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THE MOVEMENT OF SEDIMENT IN A CHANNEL IN RELATION TO MAGNITUDE AND FREQUENCY CONCEPTS — A NEW ZEALAND EXAMPLE*

C. F. PAIN
Department of Biogeography and Geomorphology, Australian National University
PETER L. HOSKING
Department of Geography, University of Auckland

Abstract

In areas where surface wash contributes most of the debris to a channel network, the effect of events of moderate magnitude and frequency appear to be more important than catastrophic events for land form development. In previous studies this idea has been emphasised, largely as a result of the fact that the contribution of bedload to sediment yield has rarely been considered.

Examination of these ideas under certain New Zealand conditions would seem to present a somewhat different picture. Where rapid mass movement is the main contributor of sediment to the channel, both the development of hill-slope form and the movement of sediment in channels must be related to the frequency of occurrence of mass movements. The evidence seems to suggest that most major mass movements are triggered during high-intensity, low-frequency storms.

The Orere River catchment in the Hunua greywacke block of South Auckland, New Zealand, is examined to test these ideas. Although historical data are limited, the character of the sediments in the lower catchment would suggest a succession of major periods of deposition. High-intensity storms of 1966 and 1967 resulted in the deposition of large amounts of material in the channels throughout the catchment, with a gradual removal of material mainly from the upper catchment since that time. From the limited evidence that is available, a simple model of sediment movement through the catchment is presented.

INTRODUCTION

In most studies of the magnitude and frequency of forces affecting geomorphic processes in drainage basins, the main source of sediment is assumed to be surface runoff. Moreover, measurements of sediment yield in these studies have been more or less confined to solution and suspension loads (Wolman and Miller, 1960; see also Guy, 1964). In areas where these assumptions are valid, as Wolman and Miller did point out, forces of moderate magnitude and frequency appear to have a greater net effect on landform development than do intense, short-lived forces associated with catastrophic events. However, under certain conditions, the role of the catastrophic event may be of profound importance for the subsequent development of the landform, resulting in a complete reversal of the relative effects of low and high frequency events. A case in point would be an area where rapid mass movement is a dominant surface form control. Changes in slope form and the rate of supply of sediment to the channel system would in this case be related to the periodicity of rapid mass movement. Leopold, Wolman and Miller (1964: p. 83-84) also point out that "In steep narrow valleys the likelihood is greater that infrequent events of major magnitude will so devastate the channel and valley that long intervening periods of more moderate flows have a relatively small effect on the landscape".

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The role of mass movement in landscape evolution has received increasing attention in New Zealand, as more traditional aspects of geomorphology developed overseas are replaced by ideas more in line with New Zealand's particular environmental conditions. It would appear that mass movement is a major agent in developing much of the present surface characteristics. This is especially so in the greywacke ranges of the North Island of New Zealand where a peculiar combination of lithological and climatological conditions results in the domination of mass movement over other forms of erosion.

THE STUDY AREA

The fifteen-square-mile Orere River Basin lies in the north-eastern Hunua block, thirty miles to the southeast of the city of Auckland (Fig. 1). The Orere River flows north from Kohukohunui (2256 ft), the highest point in the Hunua Ranges, and then swings to the east to drain into the Firth of Thames, a total distance of approximately eight miles. The underlying rock is finely-bedded, indurated Jurassic siltstones (loosely termed 'greywacke') which have weathered to a variety of depths and materials. Much of the area is covered by red-weathered greywacke, which is particularly susceptible to mass movement, perhaps because it contains a large amount of clay minerals, especially montmorillonite and metahalloysite (Fieldes, 1957). Some of the original forest cover remains, but almost one half of the basin is now grass covered.

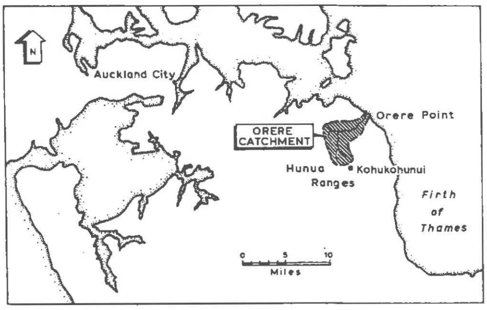

Figure 1. Location of the Orere River Basin.

The annual precipitation in the catchment, approximately 230 centimetres, is evenly distributed throughout the year, with a slight winter maximum. An important feature of the rainfall is the occurrence of high intensity rainstorms of tropical cyclonic origin which occur in late summer. In February of 1966 a storm of this nature resulted in an exceptional rainfall. Over a period of eight hours, an intensity of 2.62 centimetres per hour was maintained. Moreover, this was immediately preceded by one half-hour period when 8.23 centimetres was recorded. A storm of similar origin but with not quite the same intensities occurred in February of 1967. It has been estimated that storms of this intensity have a 20-plus year return period (Selby, 1967).

