 storm, in the 457 hectares of reserve planted in trees. Mass movements were also very much less frequent in that part of the farmed area containing mature 'space planted' poplar trees than in areas of open pasture. Indeed, the widespread and apparently undisturbed existence of Waimihia ash (dated c. 3,200 B.P., Vucetich, 1968) on ridge crests and upper valley-side slopes implies that current rates of erosion cannot have continued for long.

### PRESENT INVESTIGATION

In order to determine the general effect of mass movements on the topography a sample of 52 valley-side profiles (Figure 2) was chosen at random from profiles which were accessible and which did not contain limestone outcrops. The sample survived a Chi-Square test for randomness of profile direction and is representative of those valley-sides in the study area which, in the absence of rock outcrops, are soil covered.

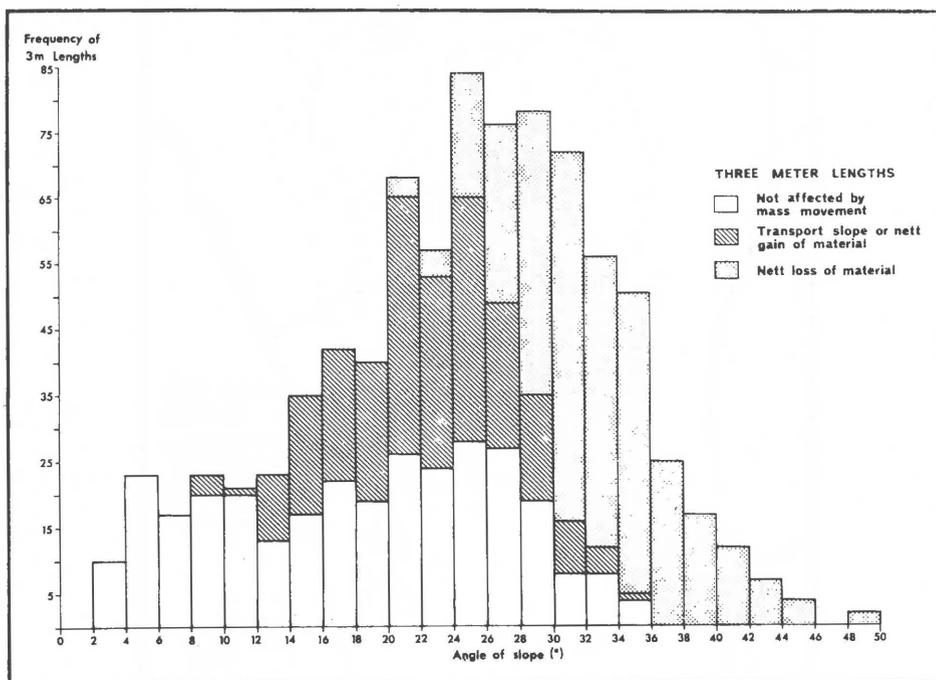


Figure 3 Histogram showing frequency of 3 metre ground lengths with various slope angles. Ground lengths are subdivided into three groups according to the way they have been influenced by mass movement.

Slope measurements, in degrees, were taken with an Abney level for successive three metre slope segments along each profile from the ridge crest to the thalweg or edge of alluvium in the valley bottom. The overall mean slope for these segments was found to be 24.4°. The frequency distribution of Figure 3 summarises segments showing (i) no evidence of mass movement, (ii) a net loss of material, and (iii) evidence of colluvial transportation and/or deposition. Mean values are 17.0°, 32.4°, and 21.7° respectively. Stable slopes range in angle from 0° to 36°, and the gentle slopes of ridge crests impart a slight bimodality to the distribution in Figure 3. The steepest slopes in the diagram are clearly those which have suffered a net loss of material due to mass movement. Because transport slopes between slip faces and colluvial 'toes' are usually short, a generalisation which can be made from Figure 3 is that about half of the slope segments in the sample have been directly affected by either mass movement erosion or deposition.

Table 2

(A) Association of profile properties with stream segment order.

(B) and (C) Properties of —

(a) profiles affected by mass movements,

(b) profiles not affected.

