EARTHFLOWS AND RELATED ENVIRONMENTAL FACTORS OF EASTERN OTAGO

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ABSTRACT

The earthflow and its expression on the loess-mantled hills of Eastern Otago are described. Two major forms are recognized — the discrete earthflow, bounded by distinct shear lines, and the older extensive earthflow displaying periglacial characteristics.

The role of climatic factors and their influence on varying rates of movement are discussed. In particular the seasonal variation of soil moisture, temperature, evaporation, and rainfall is shown to be important for a discrete earthflow on the Otago Peninsula.

Correlation coefficients are calculated for the climatic factors and the rate of movement, and indicate that variations in movement are most closely associated with variations in rainfall during winter-early spring when evaporation and temperature are lowest and soil moisture is high. The response of the earthflow to a particular variation in rainfall appears to be delayed by about one week.

INTRODUCTION

The earthflow is a landslide (landslip) displaying viscous-fluid deformation characteristics and therefore belongs to the flow category. The three main landslide types commonly recognized are the flow, fall, and slide.

Flows may be classified in terms of their constituent material, water content, morphology, and rate of movement. Earthflow is the increasingly dominant type of mass movement in Eastern Otago — an area notorious for its regolith instability (Jones, 1967; Davidson, 1920; Benson, 1940) and one that exhibits most of the recognized forms of landslides (Crozier, 1967).

Earthflows — as distinct from flows in general — are, according to Varnes (1958), " . . . of slow to very rapid velocity, involving mainly plastic or fine-grained non-plastic material." The earthflows of Eastern Otago, although lying within these conditions of classification, show two major forms. One is a discrete earthflow, the other an extensive earthflow.

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THE DISCRETE EARTHFLOW

The discrete earthflow is bounded by distinct shear lines, with a concave part — sometimes showing minor slumping below the main scarp — and a convex part, represented by a lobed toe. This type of flow is characteristic of the thickly loess-mantled coastal hills of Otago.

The discrete forms of flow have an average depth/length ratio of approximately three percent (compared to 20 percent for slumps) and are similar in this respect to certain English surface slips on boulder clay. These slips, described by Skempton (1953) showed a five-percent ratio.

In all cases the depth of the surface of rupture decreases downslope and the lobe is seldom removed. The result is a flattening of the slope, which is in keeping with Skempton's findings.

Selby (1967) compared debris slides in the Waikato Basin to Skempton's surface slips but noted that although their depth/length ratio is identical they contribute to a parallel retreat of the slope rather than a downwasting. For earthflows of the East Coast of the North Island, Davidson (1965) calculated a ratio of 1.5 percent and for those in the literature 0.8 percent. It is probable that the greater magnitude of these latter values is due to more fluid flow being produced by a higher water content and, in the first case, by a higher mineral sensitivity.

The local, small-scale variations in morphometric characteristics can be attributed to other factors as well. The depth of loess in Eastern Otago varies from about thirty feet to less than one foot, and it is this factor which exercises an important influence over the morphological ratios and size of the earthflows.

THE EXTENSIVE EARTHFLOW

The second major form of earthflow involves an extensive rumpling of the Tertiary mudstones and regolith to produce a hummocky surface akin to Tricart's (1961) "swelling topography." It is sometimes produced by a coalescing of discrete earthflows but in most cases involves the mobilization of large subsurface areas of a slope where the density of percolines is high. In this case the sward is seldom disrupted even though the unstable material has a high ratio of regolith to bedrock. This implies a type of subsurface flow.

There is evidence to suggest that much of the extensive flow movement took place under periglacial conditions that prevailed in the Pleistocene and is therefore much older than the discrete earthflow. Not only does the morphology pertain to a less viscous type of flow, as is characteristic of present-day solifluxion lobes (swelling topography), but the lithology (facet-curved sub-angular boulders) also resembles that of cold soliflual deposits. In view of this it is interesting to note that the only historic account of the occurrence of an extensive flow was in 1939 in association with the thawing of a record cover of snow (Benson, 1940).

