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TROPICAL GEOMORPHOLOGY: TECTONICS, RIVERS AND LONG-TERM LANDSCAPE EVOLUTION

The concept of tropical geomorphology suggests that there is an assemblage of processes and landforms peculiar to the tropics, different in some ways from those of extra-tropical regions. To some extent this seems self-evident, but the concept is based on a number of premises which need to be tested. In this paper I shall act as Devil's Advocate and minimise the role of climate in so-called climatic geomorphology, and furthermore try to demonstrate that it is another factor, the great length of landscape development, that gives the tropics most of its significant differences from other regions. Within that part of the earth bounded by the tropics of Cancer and Capricorn there is quite a range of climates, but I shall concentrate on the popular image of hot and wet tropical conditions. For examples I shall refer often to my own papers, not because they are better than those of others but because I can avoid any charge of misrepresentation of the ideas of other workers.

Several authors have used climatic factors to erect a theoretical basis for climatic geomorphology (PELTIER, 1950; BUDEL, 1982; BIROT, 1970; TRICART & CAILLEUX, 1965; STRAKHOV, 1967). This is what FANIRAN & JEJE (1983) call the "synthetic approach". In contrast to these more or less elaborate approaches, fig. 1 shows the relationships between climate, weathering and mass movement, in a highly simplified form. At this level only the major features are brought out, and the humid tropics are seen to be "non-extreme", and so differ from arid areas where lack of water modifies landforming processes, and frigid areas, where ice formation causes a very different assemblage of landforms to be produced. If these extreme climates are excluded, the question can be posed: are the landforms of the humid tropics different from those of temperate or other non-extreme climates? The question will be asked in relationship to several different topics.

I. TOPICS IN TROPICAL GEOMORPHOLOGY

1. TECTONICS

Tectonic processes are largely controlled by the earth's internal mechanisms, and seem to occur regardless of latitude or climate. A wide range of tectonic settings are available for study in the tropics, including ancient cratons (much of tropical Africa), island arcs (Caribbean, Indonesia), fault-block mountains (northern Andes), tectonic basins (Amazon Basin), rift valleys, and others. In many generalisations about the tropics this seems to be forgotten, and the African scene of tectonic stability is taken to be the norm. This should be contrasted with places like New Guinea where Quaternary erosion surfaces have been uplifted a thousand metres, and where Quaternary granites have thrust up active gneiss mantled domes as mountains a thousand metres high (OLLIER & PAIN, 1981; PAIN & OLLIER, 1984). Strike-slip faulting, gravity sliding and other morphotectonic processes are just as active in the tropics as elsewhere.

FANIRAN & JEJE (1983, p. 36) include "the fold mountain system" in their discussion of tectonic factors in the tropics. However, OLLIER (1981, p. 2) claims that there are no fold mountains in the simple sense of mountains simultaneously uplifted and folded by lateral pressure. The folding of rocks and their later epeirogenic or cymatogenic uplift are distinct and possibly unrelated events. The examples used by Faniran and Jeje are indeed caused by epeirogenic uplift long after much earlier folding.

2. VOLCANOES

Volcanoes of tropical regions show much the same range of landforms in the tropics as elsewhere, with radial drainage of cones being the most obvious single feature. OLLIER & MACKENZIE (1974) attempted to make some generalizations about tropical volcanoes, and believed that they were perhaps more deeply dissected and surrounded by wider belts of alluvial fans than those of non-tropical areas. Many tropical volcanoes appear to have very steep slopes, such as the so-called "vertical valleys" of Hawaii (WENTWORTH, 1943).

3. WEATHERING AND SOILS

Because the rate of most chemical reactions is increased by increasing temperature, it is reasonable to assume that weathering is faster in the tropics than in colder climates, and this appears to be generally true. The idea has been carried further, and it is sometimes suggested that regolith is deeper in the tropical regions, though TRICART (1972, p. 38) correctly points out that the thickness of regolith depends on the climate,the rock type and the intensity of erosion. However, the relationship between deep weathering and tropical climate should not be carried too far, for there are many examples of very deep weathering in extra-tropical regions (OLLIER, 1984, chapter 13). Deep weathering occurs in water-saturated rocks, below the watertable, and deep groundwater in any climate has much the same effect. Hydrolysis is the dominant mechanism, and the products of weathering can be removed by ionic diffusion even if there is no flow of water (MANN & OLLIER, 1984). Leaching is intense in the humid tropics, and silica especially tends to be removed from weathering profiles more than in temperate climates. Desilicification leads to the formation of kaolin in leached profiles. However, the solute loads of tropical streams, which should be carrying away the soluble products of weathering, do not seem to be very much greater than those of non-tropical streams. This is because the silica is captured in the build-up of montmorillonite clays

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on lower sites.