(A)

| Order  | Number of Profiles | Mean Profile Relief (m) | Mean Profile Length (m) | Mean Profile Slope (°) | Mean Max. 9m Slope (°) |
|--------|--------------------|-------------------------|-------------------------|------------------------|------------------------|
| 1      | 36                 | 17.8                    | 43.9                    | 24.2                   | 32.8                   |
| 2      | 11                 | 27.8                    | 65.5                    | 24.5                   | 33.7                   |
| 3 or 4 | 5                  | 29.6                    | 70.1                    | 25.6                   | 34.9                   |

(B)

| Profile | Frequency | Length (m) |      | Relief (m) |      | Mean Slope (°) |      | Max. 9m Slope (°) |      |
|---------|-----------|------------|------|------------|------|----------------|------|-------------------|------|
|         |           | Mean       | S.D. | Mean       | S.D. | Mean           | S.D. | Mean              | S.D. |
| (a)     | 40        | 55.6       | 18.6 | 23.3       | 7.9  | 24.9           | 3.5  | 34.3              | 3.6  |
| (b)     | 12        | 35.6       | 10.5 | 13.5       | 3.9  | 22.5           | 2.0  | 29.4              | 2.7  |

(C)

|                        | Azimuth |         |          |          | Total |
|------------------------|---------|---------|----------|----------|-------|
|                        | 1-90°   | 91-180° | 181-270° | 271-360° |       |
| Number of profiles (a) | 14      | 5       | 4        | 17       | 40    |
| Number of profiles (b) | 2       | 3       | 5        | 2        | 12    |

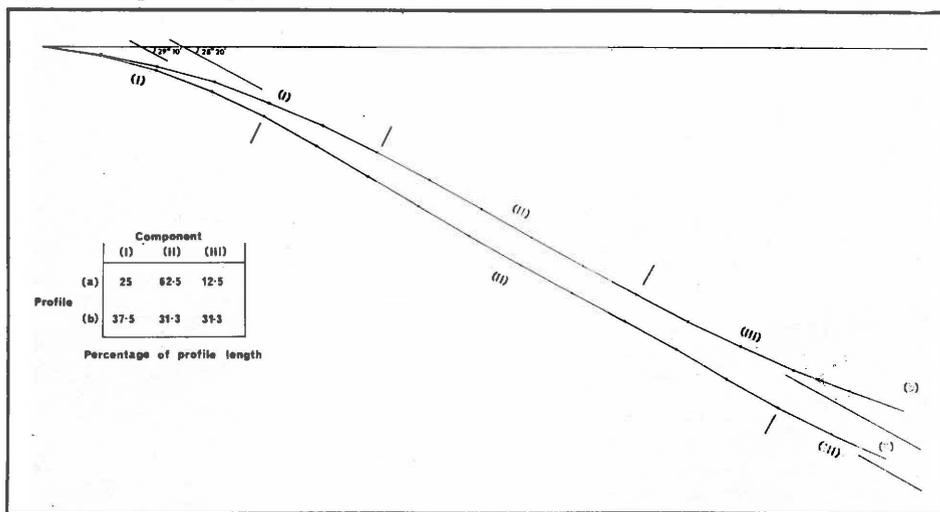


Figure 4 Mean valley-side profiles representing (a) the 40 profiles containing mass movement scars, (b) the 12 profiles not affected by mass movement. Components (I), (II) and (III) are convex, straight or rectilinear, and concave respectively. A segment of the profile is straight when the slope between two successive pairs of stations differs by less than two degrees. The two angles are the mean slopes of the straight component of each profile. The curves were calculated from profiles drawn at scales which made them of equal length and therefore graphically comparable.

Profile relief and length increase with valley or stream segment order\* (Table 2A), as is to be expected. An *F* test, however, showed that neither mean profile slope, nor maximum profile slope (represented by the maximum slope for nine metre lengths of the profile) varied significantly with stream order. This implies that parallel retreat is possibly the appropriate model for slope evolution at Tangoio.

Mass movements have occurred on 40 of the 52 sample profiles. The differences among the mean values listed in Table 2B are all significant at the 97.5% or higher levels in the 'Student *t*' test. Profiles not influenced by mass movements are therefore shorter in length, have less relief and are more gently sloping than other profiles. These morphometric properties, by reducing the influence of gravity have evidently preserved these profiles from critical shear stress and consequent mass movement.

