GLOBAL MEGAGEOMORPHOLOGY

Ian Douglas
University of Manchester
Manchester, England

Any global view of landforms must include an evaluation of the link between plate tectonics and geomorphology. To explain the broad features of the continents and ocean floors, a basic distinction between the tectogene and cratogene part of the earth's surface must be made. The tectogene areas are those that are dominated by crustal movements, earthquakes and vulcanicity at the present time and are essentially those of the great mountain belts and mid-ocean ridges. Cratogene areas comprise the plate interiors, especially the old lands of Gondwanaland and Laurasia. Fundamental as this division between plate margin areas and plate interiors is, it cannot be said to be a simple case of a distinction between tectonically active and stable areas. Indeed, in terms of megageomorphology, former plate margins and tectonic activity up to 600 million years ago have to be considered.

The other major parameter in global geomorphology is climate, which again has to be considered in two parts, present and past climate. Much has been written about the relationship between process and climate. However, the fundamental factors seem to be the space-time-duration and magnitude-frequency characteristics of water flows, and whether or not the ground is vegetated. In a few areas the activity of ice, rather than meltwater, is significant, and in a few others, the work of wind, rather than rare rain and flood events, is important. The critical thresholds for process are those that determine when there is enough water, but insufficient protective vegetation, to permit erosion, and that where there is so much water that despite highly protective vegetation, high erosion rates occur. The former threshold is critical for process change in areas where vegetation survival is marginal, such as the Sahel zone of Africa. Here overgrazing may so reduce the vegetation that gullying becomes rapid and soil degradation extreme. Such well documented effects depend on the seasonal vegetation changes which can be detected on the continental scale using the AVHRR on NOAA satellites. In this case, a continental scale change in geomorphic process efficiency results from the combined effects of human activity and drought. Similarly the occurence of severe erosion following Australian bush fires in 1983 may be related to the southern oscillation and the El Nino phenomenon in the Pacific. Both these examples relate to fluctuations within the present climate and thus suggest that the old notions of morphoclimatic zones may be largely irrelevant.

Nevertheless, the relationship between ecosystems and climate is close as is that between ecosystem dynamics and geomorphic process. Photogeology has led to great attention to the relatively sparsely vegetated zones of the earth's surface where the landforms are readily visible and their relationship to geologic structures is easily assessed. The advent of SLAR and shuttle radar has widened the scope of landform remote sensing so that the ground beneath the forest may be better understood. Far from simplifying the relationship between climate and landform, such remote sensing data have reinforced the need for geomorphology to cope with climate change, even in the present-day humid tropics.

Yet, how far is this changing climate merely a superficial, Quaternary effect? Much evidence has been adduced to suggest that during the Tertiary, long periods of climatic stability occurred and landforms evolved under steady, unchanging conditions. However, as the details of deep-sea drilling projects become available, more Pliocene and Miocene climatic fluctuations are revealed. While the human mind seems to seek and therefore postulate stability and only infrequent change, nature seems to be characterised by irregular, uneven, but continuing changes. Many of the phenomena taken to indicate long-term stability may be created in a few tens of thousands of years, such as ferricrete profiles developed between dated early Tertiary basalt flows in the New England area of eastern Australia (Francis and Walker 1978). Climate is thus a difficult parameter for geomorphologists to use. The imprint of climatic change on landform is clear, but it is difficult to quantify relationships between present climate and process. Empirical data suggest that, given a similar tectonic setting, higher erosion rates and larger river channels for a given catchment size will be found in humid tropical rain forest areas experiencing the heavy downpour of tropical cyclones than in those equatorial rainforest areas devoid of such extremes. Yet, the highest rates of erosion in humid tropical areas are from the <u>tectogene</u> tropics of Indonesia and New Guinea, where volcanic and tectonic activity create steep unstable terrain supplying great quantities of sediment to rivers at times of heavy rain.

Not suprisingly, many schemes of morphoclimatic zones distinguish the mountain areas from the rest of the continents. Nevertheless, even in the cratogene areas, climatic zones tell us relatively little about landforms as such. As a first attempt at differentiation within one climatic zone, the humid tropics, geological history has to be considered (Table 1). The vast planation surfaces, argued by some to be the product of long periods of tropical landform evolution are characteristic only of the older land surfaces of Gondwanaland remnants.

