THE ROLE OF PEDOGEOMORPHOLOGY IN TROPICAL LANDFORM STUDIES

John Gerrard, Birmingham

ABSTRACT : Tropical areas have always attracted the interest of geomorphologists and there have been numerous attempts to describe and explain the landforms of such regions. However, in spite of this interest there is still a great uncertainty about the origin of many tropical landforms. This uncertainty has been increased by much recent work that has demonstrated, quite convincingly, that many tropical areas have experienced severe environmental changes during the Pleistocene Period. Traditional geomorphological approaches seem unable, on their own, to explain satisfactorily many of these uncertainties. When progress towards explanations appears slow it is usually time to try a new approach. Soil acts as a buffer zone between the landform and the atmospheric and surface processes shaping that landform. Soil is usually very sensitive to subtle changes in the environmental conditions and the soil profile should reflect the history of the landscape if only the signals can be deciphered. This paper, by using a number of examples from several tropical areas, will attempt to show that by integrating pedology and geomorphology in a more meaningful way it should be possible to increase our understanding of landform evolution and environmental change in such areas.

INTRODUCTION

Tropical areas have fascinated geomorphologists for many years. There are many reasons for this. Early geomorphologists were impressed by features such as inselbergs, vast featureless plains, the great depth of rotted rock, large expanses of lateritic crusts and the apparently great vitality, complexity and stability of tropical ecosystems. This lead to the belief that tropical landscapes were somehow unique and could be related to zonal tropical climate. Thus tropical geomorphology often stresses the distinctiveness not of tropical landforms but of tropical climates and tropical vegetation. Tropical rainforests especially were thought of as a climax community with implications about ecological stability and associated geomorphological processes.

This approach was seemingly satisfactory until it was realised that major as well as minor environmental changes have occurred in the tropics during the Pleistocene Period. This leads to the possibility that many tropical landscapes are not necessarily in equilibrium with current climate and vegetation. It is also possible that tropical rainforests are not the stable ecosystems that they were thought to be. It is now clear that large areas of the tropics have been subjected to major changes of climate over the last 200,000 years, one of the most significant being a period of much drier, cooler and windier climate between 20,000 BP and 125,000 BP. In South America and Africa it appears that areas of tropical rainforest decreased to occupy remnant enclaves. The situation in Malesia is unclear but similar environmental changes are likely to have occurred. This means that landscapes have to be examined in greater detail to try to establish the scale and effect of such environmental changes. These will depend ultimately on the sensitivity of the landscape to change.

LANDSCAPE CHANGE

The physical landscape can be thought of as a system which is being subjected continually to external shocks. Brunsden and Thornes (1979) have subdivided these

external shocks into pulsed and ramped inputs. In pulsed inputs the external disturbance is short in relation to the time scale being considered and is usually followed by a return near to the initial state. Pulsed inputs are usually extreme, episodic events which are spatially and temporally restricted. Ramped inputs, such as climatic or land use changes, changes of sea level or tectonic activity, are usually sustained at a new level because of these relatively permanent shifts in the controlling factors. The effect of ramped inputs is also likely to be felt throughout all parts of the landscape rather than being spatially restricted. Climatic change will alter the weathering regime over the entire landscape and may upset the balance between weathering and removal of material. Vegetation and soil systems are also usually altered.

The scale and location of any landscape change will depend on the sensitivity of the landscape. Sensitivity can be expressed as the likelihood that a given change in the controls of a system will produce a sensible, recognisable and persistent change. Landscapes vary in their sensitivity to change and there are also great variations in sensitivity within landscapes. Two contrasting types can be identified (Brunsden and Thornes–1979). Mobile, fast responding systems have high sensitivities to externally generated changes, react quickly and relax to new system states with ease. They are extremely sensitive to climatic variations but are morphologically complex because they exhibit both equilibrium or characteristic landforms as well as transient forms. In contrast to these systems there are slowly responding, insensitive areas, such as interfluves and plateaux where change is rarely felt. This is due to a combination of low concentrations of flows of energy, water and materials, intermediate buffering or high storage capacity. In general, most landscapes are of intermediate sensitivity.