Selby (1967) and Pain (1968b) have suggested that these high intensity rainfalls are important factors in the initiation of rapid mass movement in the greywacke areas of South Auckland. And, since mass movement provides most of the material to the channel, the supply of debris is also regulated by the timing of large-scale mass movement. The effect of a single storm on the regime of a river has been commented upon widely in New Zealand (see for example Grant, 1965; Scott, 1963), while Tricart (1960 and 1961) has made similar observations in the French Alps.

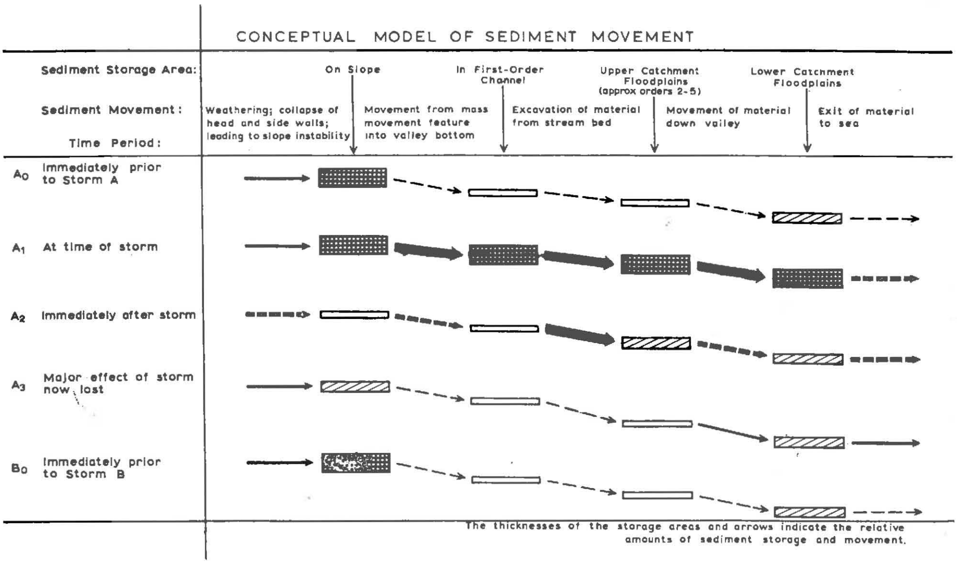

Figure 2. A Conceptual Model of Sediment Movement Through a Channel System where Mass Movement is the Dominant Sediment Source.

The extension of these ideas into the historical past has prompted some writers to suggest a single catastrophic event as the originator of certain depositional surfaces. Grant (1965) and Pullar (1965) have suggested 1650 A.D. as a possible date for a storm which resulted in considerable deposition on river floodplains in Hawke's Bay and Poverty Bay, respectively. In the lower reaches of the Orere River a series of depositional surfaces was mapped in detail by one of the authors (Pain, 1968a), and the four lowest surfaces were dated as post-Pleistocene. The nature of the materials suggested that there were at least four waves of aggradation in the catchment, each the result of a single climatic event or, more probably, a series of events. Deposition in the lower catchment as a result of the 1966 storm has been measured at up to 20.32 centimetres on surfaces which are 6 metres above the present stream level, and deposition on the present floodplain was much greater than this, in places exceeding 1 metre. High intensity storms would thus appear to be of profound importance in the supply and subsequent removal of material in the channel system.

A MODEL OF SEDIMENT MOVEMENT

From the evidence provided by the storm of 1966 and observations prior to and especially after the storm, a simple model of the movement of sediment through the catchment is presented (Fig. 2). It should be emphasised that the model is conceptual and is based on very little measured data. Thus the conclusions are not quantitative but provide a qualitative summary of the relative importance of various characteristics and movements throughout the channel system. More accurate and continued measurement could provide a firmer basis for the construction of more detailed models.

The movement of sediment is considered with reference to four major areas of sediment storage. These areas are viewed in terms of their relative importance at four major time-periods, which are measured in relation to a major storm. Material in its passage from weathered bedrock *in situ* to its exit from the channel system (in this case into the sea) is held in temporary storage in four different sequential areas :

1. Material lying on the valley-side slopes,
2. Material lying on the floor of the first-order channels,
3. Material in temporary storage in the upper catchment floodplains,
4. Material in temporary storage in the lower catchment floodplains.

