

A SYSTEMS APPROACH TO THE DESCRIPTION AND INTERPRETATION OF THE LANDSURFACE OF THE NORTHERN HALF OF THE NORTH ISLAND, NEW ZEALAND

A. J. CONACHER

University of Queensland

Abstract

The paper examines a framework of approach within which landsurface analysis may be undertaken in the humid-temperate northern half of the North Island, New Zealand; an area exhibiting a wide range of lithologies and surface cover, with evidence of recent and current tectonic and volcanic activity, and undergoing active geomorphic processes. The largely theoretical formulations of W. M. Davis, W. Penck and L. C. King are considered briefly and are rejected on both theoretical and practical grounds. General systems theory encompasses certain concepts and systems properties which have been applied by a number of geomorphologists. The open system property of dynamic equilibrium is examined, and is found to be inapplicable to the total landsurface of this region. The concepts of environment and sub-system are introduced and their relevance to the region illustrated by a physical hillslope model. Dynamic equilibrium is considered to be a possible state of certain hillslope sub-systems. Construction of a mathematical model to describe the total landsurface or the entire hillslope system is not feasible until hillslope sub-systems have been analysed. The form of a linear regression model applicable to hillslope sub-systems is introduced, and it is suggested that the pattern of the residuals from regression may be used as a statistical technique to assist in identifying significant system boundary conditions, and to provide a quantitative indication of the influence of historical factors.

INTRODUCTION

Climates in the northern half of New Zealand's North Island range from the sub-zero winter temperatures of the volcanic plateau to the so-called 'winterless north'; rainfall varies between 40 and 80 inches per annum depending on elevation and location with respect to prevailing winds. Generally however, the climate of this region may be classed as 'humid temperate'. Tectonic and volcanic activity have affected the entire region to varying degrees at different times and are still active in certain areas. Lithologies range from basalt, ignimbrite and greywacke through Tertiary mudstones, siltstones and sandstones to volcanic ashfall and pumice deposits and dune-sand in various stages of consolidation. There are differences in land cover from a near approximation to primary bush (podocarp/mixed hardwood forests), to reverted manuka (*leptospermum* sp.) scrub, and to pastures and limited areas of cultivation. The headwaters of most drainage systems show little evidence of active degradation; an observation that has prompted at least one writer to infer that no erosion has occurred in areas covered by recent ash deposits since their deposition (Lauder, 1964). Nevertheless, geomorphic processes are extremely active, and reveal a remarkable degree of uniformity throughout the region despite the physical environmental differences.

The aim of this paper is a theoretical one — to examine a framework of approach within which landsurface analysis in this part of New Zealand may be undertaken. There are a number of reasons for rejecting the Davisian cyclic formulation, including the dynamic nature of conditions in the region. Most important is the clear evidence that this landsurface does not constitute a closed system; and Chorley (1962) has ably demonstrated the close links between the Davisian cycle of erosion and the properties of closed systems. Penck's ideas constituted neither a universal theory nor were they concerned with the total landsurface (Penck, 1953). In addition, there is not only little theoretical justification for his ideas, but little if any empirical support for them in this region. Only in the question of parallel slope retreat may some evidence be adduced. L. C. King's ideas, which are claimed to have universal application and which are also relevant to the total landsurface (King, 1962, Ch. V) are also rejected, more on practical than on theoretical grounds. Field work by a number of workers over a period of five years has yielded no evidence of pedimentation and only scattered evidence of parallel slope retreat. King's four element hillslope is uncommon and there is no evidence that hillslopes in this area are tending to attain this form.

Only one other theoretical framework has received any real measure of support, although it differs from those already mentioned in that it is not directly concerned with landscape evolution or development. From the body of thought loosely termed 'general systems theory', a number of geomorphologists have considered that real advantages may be gained by viewing landforms as an assemblage of systems, and that one of the properties of open systems — dynamic equilibrium — 'explains' certain conditions observed in the landscape. Some of the concepts inherent in systems thinking, and certain attributes and properties of systems will be examined in further detail insofar as they are relevant to landsurface analysis in northern New Zealand.

DYNAMIC EQUILIBRIUM

Geomorphologists have tended to over-emphasise the dynamic equilibrium property of open systems to the virtual exclusion of other possible open system states (Strahler, 1950; Hack, 1960; Chorley, 1962). Bertalanffy has defined, mathematically, the nature of the variation of system elements over time, and has shown that the solution of these equations may lead to one of three conditions (Bertalanffy, 1950, p.146):

- (i) the system may reach a stable stationary state;
- (ii) the system may exhibit oscillations or cyclic variation around the stationary state;
- (iii) No stationary state may result.