There is also a clear difference between the two groups of profiles in terms of profile direction or aspect (Table 2C). Profiles in the two southern quadrants are protected to some extent from dry northwest winds and the summer sun. The southeasterly dip of bedrock strata also increases the supply of subsurface seepage

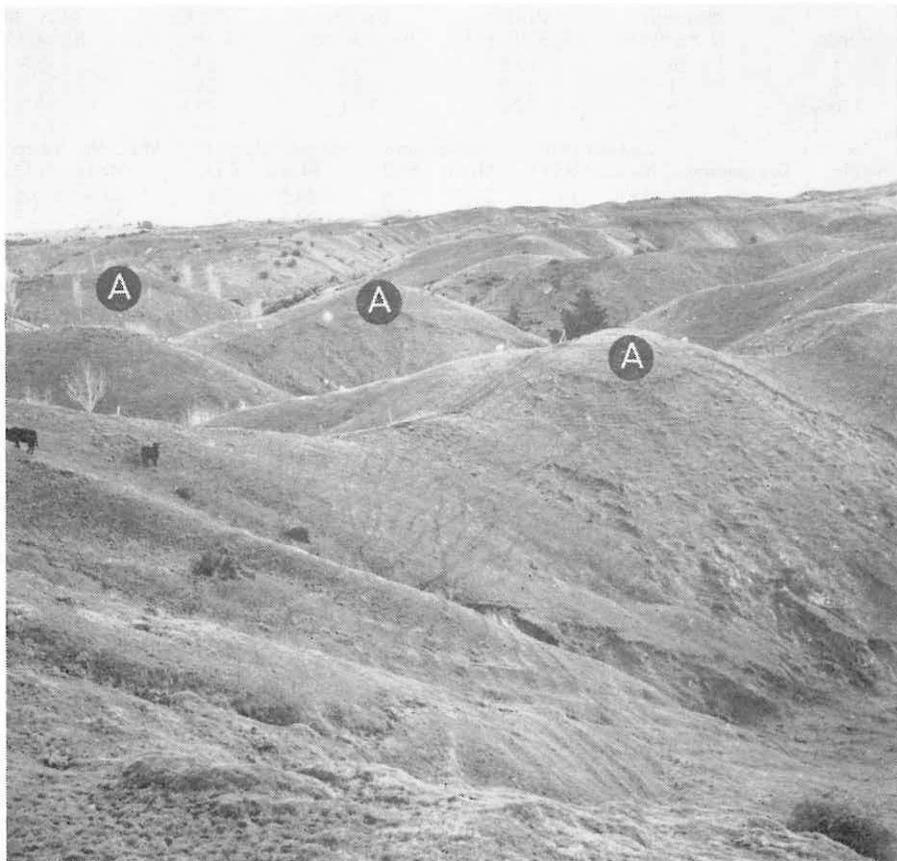


Figure 5 A series of north facing slopes showing the typical break of slope (A) between the summit convexity and rectilinear components of the profile.

\* As defined by Strahler (1950) the smallest or 'fingertip' channels in a drainage network are termed first-order segments; second order segments are formed by the joining of any two first order segments, and so on for higher orders.

water to south facing slopes. Soil moisture fluctuations are therefore less,\* the growing season is longer, vegetation is denser, and desiccation cracks do not develop so extensively. These cracks prevent runoff and allow storm water ready access to the soil on slopes of northerly aspect, thus increasing local shear stress values and increasing the possibility of mass movement.

The general effect of mass movements on the topography at Tangoio is summarised in Figure 4. Both mean profiles are convex-concave with a summit convexity, an essentially rectilinear mid-slope and a basal concavity. These three components occupy approximately equal proportions of the mean profile representing valley-sides not affected by mass movements. The rectilinear section occupies, however, 62.5% of the mean profile (a) with both convex and concave elements being correspondingly reduced. This profile has a slightly greater mean slope but the slope of the straight section is less than one degree greater. The effect of mass movements is therefore to increase the importance of the rectilinear component (Figure 5), and this tends to develop by parallel retreat.

#### *May 1971 Storm*

A slip-producing storm occurred in May 1971, enabling direct measurement of a fresh family of mass movements (Figure 2). The two storms represented in Table 3 are perhaps near each end of the spectrum of mass movement inducing



*Figure 6* A slump formed in the May 1971 storm. Backward tilting is shown by poplar A and the bulging toe by poplar B. This was the only measured movement involving mature poplars. Their binding ability at shallower depths is indicated by the exposed roots of poplar B.

\* Research using a neutron moisture probe is continuing to determine the precise nature of soil moisture variations.

events, and the table illustrates the importance both of storm properties and of antecedent moisture conditions.