The consequences of this differing sensitivity are extremely important to an understanding of longterm landform evolution. In insensitive areas characteristic forms are rarely produced unless enviornmental conditions remain constant for long periods. The polygenetic plains of Africa and Australia may be examples of this. However Street-Perrott et al. (1985) have argued that there is a possibility that in marginal climatic zones in the tropics with major but frequent alterations of different geomorphological regimes distinctive landform assemblages might be created. Highly sensitive areas will respond quickly to external changes which means that the effects of former conditions are obliterated. The key to elucidating landform development is the identification of features in the landscape of medium sensitivity.

SOILS AS LANDSCAPE INDICATORS

Soils, and their relationships with landforms, are such medium sensitivity features. Major landform types are often too insensitive to record all but the major environmental changes. They may also be structurally and tectonically determined. Vegetation and other biological features are, in general, too sensitive to enable landscape change to be established. Soil acts as a buffer zone between the landform and the atmospheric and surface processes shaping that landform. Soils are usually quite sensitive to subtle changes in the environmental conditions and the soil profile should reflect the history of the landscape if the signals can be deciphered. These principles can be examined with respect to erosion surfaces (Gerrard, 1981). Erosion surfaces require a long time to be produced and during that time external conditions may have changed. Many erosion surfaces are now isolated from the processes that creaed them. Also erosion surfaces are not everywhere synchronous. Active erosion surfaces are those still being

shaped by their formative processes, dormant surfaces are those whose active shaping has ceased temporarily, perhaps by climatic change, and are expected to function again in the near future, exotic surfaces were formed under conditions that no longer exist and defunct surfaces have been removed from the action of erosive processes by uplift or depression.

Simply by examining their form and geomorphological relations it is usually extremely difficult to establish the current status of erosion surfaces. However, soils may provide a pointer to the status of any erosion surface. Exotic surfaces can be identified by a soil cover that indicates that there have been gross changes of climate. The type and distribution of soils may also make it clear when active surfaces are being formed at the expense of dormant or exotic surfaces. This is true of many parts of Africa. Analysis of soils and weathering products enabled Ollier (1959) to establish the sequence of erosion surface formation in Uganda. The relationship between duricrusts and erosion surfaces has been crucial in the construction of denudation chronologies in many parts of the world. Also many workers have used duricrusts as indicators of past climates. Calcretes appear to be related to semi-arid climates where annual rainfall is between 200–500 mm and ferricretes and alcretes form under relatively humid conditions. There is more uncertainty concerning the development of silcrete. Summerfield (1983) has argued that silcretes may form under two distinct climatic regimes. He makes the distinction between ' the nonweathering profile ' silcretes which result from localised silica mobility and concentration in high pH conditions in arid and semi-arid climates and ' the weathering profile ' silcretes which have formed under more humid climates in highly acidic, poorly drained environments.

Soils can also be used to identify periodic pheneomena in the landscape. Gile and Hawley (1966), using soil and sediment analysis on alluvial fans in southern New Mexico, were able to demonstrate the way in which the fans had been formed by alternating phases of deposition and erosion. Lengthy periods of stability are indicated by prominent, well developed buried soils. The buried soils indicate complexities far greater than are suggested by the relatively smooth surface relief. The methodology developed by Butler (1959, 1967) allows the use of buried soils to indicate changing relationships between soils and landforms.

Soil profiles are also of use in determining the nature of current geomorphological activity. Many slope processes, such as overland flow and throughflow, exhibit extreme spatial and temporal variability, making detailed process measurements extremely difficult. Detailed process measurements are especially difficult in tropical areas. But the operation of such processes are often visible in soils. Sub–surface soil water movement can usually be inferred from soil properties. Having established some general principles some specific applications to tropical geomorphology can be examined.

IDENTIFICATION OF ENVIRONMENTAL CHANGES

It is now clear that central Amazonia has suffered effects of dry periods when the landscape was not covered by the present type of rainforest. Some of the evidence of these effects is very obvious, such as fossil dune fields on its margins, but much is more subtle and includes evidence from soils (Tricart, 1985). Two characteritic plant associations in the region are the 'cerrados' and the 'tabuleiros'. The 'cerrados' are a xeromorphic plant association, with an open stratum of trees, a denser shrub stratum and an open lower stratum. Runoff is active under such a vegetation type. The 'tabuleiros' are thought to be a relict formation of similar physiognomy found on

plateaux remnants with poor drainage during heavy rains and with an extremely low soil moisture retention capacity. ' Tabuleiro ' vegetation usually grows on structureless, nutrient–deficient, white quartz sands. This vegetation, its specific morphodynamics and relationships with soils and landforms, has been used to explain dissection following the dry period. Tabuleiro vegetation was widespread on coarse detrial rocks in Central Amazonia during the drier period but as the climate became more humid it became more and more restricted in occurrence. At the present time it survives on soils that provide the worst conditions for forest growth.