Isolated systems (Foster, *et. al.*, 1957, p.9) or 'closed' systems as defined by Chorley, always behave in the first way. However, this may also be considered as a special case of the open system, when the exchange of matter and energy across the system's boundary approaches zero. The second possibility is dynamic equilibrium; and here it has been shown by Reiner and Spiegelman (1945) and by Bertalanffy (1952, p.125) that the maintenance and preservation of this condition are ultimately determined by conditions at the boundary — as is true for any state of a system. In particular, the system boundary conditions must remain stable for a period of time sufficient for the system to adjust to them. The length of time required is determined by the adjustability of the system to change. In northern New Zealand, subject to volcanic and tectonic activity as well as the considerable changes to surface cover wrought by man, the land-

surface boundary conditions are not stable. Although adjustment to change is generally rapid, the landsurface as a whole cannot be considered to exhibit the property of dynamic equilibrium. The possibilities of the third type of condition are presumably numerous and yet appear to have been totally neglected by geomorphologists. Moreover, systems theory literature offers little indication as to the possible nature of systems adjustments to changing boundary conditions. One exception is Maruyama's deviation-amplifying concept, in which the system's "relationships . . . amplify an insignificant or accidental initial kick, build up deviation and consistently diverge from the initial condition" (Maruyama, 1963, p.164).

While the landsurface as a whole cannot be considered as a system in dynamic equilibrium, it is possible that smaller landsurface units may well exhibit this condition. Indeed, such an approach not only has the advantage of focusing the analysis at a more detailed level of enquiry, but it may also be necessary on theoretical grounds. Systems theory provides an approach with its allied concepts of environment and sub-system.

Environment and Sub-system

Recognition that a system is usually influenced by objects external to the complex introduces the concept of environment, and Hall and Fagen provide the definition (1956, p.20): "For a given system the environment is the set of all objects a change in whose attributes affects the system, and also those objects whose attributes are changed by the behaviour of the system". In the same way that distinctions are made between system and environment, a given system may be further divided into a series of sub-systems. Objects in one sub-system may then be considered as part of the environment of the other sub-systems. Thus the hillslope system — a three-dimensional complex extending from the water parting to the centre of the channel bed, and from the surface to the uppermost boundary of unweathered rock — may be considered as a landsurface sub-system. The hillslope in turn may be divided into a number of sub-systems. Recent work in the northern half of the North Island suggests such a sub-system approach to landsurface analysis. The results of five years' research have been summarised in the form of an hypothesis stated as a 'nine unit landsurface model' (Dalrymple *et al.*, in press). This physical model describes an hypothetical hillslope extending from the water parting to the centre of the channel bed, divided into nine 'units'. Each unit is defined in terms of form and the dominant geomorphic and pedological processes currently acting on it. A brief summary follows.

Unit 1 is the interfluvium. It has a modal slope angle of zero to one degrees and "the dominant processes are primarily pedological in nature, being those associated with vertical sub-surface water movement". Unit 2 has been termed the 'seepage slope'. It is an irregular facet,⁽¹⁾ with modal slope angles between two and four degrees, but it may be as steep as about 10 degrees. "Lateral sub-surface water movement is the most important geomorphic agent operating on unit 2, giving rise to the dominant processes of lateral mechanical and chemical eluviation . . .". Unit 3 — the 'convex creep slope' — is an irregular slope segment (Savigear, 1965, p.517), markedly convex in form. Soil creep is considered to be the dominant process. Unit 4 is the fall face. Unit 5, an irregular facet, has a possible range of slope angles from 45 degrees to less than 20 degrees, and is similar but not equivalent to the 'constant slope' of earlier hillslope models. In the North Island of New Zealand this unit

is characterised primarily by the initiation of the more rapid varieties of mass movement. However, the dominant process is considered to be the transportation of material across the unit. Unit 6 is "essentially the zone of redeposition of colluvial material derived from higher up the slope profile whether by mass movement processes or by surface or sub-surface water action". Unit 7 may be regarded as equivalent to a flood plain, "with modal slope angles ranging between zero and four degrees. The dominant process occurring on this unit is the redeposition of alluvial material carried downvalley by the major stream or river . . .". Unit 8 is the channel wall of the major stream or river; corrasion by surface water action and slumping of the banks are the co-dominant processes. Unit 9 is the channel bed; the dominant process is considered to be neither degradation nor aggradation but rather transportation by surface water action.