Both major forms are essentially shallow phenomena occurring in a regolith which is made up largely of slope wash and Pleistocene solifluxion debris. This material is derived from the loess and weathered bedrock and rests on a zone of weakness offered by the contact with an impermeable stratum. This stratum is often the clay of weathering trachyte and other volcanic rocks in the case of the discrete flow, and Tertiary mudstones in the case of the extensive flow.

CLIMATIC FACTORS AND EARTHFLOW

What is the cause of earthflow? There are so many contributing factors that it would be impossible to isolate any one as the cause, although the triggering factor may be fairly obvious; this trigger is usually an extraordinary climatic condition. Before a trigger can be of use, however, the gun must be loaded — so also the condition of the landslide material must be made potentially unstable through the continued action of many factors before a triggering factor will be effective. Once an earthflow has been triggered, it is generally recognized that the mechanism of flow involves the transfer of intergranular pressures to the pore water of the soil.

Climatic factors, and in particular rainfall, can act in three main roles:

(i) As a creator of potentially unstable ground. This is usually through prolonged soil physico-chemical changes (for instance hydration or cracking).

(ii) As a triggering factor — usually by increased lubrication and weight.

(Both of these first two are concerned with the initiation of landslides.)

(iii) As a perpetuating factor.

Each of these roles may consist of identical processes operating at different stages in time.

It is with climatic factors in their perpetuating role that this paper is primarily concerned.

Rates of Movement

The rate of earth movement and its controlling factors are of interest to the geomorphologist in providing a means by which he can view slope development and landform genesis in their true perspective. The interpretation and application of his findings, however, must be tempered by the possibilities of environmental change.

The writer has discussed elsewhere (Crozier, 1967) the problems of using the rate of movement as a classificatory parameter. Despite its limitations it is an invaluable index of processes occurring at the atmosphere-lithosphere interface. Unfortunately, standardization of technique is lacking in this field. There is no agreement, for example, on what point on a flow at which to gauge the average rate of movement, or on how many points are needed, or on whether to take into account movement at depth.

Varnes (1958) considers earthflows to have velocities ranging from "slow" (five feet per year) to "very rapid" (10 feet per second).

At Otakou, on the Otago Peninsula, a large discrete earthflow has yielded the following results: the average rate of movement, from an aggregate of 10 surface points on a transverse line at the foot, was 0.6 inch/day, which would correspond to Varnes' "slow" category; the average maximum was 0.7 inch/day, and extreme maximum was 2.4 inches/day in 1967 but as great as 5.1 inches/day in 1966. Both of the latter values correspond to the "moderate" category, which emphasizes the need for standardization — especially if the rate of movement is intended to be used in the classification of landslides.

These results may be compared with Benson's work (1940) which indicates that a large slump-earthflow on Abbotsford mudstone, after its initial extremely rapid movement, flowed for about a year at an average rate of 13 inches/day. In comparison, the Waerenga-O-Kuri Valley earthflow on Tertiary mudstone in the Gisborne district showed, over three years, an average rate of 0.4 inch/day, with an average maximum of 2 inches/day (Campbell, 1966). The Utiku subsidence, south of Taihape, had an average rate, for three months, of 0.5 inch/day, although it has reached 4 inches/day in July (Belz, 1967).

At Otakou the rate of movement is never the same for any two positions in space or time. Velocities vary transversely (the greatest rate being in the midline), longitudinally (greatest just downslope of the foot line) and vertically (maximum rate about halfway down to the surface of rupture). In time, the rate of earthflow movement varies from its initiation through to its quiescence.

Superimposed on this there is a marked seasonal variation in movement. Results to date indicate that the spring rate of movement is four times that of winter, three and a half times that of autumn, and twice that of summer (Fig. 1). Waerenga-O-Kuri also exhibited a maximum rate of movement during the spring before becoming quiescent. At the Utiku earthflow, on the other hand, the maximum was during the winter.