The weathering of clay minerals seems to go further in tropical regions: the combination of kaolin and iron oxide seems to be very typical of tropical regions and produces the widespread tropical red soils; the further desilicification to form bauxite seems to be confined to the very wet tropics. Nevertheless ideas of tropical soils must not be too rigid: in Madagascar there are tropical podzols formed under bracken which are almost indistinguishable from podzols formed under bracken in Scotland, and in Australia the "Australian podzols" have upper horizons like podzols but lower horizons like laterites. It is not clear what they tell us about climate.

4. KARST

The solubility of carbon dioxide in water is lowered by increasing temperature, so limestone solution in tropics could be less than in temperate regions. In reality this does not seem to be true, and it is not easy to find specific features of karst landscape that are distinctly tropical. It is sometimes alleged that limestone in the tropics stands in positive relief, higher than the surroundings, whereas limestone in temperate regions is lower in relief. My own experience is that limestone stands in positive relief in all climates. There may be a tendency for tower karst to be formed in the tropics and doline karst in temperate region, but JENNINGS & BIK (1962) have shown that some karst landforms commonly attributed to different climates can occur in close proximity, and BROOK & FORD (1978) have described limestone towers up to 125 m high from the North-West Territories of Canada. However, BUDEL (1982) claims that "Cone karst has been described almost exclusively from the perhumid tropics".

In a study of coral island caves OLLIER (1975) showed that the entire range of vadose, phreatic and watertable caves can all be formed in the same island under the same climatic regime. Coral island caves perhaps have more speleothems (stalactites etc.) than temperate caves, but temperature is probably not the important factor. Some other tropical caves, such as those of Zaire (OLLIER & HARROP, 1964), are generally poor in speleothems. Possibly the dominant factor in carbonate solution and reprecipitation is organic carbon dioxide: this is limited where the climate is too cold or too dry to support vegetation, but in non-extreme climates limestone solution is likely to be very similar. Swamp notches are a karst feature that may be confined to tropical areas.

5. SHEETWASH

There are two very different views on the effects of water on groundsurfaces in the tropics, even in forested areas (OLLIER, 1974). One school of thought suggests that forest canopies intercept a considerable amount of rainfall, breaking the force of raindrop impact which anyway strikes an absorbent layer of leaf litter. Beyond this the deeply weathered rocks absorb water well, so sheetwash is greatly reduced. The opposite view (RUXTON, 1967), is that there are many openings in the forest canopy which let the rain in, and because of the high decay rate there is little leaf litter to protect the soil. Rainfall intensity is high, so even porous soils are rapidly saturated and sheetflow occurs. This is indicated by the common occurrence of earth pillars and patches of bare ground. Leaf litter is floated away, and fine sediment may be removed to leave a lag gravel. On slopes each exposed root becomes a local base level with deposition on the upper side and erosion below, so that hillslopes become stepped. This range of variation within tropical rainforest is equal to that found between temperate and tropical regions, so no specific features can be attributed to the tropical climate.

6. RIVERS

One of the myths of tropical geomorphology is the idea that because of extensive weathering the rivers have little coarse debris load, and so have no tools for erosion.

BIROT (1970) claims "A well-established principle is that the river appears devoid of power, for it lacks pebbles to scour potholes". TRICART (1972, p. 58) expresses it thus: "Because of it (the predominance of chemical over physical weathering) the alluvium of tropical rivers is characterized by the near absence of pebbles and falls within the two size ranges of clay and sands. These materials not only influence the nature of the depositional forms, but also the kind of wear the bedrock of stream channels is subjected to, which is not more than a light mechanical abrasion".

TWIDALE (1976, p. 58) wrote: "In the humid tropical regions ... chemical weathering is rapid and intense. Few fragments of a size greater than the sand survive weathering. The rivers lack ... the tools to abrade the bed and banks ...".

THOMAS (1974) wrote: "... the rivers may carry only fine gravel, sand and suspended clay particles, with an almost total absence of coarse bedload. Under such conditions erosion by tropical streams is relatively feeble ...".