In reality it is most unusual to find all nine units occurring on one slope profile. They do not necessarily occur in the order outlined above, and individual units may recur in a single profile. Thus the nine unit model is not representative of an 'ideal' hillslope; neither is it intended to suggest a form towards which hillslope profiles develop. Rather, the model summarises the forms and the contemporary dominant processes as they occur in the region, and provides a means whereby the total landsurface in this area may be described and interpreted at a fairly general level of enquiry.

If the assumption that the state of a system is determined by its boundary conditions is correct, then the differences between units of the hillslope such as those described above result from differences in the boundary conditions of each unit, or sub-system. Not least of these is the location of each unit with respect to the other units. Differences in the nature of the underlying lithology will affect the rates of supply of material and the nature of the weathered material, resulting in possible differences in the processes operating between the elements of the sub-system and in a consequent particular form. There may be differences in land cover and land utilisation from top to bottom of the profile; certainly the supply of solid and liquid matter will be theoretically greater in the lower portions of the hillslope. Differences in the form itself, through its self-regulating function, will be a significant factor.

In the context of mathematical model building in an urban area, Garrison has stated that "much experimental work must be done with the individual aspects of urban systems before these elements can be brought together into a large model" (Garrison, 1960, p.95), and the necessity of understanding the whole through an appreciation of the functions and interrelations of each of the component sub-systems has been reiterated by Berry (1964, p.132). These comments assume greater significance when it is appreciated that processes relevant to the interaction between elements of a given sub-system may not be the same as those relevant to other sub-systems or to the parent system. Thus if a model embodying a specific process is used to explore the behaviour of a given system, it must be verified that the process is applicable to the whole and not merely to some part of the whole.

It would seem, then, that it may well not be possible to attempt construction of a hillslope or a landsurface system model until the nature and functions of the sub-systems are clearly understood, and their interrelations amongst themselves and with the parent system determined.

The present state of knowledge provides some indications — particularly with respect to channel systems — but much more work remains to be done on the remaining hillslope units.

Two major problems remain: identification of the hillslope unit boundary conditions which determine the state of the sub-system (measured by a parameter such as the form of the hillslope unit); and assessment of the influence of historical factors. It is suggested that construction of a mathematical model — in itself one of the basic aims of a systems approach to a given problem — may provide an approach towards the solution of these problems.

Models necessarily involve a simplification of the real world. "They are representatives of states, objects and events. They are idealised in the sense that they are less complicated than reality The simplicity of models, compared with reality, lies in the fact that only the *relevant* properties of reality are represented" (Ackoff, 1962, p.108). Thus although those processes which determine the major sources of interaction at the system boundary may have been identified, there may be a significant proportion of interactions not accounted for by the model. It is in relation to this residue — the proportion of interactions not accounted for — that the concept of random behaviour has most commonly been introduced into analytical schemes. This concept may be developed to provide a useful statistical technique (Moore, 1966). If linear regression methods are applied to the analysis of a given set of areal data with a view to accounting for the variation of one variable by the variation in other selected variables, an equation of the following type will result:

$$Y = a_1X_1 + a_2X_2 + \dots + a_nX_n + U$$

where Y is the chosen dependant variable (the hillslope unit form), the X's the independent variables (the boundary conditions) and U the specific residual for each area. If all the systematic variation in Y is to be accounted for by the variation in the X's, then the values of U will demonstrate a purely random distribution. If the values of U depart significantly from that associated with a random distribution, a search for a further correlate of Y is suggested.

Once all the significant boundary conditions have been accounted for, then any further deviation of the values of the residuals from a normal distribution will reflect the significance of historical factors. Note that the pattern of residuals cannot 'explain' their influence — this must be determined from field observations — but it can provide a quantitative indication of their degree of influence. Thus largely 'fossil' units will exhibit a low correlation with contemporary boundary conditions: this can be expected to be the case for many units 4, or fall faces; while units 5 will probably exhibit a generally close approximation to a state of dynamic equilibrium.

Footnotes

(1) A *facet* is a plane, horizontal, inclined or vertical surface area (Savigear, 1965, p. 517).

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