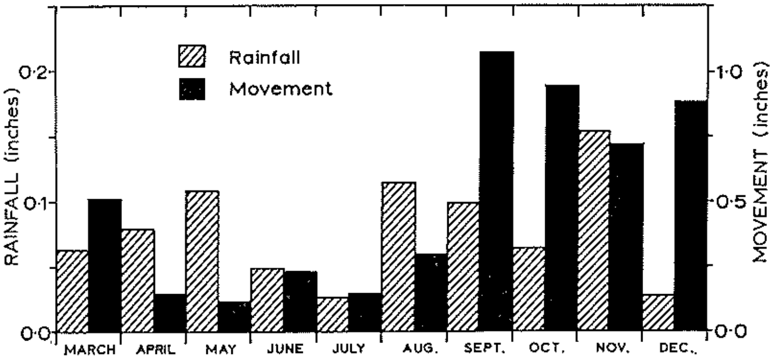

Fig. 1 — Histogram of rainfall and movement (monthly) at Otakou earthflow.

Soil Moisture

There are numerous interrelated factors effecting the tendency to move — and when mobile, the rate of movement. One would not expect any one of these to show a particularly high correlation with movement. The most important factor, or at least the one that might be expected to reflect or effect the variations in most other factors, is water content; this is difficult to measure, however soil moisture was measured in the hope that it might give some index of the effective water content.

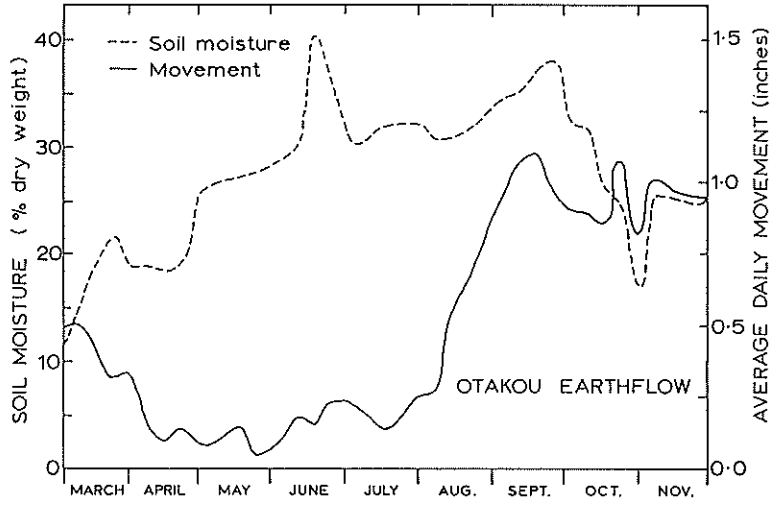

Fig. 2 — Four-week running mean of movement and soil moisture.

Fig. 2 shows a build up of soil moisture in winter and early spring. The highest average value for any month was 35 percent in September (early spring). Significantly, the same month showed the highest rate of movement. The high moisture of winter with no apparent response in movement may be a reflection of the depth of sampling. The soil may have been relatively dry at depth during this season and therefore shallow sampling would, during winter, give a false impression of saturation.

Correlating daily average soil moisture for each week against daily average movement for the same period, over the year, gave a correlation coefficient of 0.39, significant at the five-percent level. The season with the highest correlation was spring, where the correlation coefficient of 0.43 was also significant at the five-percent level.

This important build up of soil moisture in winter–early spring is not in direct response to precipitation. The rainfall does not increase in the winter — in fact there was less rainfall than in any other season. The wetness is mainly due to low temperature and low evaporation in this season, which results in a high ratio of effective rainfall to gross rainfall.