Plate Tectonics and megageomorphology

The southern hemisphere is the appropriate place to begin to analyse global megageomorphology for here can be seen great similarities from one continent to another and the existence of old land surfaces forming high level erosion surfaces. From the high ground of the plateaux of Africa, Australia or Brazil, the uniformity of the landscape is apparent in a way that cannot easily be recognised from aerial photographs or from the valley floors. However, it must not be assumed that all that is now at the same level is of the same age. King (1983) argues that the features of a planation surface remain recognizably the same whether it remains close to sea level or is raised up by tectonic movements. Although a planation surface may be broken by faults or tilted by warpings, its surface characteristics should remain the same. Thus King recognises 6 global planation cycles (Table 2) remnants of which are to be found not only in the cratogene areas but also in such tectonically disturbed zones as the Andes and New Zealand Alps. The oldest cycle, the 'Gondwanaland' planation took place before the breakup of Gondwanaland and Laurasia. These platforms were largely destroyed by events on each continent as rivers drained to new base levels in the opening seas. The 'Kretacic' planation which followed is correlated with Jurassic to mid-Cretaceous oceanic sediments, and was terminated by vertical uplift in mid-Cretaceous time.

King (1983) sees the period of late Cretaceous to early Miocene time as one of tectonic quiet over large areas, <u>outside the belt of Alpine</u>, orogenesis. The 'Moorland' planation surface of this period can be found, he claims, over large areas of all the continents. Residual soils such as bauxite and ferricretes are widespread. For King, the 'Moorland' surface is the dominant landform feature from which most of the world's present scenery has been carved. At this stage is is unnecessary to go into detail on the other three planation surfaces, but it is important to look at their relationship to the break up of Gondwanaland and Laurasia.

While the breakup of Gondwanaland began about 200 million years ago, at the end of the Jurassic, 135 million years ago, the birth of the South Atlantic had only just begun by the opening of a rift and Madagascar was still joined to the east coast of Africa. Antarctica and Australia were still joined, and did not separate until the early Tertiary, the time at which the north Atlantic began to open between Rockall and Greenland in the final stage of the separation of Europe from America. On many of these land masses, great volumes of basaltic activity occurred, including that of the Deccan in India and in the British Isles from Antrim to Skye. However, such basalt flows were locally relatively shortlived, often spreading out over phenomena indicative of stable conditions, such as the erosion surfaces of the eastern highlands of Australia or the Cretaceous chalk of Antrim. All the evidence suggests that uparching, or cymatogeny (King 1983), possibly as continental plates pass over hot spots, may occur relatively quickly as the lithosphere becomes veined with magma. Thus the long period of 'Moorland' planation could easily be locally interrupted by doming, volcanicity and rifting as in the Rhine, Lake Baikal and Ethopian rifts. (Bott 1982). The cracking-up of Gondwanaland and Laurasia is fundamental to much of the present day relief. The relationship of Britain to North America might have been closer if the North Sea rift had developed as fully as the mid-Atlantic rift did later. In fact the large-scale geomorphology of the British Isles has much in common with that of the Basin and Range province of the U.S. southwest.

Re-assessment of global climatic geomorphology

The emphasis on the role of plate tectonic mechanisms continually disrupting the processes of erosion surface development finally forces geomorphologists to adopt a truly dynamic geomorphology which copes with both tectonic and climatic change. The old contrasts between tectonic activity and stability and between arid phases and wet phases have to be rejected as we move to a more critical event-based interpretation of the stratigraphy of the deposits which correlate with the development of our erosion landforms. The length of a climatic fluctuation required to produce a particular deposit or paleosoil is unknown. The last ten thousand years, studied in such detail, suggests that ecosystems can change quite rapidly, yet even in terms of Tertiary time, 10,000 years is very short. Given that the same thickness of sediments may be produced by both long, gradual deposition and a single rare, catastrophic event, the re-assessment of the principles of global climatic geomorphology becomes a challenging task. Since 1960 the mean annual sediment yields of the world's major rivers have been established. For many major rivers there are now several decades of records. In smaller basins long-term investigation such as the Coon Creek 1853-1975 study (Trimble 1981), have revealed how actual sediment yield has a temporal log often related to land use and river management changes. Yet with the data on vegetation conditions from AVHRR, the new WMO global studies of areas of unusually high or unusually low precipitation and the growing hydrologic and sediment yield data, it ought to be possible to link climatic variations to ecological change and seasonal and annual sediment yields. The duration and extent of ice, snow and wind-blown materials such as loess, could also be monitored in this way. The knowledge of the dynamics of the present day morphoclimate is an essential first step in the reassessment of global climatic geomorphology.