The distinction between the last two areas of storage is rather arbitrary. In the Orere River catchment the transition can be easily discerned by noting where floodplains increase rapidly in extent and terrace remnants begin to appear. The river at this stage has reached its maximum order number of five. The general distinction, however, is dynamic and reflects the susceptibility of the floodplain to short-term changes in sediment storage capacity, the lower catchment areas being less susceptible.

The fact that the 1967 storm in the Orere River catchment failed to initiate new large-scale mass movement, but rather resulted in small-scale extensions of features which were initiated one year earlier, leads to the conclusion that major mass movement operates in a cyclical system. A slope, through weathering and minor movements, gradually increases its instability until it reaches a point when any triggering mechanism such as an intense rainstorm results in a considerable movement of material downslope. Immediately after the storm, movement still occurs as the head and sidewalls of mass movement features are still unstable, and scouring of the shear plane and depositional area of the feature provides a large quantity of sediment. Compared to its earlier condition, however, the slope is soon rendered stable, and the development of instability begins again. The timing of this period of maximum instability varies both with the speed at which slope instability can develop and with the frequency of storms of sufficient magnitude to trigger the mechanism.

It appears, then, that the major source of material in first order channels is mass movement occurring on the valley sides. The passage of mass movement debris down the first order channel is inferred to be in the form of a debris flow, with high competence for transporting material. This is evidenced both by the removal of the loose material infilling the first order channels, often down to the unweathered greywacke, and also by the destruction and removal of any vegetation on the channel walls. This is especially so under forest vegetation where a swath twelve feet wide on either side of the channel has been observed. (For an extended discussion of movement of sediment in the lower orders of a channel system, see Pain, 1968b.)

Movement of sediment through low order channels under forest is disrupted to a large extent by the presence of large amounts of vegetation. This vegetation, consisting mainly of logs and branches, accompanies mass movement debris in its movement from the slopes to the channels. A result of this is the formation of debris dams, which during storms quickly lead to the accumulation of large amounts of sediment.

The net result is a contrast between grassed and forested catchments in the timing of movement of material from first order into higher order channels. Under forest, the effect of debris dams is to slow down the movement of material in a way which rarely occurs under grass. Thus, while the movement of debris down forested channels appears to be intermittent, debris movement down channels of grass catchments is relatively a more steady process.

The amount of sediment stored in upper catchment floodplains varies considerably. The total amount of sediment in storage is increased drastically during and immediately following the storm when the sediment from the first order channels passes into, and perhaps through, these floodplains. However, the source is soon diminished to a state where additions to the floodplains are small. Then, as the finer material is moved by more 'normal' flow, the total sediment storage capacity decreases.

Storage capacity in floodplains in the lower catchment, on the other hand, varies little throughout much of their existence. At the time of a major storm, there is a greatly increased flow of sediment from the system, but once the sediment from the upper portions of the drainage network has been deposited in or moved through the floodplains, the balance of input and output is restored. The size and amount of sediment moved is not as strictly controlled by discharge as it is in the upper catchment, because the higher and less variable discharges and the generally smaller material (diminution with distance) of the lower catchment allow for a more uniform sediment discharge. It is only when a major modification in the environmental conditions of the upper catchment results in a complete change of the sediment budget of the whole system that a basic fluctuation of depositional levels of the lower floodplain would occur. This excludes, of course, the obvious change that would occur if base level was altered. Such changing environmental conditions in the post-Pleistocene are thought to be the cause of the four major depositional levels in the lower catchment.

High intensity, low frequency storms are important for the development of the floodplains of the upper and lower catchments, in that they provide discharges which can move material that otherwise would be too large for movement. Moreover, they provide the bulk of the material which forms the sediment load of the river, including material that is deposited in a position where it cannot become a sediment source until a high discharge again occurs.

Without being able to affix any definite time spans to the periods, four sequential changes in the characteristics of sediment movement are indicated in Fig. 2. Assuming that the 20-year-plus return period for a high intensity storm similar to that which occurred in 1966 has more than just statistical significance, a basic time length for the complete 'cycle' could be assessed. This, however, also assumes that storms of this intensity are necessary for initiation of major slope failure and that slopes require a period of approximately this dimension to achieve a state where instability reaches some sort of peak. Both assumptions may be invalid, and thus any direct time scale is omitted.

Ignoring very short-term fluctuations, the following sequential changes are hypothesised :

Time Period A_0

Immediately prior to a storm there is a small amount of sediment moved through the channel system, mainly fines derived from surface wash from the slopes, small scale mass movement, and movement from one section of a floodplain to another. At the same time, because of a build-up over the previous years, there is a large amount of material in a position on the slopes which would be rendered unstable if high intensity rain occurs.