Table 3 Comparison of June 1963 and May 1971 storms

| Date          | Total Fall (mm) | Duration (hours) | Maximum Hourly Intensity (mm/hr) | Rain (mm) for previous: |          | Approx. number of mass movements |
|---------------|-----------------|------------------|----------------------------------|-------------------------|----------|----------------------------------|
|               |                 |                  |                                  | month                   | 3 months |                                  |
| 1-3 June 1963 | 498             | 58               | 66                               | 10                      | 199      | 160†                             |
| 2-4 May 1971  | 204             | 31.5             | 12                               | 292                     | 661      | 50                               |

† N. Sutherland (pers. comm.)

The May 1971 storm has the smallest total rainfall amount and maximum intensity associated with more than a few isolated mass movements at Tangoio. Soil moisture levels before the storm were, however, exceptionally high; the 292mm of the preceding month included a fall of 197mm one week before. The June 1963 storm, on the other hand, followed a period of unusually dry weather during which the development of surficial cracks would have markedly increased the infiltration capacity of north-facing slopes. The unusually high intensity (Table 3) of much of the storm quickly led to saturation, the creation of critical shear stresses and mass movements on many slopes. Unfortunately, detailed measure-



Figure 7 A typical debris slide with the shear plane approximately parallel to the former ground surface and located at a median depth of 0.5m in soft silt immediately below the soil A and B horizons. Notice the 'rafts' of sod and topsoil which have slid part way down the scar and the tension cracks (A) further upslope. The scar has been slightly rilled by runoff due to the low permeability of the compact silt immediately beneath the shear plane.

ments for 1963 are not available and it is difficult to discern possible differences in the families of mass movements resulting from the two storms.

Twenty-nine mass movements, representing most of the large movements caused by the May 1971 storm were investigated by the writer and Mr G. J. Smith during mid-May. Measurements taken for each scar included: length, breadth, the approximate geometric shape, median and maximum depth, azimuth, slope of the shear plane, the general slope between undisturbed ground immediately above and below the slip-scar, the ground slope immediately above the slip-head, and distances from the ridge crest and valley bottom. Details of the soil profile exposed in the slip-head and the geology on the slip-scar were also recorded.

Two of the mass movements are slumps (Figure 6), the remaining 27 falling broadly within Sharpe's (1938, p. 74) definition of debris slides (exemplified by Figure 7). These are shallow (mean depth 0.6m, range in depth 0.4 to 0.9m), up to 27m in length, and 27m in breadth, and have a mean depth/length ratio (Skempton, 1953) of five per cent. Selby (1967) and Crozier (1968) have reported very similar mass movements and the measurements quoted above are probably typical of the shallow 'slips' common to many parts of New Zealand.



*Figure 8* Debris slide in a valley-head location. There is very little colluvial toe and the eroded material, moving as a mudflow, was deposited along the valley floor, much of it being carried right out of the study area.

(A) tension cracks around the head of the slide.

(B) an old debris slide scar, part of which was re-excavated in the May 1971 movement.

Seven of the movements have azimuth readings in the southern two quadrants. This is a significantly smaller number ( $\chi^2 = 8.01$ , significant at the 95% level with 3 degrees of freedom) than would be expected if slide and slump direction was randomly distributed; this again illustrates the importance of aspect to mass movement generation.

Six movements (including the two slumps) occupy 'valley-head' locations where convergence of surface and sub-surface flow occurs and where soils are deeper. The four slides (Figure 8) are more elongate than most others and have deeper curving shear planes. They could almost be classified as debris avalanches (Sharpe, 1938).

Previously stable material on slopes hitherto unaffected by mass movements was involved in 26 out of the 29 cases. Eighteen movements, were, however, associated with older debris slides (e.g. Figure 8), and represented an upslope migration of the process, and an increase in the importance of the rectilinear mid-slope component at the expense of the summit convexity. Parallel retreat of that portion of the slope which suffered a net loss of material is indicated by the fact that on 16 of the debris slides shear plane slope differed from the former ground slope by less than two degrees.

Two of the debris slides occurred on slopes that had acted as transport or accretionary slopes during one or more earlier mass movements, and one was located on the face of a former scar dating from 1938, illustrating that movement may recur on a given site.