The second step is to look at the great synthesis of Julius Budel (1983) with his 10 present-day morphoclimatic zones (Table 3) and his emphasis on the great importance of the peritropical zone of excessive planation and the subpolar zones as the most effective morphoclimates. His approach to European landforms produces and elegant synthesis of successive phases of relief development, adequately emphasising changing geomorphic processes back to the late Cretaceous. Budel's _tropical paleoearth_ would have existed over King's 'Moorland' planation period. Evidence of tropical conditions in relatively high latitudes in deposits such as the London Clay and the weathered interbasaltic bed in the Antrim basalts the stability of such climates and the magnitude of their short term variations is unknown. All that can be examined is the net result. Ocean areas indicate much more dramatic shifts of climate in the Miocene than once were expected. Similar detail for earlier periods may reveal comparable oscillations. Thus for megageomorphology the history of megadeltas and the details beneath desert sands become important. While the former depends on the drill bit, seismic and sonar records, the latter has been greatly helped by space shuttle radar.

The Magdalena Fan in the southern Caribbean Sea (Kolla et al. 1984), for example, provides a record of sedimentation since the late Cretaceous, with three late Cenozoic sequences associated with the uplift of the Andes. Analysis of the sediments in these areas can help reveal the timing and nature of changes in terrestrial ecosystems and denudation systems. Interpretation will only be improved if understanding of the variety of products of present-day morphogenesis is more closely analysed.

Spatio-temporal thresholds

The critical state of a denudation system likely to produce a change in landform may depend on some major external factor, such as a succession of drought seasons, or on some internal condition, such as a massive random mass movement or the beginning of the undercutting of an unstable, weak material such as a dispersible mudstone. Any meaningful global geomorphology has to concentrate on the major continental fluctuations, probably best analysed in terms of seasonal changes. World climate data collection systems and weather satellite images will help in this. The studies of Saharan dust storms (Coude-Gaussen and Rognon 1983) or the examination of climatic crises (Rognon 1983) indicate the way to go. Geomorphology is moving towards an event-based analysis. Progress will be made continuing to explore for the evidence of past changes and the analysis of present-day thresholds and major events. Only from the latter will the possibility of quantification emerge. However, unless these climatic events are coupled to tectonics, the full geomorphic significance of events like the El Chichon or Mt. St. Helens eruptions, or even the British earthquake of July 1984, will not be understood.

REFERENCES

Bott, M.H.P. (1982) *The Interior of the Earth: its structure, constitution and evolution*, Arnold, London

Budel, J. (1982) *Climatic Geomorphology*, Princeton University Press, Princeton

Coude-Gaussen, G. & Rognon, P. (1983) "Les poussieres sahariennes" *La Recherche*, 14, 1050-61

Douglas, I. (1978) "Tropical Geomorphology: present problems and fture prospects" In: Embleton, C., Brunsden, D., & Jones, D.F.C. (eds), *Geomorphology Present Problems and Future Prospects* Oxford University Press, Oxford, 162-84

Francis, G., & Walker, G.T. (1978) "Multiple Laterite Surfaces near Armidale", *Search*, 9, 191-2

Gallaway, R.W. & Loffler, E. (1972) "Aspects of Geomorphology and Soils of the Torres Strait Region." In: Walker, D. (ed) *Bridge and barrier: the natural and cultural history of Torres Strait* (ANU Publication BG/3), 11-28