Changes during the Quaternary in Central Amazonia have been described by Tricart (1985) in the following terms. The last major phase occurred during the last stage of low sea level when there was intense dissection favoured by the lower sea level and by the drier climate which eliminated the rainforest from the lowlands along the Amazon River. During the Holocene, a wetter climate and a rise of sea level occurred simultaneously. The recolonisation of the landscape by rainforest lead to a decrease in sediment yield and consequently limited accumulation of alluvium. This explain why levees along the Amazon River are no longer developing and are covered by many metres of water. This chronology has been established by a detailed analysis of many interrelated factors of which soils and their relationships with vegetation and landforms have been especially crucial.

Spath (1985) has been able to use similar arguments in explaining relief generation in the dry zone of Sri Lanka. The dominant reddish–brown soils of the dry zone differ markedly from the latosols and plastosols of the wet zone. They are shallow, skeletal, rich in grus and have an earthy structure. They are also well drained with a high porosity. Kaolinite is the dominant clay mineral however kaolinitic weathering is much less

intensive than in the wet zone. Profiles show little silt and are poorly sorted. Spath (1985) describes a typical catena between a wash divide and a wash depression in the dry zone. Above the crystalline bedrock is a decomposed zone several metres thick followed by a mottled zone with a dense red-brown loam with pisolites and quartz grus. This profile exhibits features of an altered latosol of the wet zone. This is clearly a relict soil from former wetter conditions. These relics thin out down slope indicating that the latosol was once continuous to the wash depressions and has since been truncated by the lowering of the depression.

Thus the catena is only partially the result of the present climate. On the divides the soils are complex and polygenetic with the latosol relics derived from a wetter climate. Heterogeneous soils with relics of a wetter climate and diverse sediments and other palaeosols from a drier period of the Upper Pleistocene demonstrate the intricate evolution of the landscape. Thus, in the dry zone of Sri Lanka it is difficult to define the ' normal landscape '. The situation in the adjacent areas of south-east India may be similar. The Tamilnadu surface has been interpreted as polygenetic with evidence for several changes of climate.

In all these examples it has not been possible to use morphological evidence on its own to interpret the effects of environmental change. The nature of the soils and sediments has been vital to unravelling some of the ambiguity presented by landforms. Thus, Thomas and Thorp (1980) have shown that in parts of Sierra Leone, surface morphology under rainforest can be interpreted as being typical features of tropical rainforest morphogenetic systems. However, the soils and sediments indicate very complex sequences beneath simple morphologies and demonstrate the polygenetic nature of the morphology. Soil types and particular soil properties can also help indicate the operation of

current geomorphological processes and the response of tropical landscape to the type of pulsed inputs discussed earlier.

SOILS AND GEOMORPHOLOGICAL SENSITIVITY

Measurements of rates of water and sediment movement on slopes under tropical rainforest have demonstrated the considerable variability that exists even in apparently similar climates. This, in itself, should warn against making sweeping generalisations concerning tropical geomorphological systems. Much of the variability of response can be explained by the nature of the soils. Where the soils, as discussed earlier, are relic and polygenetic, variability of soil and water movement is going to be even greater. Douglas and Spencer (1985) have summarised some of the available information from a veriety of tropical areas. Surface wash in the Pasoh forest reserve in Malaysia is an important contributor to river flow, water moving over the surface being about equal to subsurface flow. In north Queensland, Australia, the surface 10 cm of soil under rainforest has a high permeability. However, permeability decreases with depth and even moderate intensity rainfalls will not penetrate below 20 cm, the surface soil becomes saturated and rapidly produces overland flow. This can be contrasted with a typical Amazon slope where water moves rapidly through the soil and saturated conditions are only found on the lower slopes and floodplains. Overland flow on the floodplain is the main cause of the rapid response of the streams to rain.