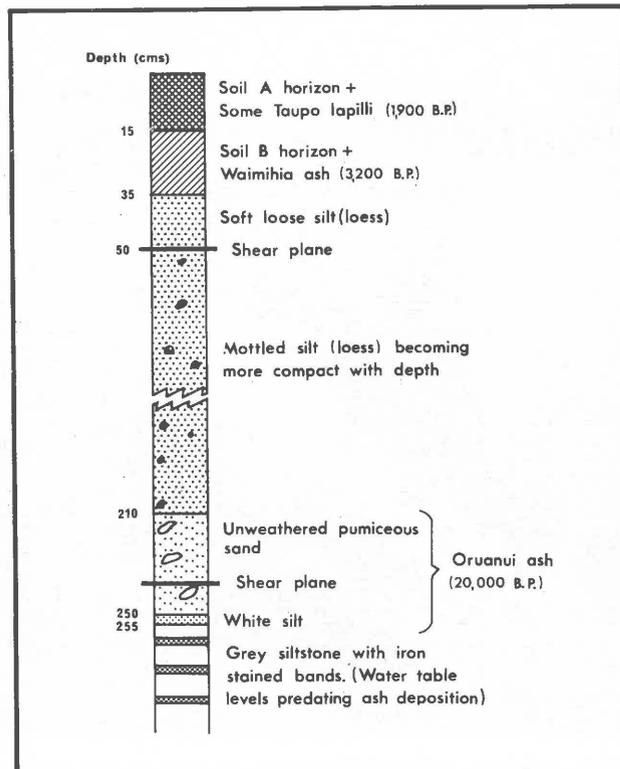


Figure 9 A composite profile of ash and loess beds over siltstone bedrock based on observations by the writer and Mr G. J. Smith near ridge summits in the southern part of the study area. Characteristic shear plane positions for debris slides appear to be related mainly to low permeability of underlying beds. Dates from Vucetich, 1968.

On some of the longest northerly facing slopes up to three debris slides exist on the same profile, each being reactivated when the depth of soil formation and amount of colluvium from higher up the slope is sufficient to cause shear failure during a storm. Three of the largest slides in the 1971 family (an example is shown in Figure 7) occurred on a valley-side profile that showed no sign of mass movement in photographs dated 1943. The period of any mass movement cycle of recurrence at Tangoio therefore varies considerably from slope to slope, the minimum value being about 30 years under current conditions.

The location of shear planes in the stratigraphic profile was found to be unexpectedly uniform, with failure in 21 of the debris slides occurring in a layer of soft silt immediately below the soil A and B horizons and the layer of Waimihia ash (Figure 9). In another four slides a shear plane was located in a layer of coarse pumiceous sand (tentatively interpreted as Oruanui Tephra; C. G. Vucetich, *pers. comm.*) immediately above bedrock. While recognisable bedrock is exposed on the shear planes of 24 debris slides, in no case is it exposed in the slip head of a debris slide. Movement thus appeared to be confined within the loess and ash layers, the depth of this material decreasing down the face of the slides until bedrock is exposed.

### Slope Evolution

Rapid movement of material down valley-side slopes at Tangoio is effected by only one process in addition to the forms of mass movement already discussed. This is piping (reviewed by Visser, 1969), known locally as tunnel gullying. Piping has not been studied in detail at Tangoio but appears to be a process complementary to debris sliding with pipes being located in the same soft silt layer as the average shear plane. Pipes are common in the alluvium covering many valley floors and in footslope colluvium. Higher up valley-sides, pipes, by acting as efficient subsurface drainage channels, protect some slopes from mass movement. In terms of slope area influenced and total mass of material eroded, pipes are, however, of minor importance and evolution of valley-side slips is largely controlled by mass movements, particularly debris sliding.

Contemporary mass movements represent an episode of valley side erosion which is rapidly changing hillside form from relatively smooth convexo-concavity, still evident in the northern portion of the study area, to rectilinearity. Ridges affected by mass movements are transitional in form with the summit convexity developed on ash and loess remnants being reduced in area by each new debris slide

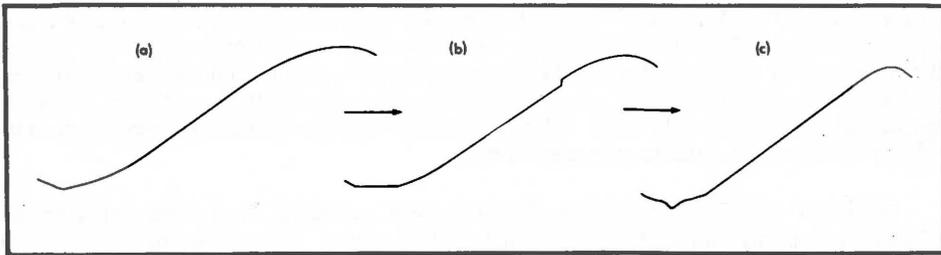


Figure 10 Slope change at Tangoio: (a) postulated convexo-concave equilibrium form under forest; (b) present transitional form with a narrowing of summit convexity, an increase in the length of the mid-slope rectilinear component and stream aggradation; (c) future equilibrium form under grass with straight sided ridges. Stream aggradation may cease as supply of easily eroded ash and loess from summits decreases.