King, L.C. (1983) *Wandering Continents and Spreading Sea Floors on an Expanding Earth*, Wiley, Chichester

Kolla, V., Buffler, R.T. & Ladd, J.W. (1984) "Seismic Stratigraphy and Sedimentation of Magdalana Fan, Southern Colombian Basin, Caribbean Sea" *American Association of Petroleum Geologists Bulletin*, 68, 316-32

Rognon, P. (1983) "Esai de definition et typologie des crises climatiques" *Actes Coll. AGSO Bordeaux Mai 1983, Bull Inst. Geol. Basin d'Aquitaire, Bordeaux no 34, et CNRS Cahiers du Quaternaire No. Special*, 151-64

Trimble, S.W. (1981) "Changes in sediment storage in the Coon Creek Basin, Driftless Area, Wisconsin, 1853 to 1975" *Science*, 214, 181-3

TABLE 1 (after Douglas 1978)

Comparison of some pedological and geomorphological features of erosional landscapes
Northern Australia, Sri Lanka, Peninsular-Malaysia, Borneo, New Guinea and Hawaii

Feature:	Australia	Sri Lanka	Malaysia	Borneo	New Guinea	Hawaii
Dominant age of landscape	Old	Old	Moderately old	Young	Very Young	Very Young
Proportion of fabile rocks	Low	Low	Moderate	Moderate	High	Moderate
Recent Tectonism	Practically none	Practically none	Negligible	Some	Intense	Infrequent
Cainozoic vulcanism	Practically absent	Practically absent	Practically absent	Some	Abundant	Highly abundant
Tropical Karst	Practically absent	Virtually absent	Residuals only	Abundant	Abundant	None
Relief	Low to moderate	Moderate	Moderate	Moderate(save for Kmabulu)	Very High	High
Rate of Current soil development	Slow	Slow	Slow to moderate	Moderate	Rapid	Rapid
Rate of Current erosion and deposition	Low to moderate	Low to moderate	moderate	High	Very High	Very High
Depth of soil on slopes	Generally shallow	Generally shallow	Variable	Variable	Variable	Variable but usually high
Lateritic Crusts	Widespread	Widespread	Fragments	Possible	Absent	Absent
Palid zone of deep weathering	Widespread	Widespread	Few	Unknown	Rare	Rare

Note: The inspiration for this Table comes from Galloway and Laffler (1972) Table 2:1

TABLE 2 (after King 1983)

The several global planation cycles and their recognition

Planation Cycles:	Recognition:
I. The 'Gondwana; planation	Of Jurassic Age, only rarely preserved.
II. The 'Kretacic' planation	Early-Mid Cretacious Age, on certain very high plateaux and ridges in Lesotho.
III. The 'Moorland' planation	Current from late Cretaceous till the mid-Cenozoic. Planed uplands, treeless and with poor soils. Often the oldest planation identifiable in Natal. Occurs below the Drakensburg escarpment. At the coast is overlain by marine Miocene strata.
IV. The 'Rolling' landsurface	Mostly of Miocene Age, forms undulating country above young incised valleys.
V. The 'Widespread' landscape	The most widespread global cycle, but more often in basins, lowlands and coastal plains than uplifted by recent tectonics to form mountain tops. Pliocene in age.
VI. The 'Youngest' cycle	Modern (Quarternary in age) represented by the deep valleys and gorges of the main rivers. Sometimes has glacial features.

TABLE 3

Budel's morpho-climatic zones of the present

1.	Glacial zone (and imediately adjacent area).
2.	Subpolar zone of excessive valley-cutting.
3.	Taiga valley-cutting zone, in the permafrost region.
4.	Ectropic zone of retarded valley-cutting.
5.	Subtropic zone of mixed relief development, etesian region.
6.	Subtropic zone of mixed relief development, monsoonal region.
7.	Winter cold arid zone of surface transformation, largely through pediments and glacis.
8.	Warm arid zone of surface preservation and traditionally continued development, largely through fluvio-eolian sandplains.
9.	Peritropical zone of excessive planation.
10.	Inner tropical zone of partial planation.