Some of the most interesting results have been obtained by Walsh (1985) working in the Windward Islands. Smectoid (montmorillonitic rich) clays of the highly seasonal areas with less than 2500 mm of rain are characterised by shallow topsoils, low topsoil water holding capacity and very low subsoil permeabilities. Thus saturated overland flow is generated quickly and is widespread. On kandoid (kaolinite rich) clay, permeabilities of topsoil and subsoil are much higher and also deeper topsoils have a greater water-holding capacity. Therefore saturated overland flow is very rare and probably confined to cyclonic rainfall. In allophane latosolic areas the soils are of low bulk density and are extremely permeable. Despite frequent heavy rainfalls, widespread saturated overland flow has never been observed. Throughflow is dominant.

These results have interesting repercussions for the concept of landscape sensitivity and the application of magnitude-frequency ideas. Clearly landform evolution models based on the magnitude and frequency of geomorphological events need to include soil and vegetation factors so that landform response to any external stress or input can be assessed realistically.

CONCLUSIONS

In any subject it is important, every now and then, to assess the progress being made, whether the right questions are being asked and whether the correct methodology is being applied. The geomorphology of tropical areas has now been shown to be much more complicated than was originally thought and it seems likely that attempts to develop broad syntheses based on climate-landform relationships are going to be thwarted. Landforms alone are poor indicators of genesis, notwithstadning the problems of convergence or equifinality. It is suggested here that by combining landform studies with analyses of soils and developing pedogeomorphological concepts a more realistic account of the evolution of tropical landscapes can be achieved.

REFERENCES

Brunsden, D. and Thornes, J. B. (1979) : Landscape sensitivity and change, Transactions of the Institute of British Geographers, NS. 4, 463–484.

Butler, B. E. (1959) : Periodic phenomena in landscapes as a basis for soil studies, CSIRO, Australia Soil Publication No. 14, Canberra.

Butler, B. E. (1967) : Soil periodicity in relation to landform development in south–eastern Australia, in J. Jennings and J. A. Mabbutt (eds.), Landform studies from Australia and New Guinea, Cambridge University Press, Cambridge, 231–255.

Douglas, I. and Spencer, T. (1985) : Present day processes as a key to the effects if environmental change, in I. Douglas and T. Spencer (eds.), Environmental Change and Tropical Geomorphology, Allen and Unwin, London, 39–73.

Gerrard, A. J. (1981) : Soils and Landforms Allen, and Unwin, London.

Gile, L. H. and Hawley, J. W. (1966) : Periodic sedimentation and soil formation on an alluvial–fan piedmont in southern New Mexico, Proceedings of the Soil Science Society of America, 30, 261–268.

Ollier, C. D. (1959) : A two-cycle theory of tropical pedology, Journal of Soil Science, 10, 137–148.

Spath, H. (1985) : Relief generation and soil in the dry zone of Sri Lanka, in I. Douglas, and T. Spencer (eds.), Environmental Change and Tropical Geomorphology, Allen and Unwin, London, 303–315.

Street–Perrott, F. A., Roberts, N. and Metcalfe, S. (1985) : Geomorphic implications of late Quaternary hydrological and climatic changes in the Northern Hemisphere tropics, in I. Douglas and T. Spencer (eds.), Environmental Change and Tropical Geomorphology, Allen and Unwin, London, 165–183.

Summerfield, M. A. (1983) : Silcrete as a palaeoclimatic indicator : evidence from southern Africa, Palaeogeog. Palaeoclim. Palaeoecol., 41, 65–79.

Thomas, M. F. and Thorp, M. B. (1980) : Some apsects of the geomorphological interpretation if Quaternary alluvial sediments in Sierra Leone, Zeitschrift fur Geomorphologie Supplement-band, 36, 140–161.

Tricart, J. (1985) : Evidence of Upper Pleistocene dry climates in Northern South America, in I. Douglas and T. Spencer (eds.), Enviromnmental Change and Tropical Geomorphology, Allen and Unwin, London, 197–217.

Walsh, R. P. D. (1985) : The influence of climate, lithology and time on drainage density and relief development on the tropical volcanic terrain of the Qindward Islands, in I. Douglas and T. Spencer (eds.), Environmental Change and Tropical Geomorphology, Allen and Unwin, London, 93–122.

Address of the Author

Dr. John Gerrard
Department of Geography,
University of Birmingham, England.