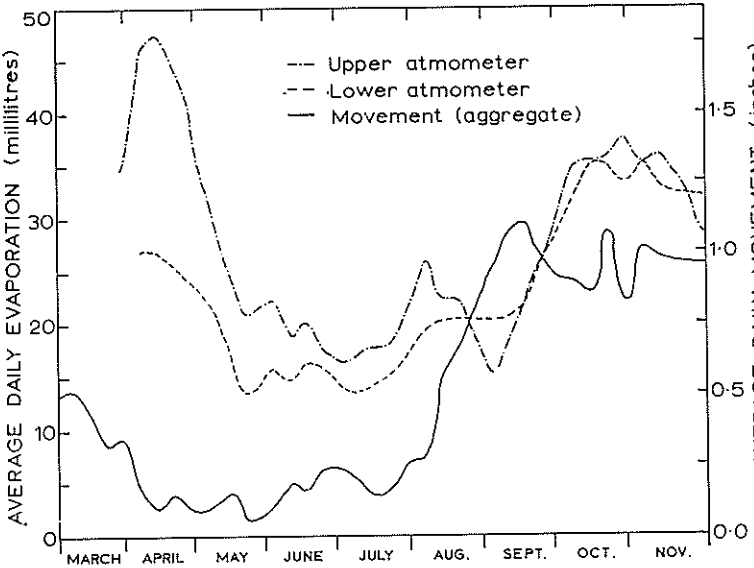

Fig. 3 — Four-week running mean of evaporation and movement.

Evaporation

In Fig. 3 both atmometers show low evaporation until just after September. The paradox of a low rate of movement being associated with a period of low evaporation can perhaps be attributed to the unusually dry winter. Normally one would expect high rates of movement at a time when low evaporation is allowing the water content to build up. This would have been so in this instance, had there been an adequate supply of water. In fact, however, this did not come until the high rainfall of late winter–early spring — then the movement was seen to increase.

Rainfall

An examination of unsmoothed weekly data suggests that movement is most sensitive to rainfall when evaporation and temperature are lowest (winter–early spring) — the period when soil moisture is also the greatest. This observation is quantitatively verified by the correlation coefficient for rainfall and movement, which is 0.45, significant at the five-percent level. The importance of rainfall in winter–early spring is further confirmed when a delay factor is introduced into the correlation. By this method it was found that the highest correlation occurs (in winter–early spring) when the movement observation is displaced from its contemporary rainfall observation by one week. This afforded a correlation coefficient as high as 0.60, significant at the one-percent level. Fig. 4 shows regression lines illustrating this relationship and comparing the situation in 1967 with that of 1966. Such a comparison stresses the danger of using these short-term correlations for prediction.

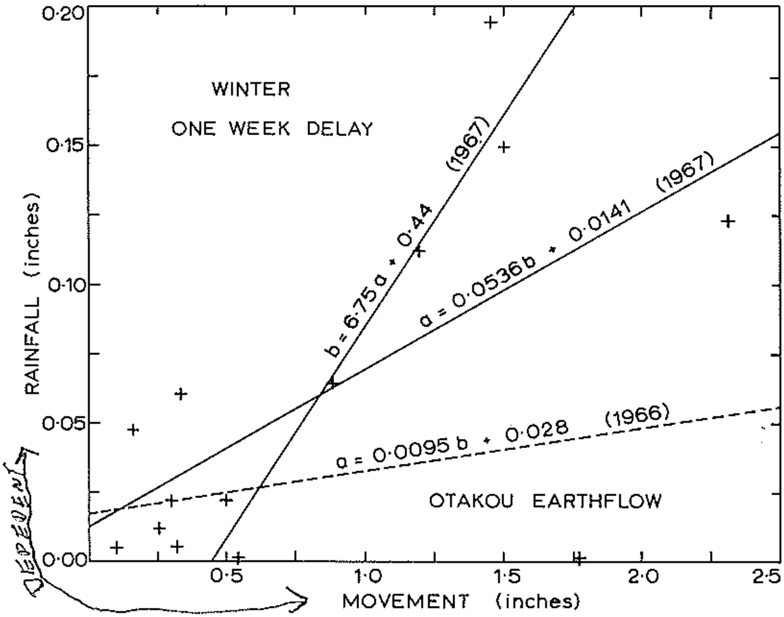

Fig. 4 — Regression lines for rainfall and downslope movement.

It is interesting to note that no significant correlation was found between rainfall and movement for a delay period of two or three weeks as suggested for Waerenga-O-Kuri by Campbell (1966). But, in agreement with him, "the relatively small effect of summer–autumn rains compared with similar storms occurring in winter–spring period" is verified (Fig. 5).