Time Period A_1

During the storm itself, discharge in all sections of the channel rises, increasing movement of sediment from the floor and banks of the channel. Surface wash of material from the slopes to the channel system increases, and major mass movement is initiated. The immediate effect of mass movement is the addition of immense quantities of material into the first order channels and in some instances directly into the high order channels. The great increase in sediment in the channel system results in deposition in all sections of the system as well as a higher discharge of sediment into the sea. In all probability, at the end of the storm, much material initially deposited in the first order channels (debris dams apart) has been moved into high order channels.

Time Period A_2

In the days and months following the storm, the mass movement features themselves continue to add sediment to the channel system by collapse of head and side walls and by scouring of the shear-planes and depositional zones. Some first order channels are completely scoured out, and at times of slightly higher discharges, a considerable quantity of material is moved into and through the upper and lower catchments.

Time Period A_3

After a matter of a few years, the major effect of the storm is lost, and the upper catchment is restored basically to its former character, except that it contains material deposited during the storm which cannot be moved until the next extreme discharge. There is continual scouring of material deposited in the upper and lower catchment floodplains during the storm, but this is selective in that only the fines are removed.

Time Period B_0

Eventually the whole channel system is restored basically to its original equilibrium character, with the slopes slowly but gradually increasing in instability.

CONCLUSION

Although the accuracy of the observations and the validity of the steps in the model leave much to be desired, they do lead to a conclusion of some significance. In an environment where much of the moulding of the land surface is contingent upon events (namely rapid mass movement) which occur intermittently and catastrophically, the conclusion of Wolman and Miller in regard to the importance of these infrequent events needs to be re-evaluated. It has been suggested that the movement of sediment through all sections of the channel system is affected by the timing of deposition from the major source of supply of debris.

In the Orere River basin the importance of a single storm on the sediment regime of the river must be assessed on the basis of the following five premises :

1. Major rapid mass movement occurs intermittently, in response to high intensity, low frequency storms.
2. Most of the material available for transport from the slopes reaches the channel network, especially the first order segments, by the mechanism of slope failure.
3. Apart from re-sorting of material already in a floodplain, the bulk of sediment moving through the channel system comes from material deposited in the lower order channels.
4. High discharges associated with high intensity storms move large material which otherwise would not be capable of movement. The lack of assessment of the contribution of bedload to total sediment movement may lead to misconceptions when analysis of discharge is derived from solution and suspension measurements alone.
5. A single high intensity storm may so disrupt the channel system that its effects may be felt many years after the initial event.

For the Orere River basin it is concluded that high intensity, low frequency events are the dominant control, both directly and indirectly, of sediment movement throughout the channel system. It would be expected that similar conclusions would be reached in areas where the same premises hold true.

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REFERENCES

Fieldes, M., 1957 : Clay mineralogy of New Zealand soils : Part IV, Differential thermal analysis, *N.Z.J. Sci. Tech.*, B38 (6) : 533-570.

Grant, P. J., 1965 : Major regime changes of the Tukituki River, Hawke's Bay, since about 1650 A.D., *J. Hydrol. (N.Z.)*, 4(1) : 17-30.

Guy, H. P., 1964 : An analysis of some storm-period variables affecting stream sediment transport, *U.S. Geol. Surv. Prof. Paper* 462-E : 1-46.

Leopold, L. B., M. G. Wolman, & J. P. Miller, 1964 : *Fluvial Processes in Geomorphology*, Freeman, 522p.

Pain, C. F., 1968a : Depositional surfaces in the lower Orere River Valley, Eastern Hunua Ranges, *Auckland Student Geogr.*, 5 : 6-12.

——————, 1968b : Geomorphic effects of floods in the Orere River Catchment, Eastern Hunua Ranges, *J. Hydrol. (N.Z.)*, 7(2) : 62-74.

Pullar, W. A., 1965 : Ground surfaces on floodplains, *J. Hydrol. (N.Z.)*, 4(1) : 31-34.

Scott, P., 1963 : Erosional effects of recent and past cloud bursts in the Godley Valley, Lake Tekapo, *Procs. N.Z. Ecol. Soc.*, 10 : 19-20.

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.

Tricart, J., 1960 : Les modalites de la morphogénèse dans le lit du Guil au cours de la crue de la mi-juin 1967, *l'A.I.H.S. Commission d'Erosion Continentale, publi.* No. 53 : 65-73.

——————, *et al.*, 1961 : Mécanismes normaux et phénomènes catastrophiques dans l'evolution des versants du basin du Guil (Htes-Alpes, France) (1), *Zeits. für Geomorph.*, 5(4) : 177-301.

Wolman, M. G., and J. P. Miller, 1960 : Magnitude and frequency of forces in geomorphic processes, *J. Geol.*, 68(1) : 54-74.