The rate of this evolution will depend on slope length and azimuth and the presence or not of limestone outcrops. The result will be an increase in diversity of valley-side profile form.

(Figure 10). This episode of erosion and rapid change of morphometry has succeeded a phase of deposition and slope stability which may have lasted from 20,000 B.P. to at least 1900 B.P. (the dates respectively of the Oruanui and Taupo ash showers) and possibly until destruction of the forest several hundred years ago. This phase must have been to some extent discontinuous as Oruanui ash has only been identified at five sites; a dark red, deeply weathered and fine-grained ash of unknown age is preserved in small pockets in the northern half of the study area and occasional small gullies cut in loess and filled with Waimihia ash have been revealed on debris slides. At least near ridge summits, however, deposition was dominant with net accretions of up to three metres of loess. The present olive grey to yellow colour of the loess with incipient ilmenitic mottling and slight increase in proportion of clay with depth denotes weathering during and since deposition. Source areas must have existed during the last stadial on the exposed floor of much of Hawke Bay to the east, the braided channels of the Ngaruroro and other major rivers to the south, and ash deposits and greywacke bedrock exposed above the lowered tree line on the western mountain ranges.

Some idea of the vigour of the present phase of hillside erosion can be gained by calculations of the weight of material involved in mass movements during particular events. The volume of material removed in each of the 29 mass movements representing the May 1971 storm was calculated (median depth multiplied by surface area) to be 8,283m<sup>3</sup>. Dry density was determined from 47 samples of soil down to 0.9m to have a mean value of 1.164gm/cc.\* Total weight of material was therefore 9,650 tonnes. The 29 measured movements included an estimated two-thirds of the total of material moved during the storm. This, then, was calculated to be 14,475 tonnes for the 162 hectares of study area, or 8,936 tonnes/km<sup>2</sup> of horizontally projected area. Assuming the return period of a storm with the same erosional effect as the May 1971 storm to be five years, this represents a vertical denudation rate of 1.5mm/yr. An event of much longer return period is represented by the Anzac storm of 1938. Using a polar planimeter on photographs dated 1943 in which mass movement scars were still visible the writer calculated that 17 per cent of the Tangoio study area had suffered a net loss of material during that storm. Assuming a mean shear plane depth of 0.6m, a mean ground slope of 29°10' (Figure 4) and a dry density of 1.164gm/cc, this leads to a weight of 220,000 tonnes, or 15 times the weight of material involved in mass movement during the May 1971 storm. Assuming a return period of 50 years for the 1938 event, storms of this magnitude reduce the landscape vertically at a rate of 2.3mm/yr. The denudation rates for storms of different return period are independent; the total rate is therefore the sum of that for storms of each magnitude and represents extremely rapid erosion (Schumm, 1963). Not all the material is, however, removed from the area during each storm and much accumulates as colluvial footslopes or in valley bottoms (Figure 10). All valleys of the second or higher order are flat-floored in cross section. The writer calculated, for example, on the basis of sample augering, that one valley contained an average depth of 3.7m of alluvium. Fluvial erosion cannot, therefore, keep pace with hillside erosion and streams are aggrading.

Wellman (1967) mapped the Tangoio area as being in a zone experiencing 0-2mm/yr tectonic uplift during the last 10,000 years. Assuming the present rate of uplift to be 1mm/yr and the rate of hillside erosion to be between 5 and 10mm/yr, streams would need only to remove from the area between 10 and 20% of the colluvial detritus for a gross equilibrium between rates of uplift and denudation to be established.

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\* This low density is due to the high proportion of vesicular pumice in upper layers of the soil profile (Figure 9).

The initiation of rapid hillside erosion was probably connected with the vegetational change from forest to scrub and it may have been enhanced by the further change to grass. While grass continues to be the main vegetation, mass movement and the change in slope form to a new equilibrium of razor-backed, straight-sided ridges is likely to continue (Figure 10). Tree planting is probably necessary to reduce significantly the rate of mass movement; either a return to forest or the 'space planting' of trees. Trials with poplars at present being conducted to Tangoio could lead to optimum tree densities for given species on particular slope classes to control mass movement and give a maximum economic return from both pasture and timber production.

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