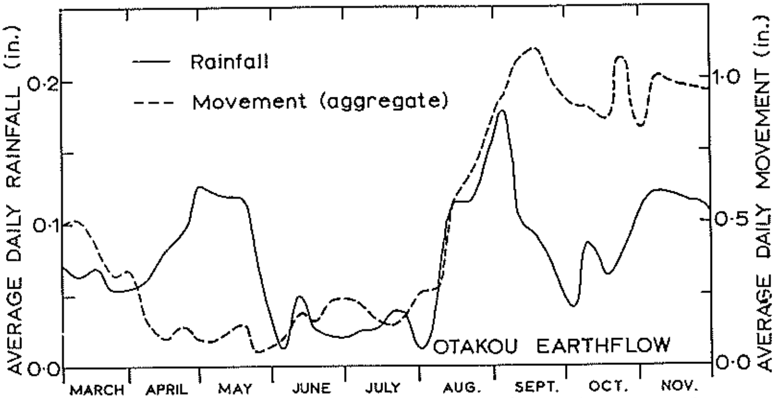

Fig. 5 — Four-week running mean of rainfall and movement.

In order to test whether the earthflow was more sensitive to rainfall during a period of rapid movement than it was during a period of slow movement, correlation coefficients were calculated for two periods of marked fast flow (August–December) and slow flow (March–July). This is shown in Fig. 5. In both cases the correlation coefficients were not significant, probably because each period involved months when rainfall was not effective because of high temperatures and evaporation.

CONCLUSIONS

There are two distinct types of earthflow in Eastern Otago, reflecting different geological situations and periods of development. Minor variations in form can be related to water content, depth and sensitivity of the regolith.

Rates of movement are so varied as to prohibit their use as parameters for prediction or classification.

The variation in the seasonal rate of earthflow movement reflects the response to climatic factors. In particular, variations in movement are most closely associated with variations in rainfall during the winter–early spring period, when evaporation and temperature are lowest and soil moisture is high. Finally, there is an indication that the effect of rainfall on the rate of movement, in winter–early spring, is not immediate but is delayed, and in this case by about a week.

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REFERENCES

Belz, D. T. 1967: Investigations of subsidence at Utiku. *Soil and Water 4 (1)*: 19–22.

Benson, W. N. 1940: Landslides and allied features in the Dunedin district in relation to geological structure, topography, and engineering. *Trans. Roy. Soc. N.Z. 70 (3)*: 249–263.

Campbell, A. P. 1966: Measurement of movement of an earthflow. *Soil and Water 2 (3)*: 23–24.

Crozier, M. J. 1967: Landslides and the Dunedin district. *Science Record 17*: 9–11.

Davidson, C. F. 1965: *Mass movement on the Gisborne coastline.* (M.A. thesis, University of Canterbury.)

Davidson, W. R. 1920: The duplication and reconstruction of the Dunedin–Mosgiel railway 1906–1914. *Proc. N.Z. Inst. Engr 7*: 110–133.

Jones, G. J. 1967: Dunedin's southern road outlet. *N.Z. Engng 22 (11)*: 463–471.

Selby, M. J. 1967: Aspects of the geomorphology of the greywacke ranges bordering the lower and middle Waikato basins. *Earth Sci. J. 1 (1)*: 37–58.

Skempton, A. W. 1953: Soil mechanics in relation to geology. *Proc. Yorks. Geol. Soc. 29 1 (3)*: 33–62.

Tricart, J., *et al.* 1961: Mécanismes normaux et phénomènes catastrophiques dans l'évolution des versants du basin du Guil (Hts. Alpes, France). *Zeitschr. f. Geomorph. 5*: 277–301.

Varnes, D. J. 1958: Landslides types and processes. In: *Landslides and engineering practice.* (Highway Research Board Special Report 29, NAS-NRC Pub. 544.) Washington, NAS-NRC. pp. 20–47.