But many tropical rivers carry a coarse bedload. LOFFLER (1977) writes:

"Fluvial erosion is undoubtedly the most important process operating in the mountainous landscape of Papua New Guinea ... The rivers contain large amounts of coarse gravel and boulders which travel considerable distances downstream. In the Strickland, for example, coarse gravel, mainly quartzite and limestone, forming extensive banks and bars, is to be found up to 100 km downstream from where the stream leaves the mountains. Similar observations are reported by SPEIGHT (1963) from the Angabunga River, Papua, and LOFFLER (1972) from the Pual River, Vanimo area."

"The calibre of the bedload is also truly impressive. Boulders of several cubic metres have been observed by the author in numerous large rivers ... in many instances the source area has been found to be many kilometres upstream."

"The difference between humid tropical rivers and extratropical rivers appears to be more a matter of degree than kind and is largely a result of the higher run-off associated with this climatic zone."

The argument is presented further by DOUGLAS & SPENCER (1985, pp. 65-68) who quote several specific instances of coarse bedload in tropical rivers. In Surinam, BAKKER (1957) noted that the erosive action of the river broke fragments of rock away from the bed of the channel. In the Amazon headwaters pebbles up to 50 cm in diameter are moved by major floods. These include grey granites and limestone. BIROT himself noted stream channels in Puerto Rico with large quantities of pebbles, some over 50 cm in diameter. Malaysian rivers in their headwaters have much gravel in their beds ... even well down the courses of major rivers.

An alternative view of tropical river geomorphology is simply stated by FANIRAN & JEJE (1983) who wrote "... many tropical rivers ... flow ... directly on bedrock, while the depth of the weathered rock increases with distance from such channels to the water divide ...". A similar situation was described from Puerto Rico, where BIROT (1970) noted that the rivers have cut down to bedrock along practically their entire length. The pebbles come from the bed rather than from the slopes. PAIN & OLLIER (1981) described a similar situation from Fergusson Island, with straight slopes covered in regolith, but streams in bedrock. In the geological surveying of Papua New Guinea the strategy is to follow streams, where bedrock is revealed, rather than slopes or ridges which are usually covered in regolith.

Let LOFFLER have the last word on rivers:
"The transport of material in these tropical rivers does not ... appear to be fundamentally different from that in extratropical areas as often claimed by climatic geomorphologists (BUDEL, 1972; BREMER, 1971, 1972). There is no evidence to suggest that rivers in the tropics erode their beds more by solution processes than by physical corrasion by the bedload. This applies not only to the streams and rivers in the mountain areas but also to those in the lowlands."

II. PLYGENETIC LANDSCAPES

The concept of climatic geomorphology becomes harder to test if past climates are taken into account. It is possible to rationalize allegedly non-tropical features found in the tropics, or allegedly tropical features found outside the tropics, by appeal to conjectural past climates. There is no doubt that climates have been different in the past, but it is as well to try to work from evidence and not jump to unfounded climatic conclusions.

In the 1930s it seemed a reasonable assumption that the glacial periods of the higher latitudes would be matched by rainy periods - "pluvial" - in the tropics. River terraces in Uganda were attributed to these pluvials, but later work shows that they probably have a tectonic origin. Modern work suggests that glacial periods are accompanied by aridity in at least some tropical areas.

The idea of alternating humid and arid phases in a tropical environment can be used to establish a scheme of alternating morphogenetic systems. Such schemes are favoured by several authors, including GARNER (1968). Such schemes may be primitive and speculative, based on simple alternating arid and humid regimes and their assumed landform indicators. The better ones (e.g. GARNER, 1983) pay careful attention to many lines of evidence for tectonic and climatic changes (related to global changes) and to such features as changes in ocean currents. By the extension of such work our knowledge of climatic geomorphology will be extended from a firm-base, rather than built on naive assumptions.

Caution is needed in interpreting past climates. Firstly, we do not know in much detail how changes occur. BUDEL (1982) has a kind of concertina system, with the climatic belts moving in and out as the ice-caps grow and decline. An alternative scheme is probably more likely, with limited movements of climatic belts and increasing gradients between them. This could give rise to extra effects, such as stronger winds than those of today. Secondly, there is a great choice of past climates available, and it is hard to know which particular past climate is responsible for any specific effect. The old idea of four glacials has now gone, and is replaced by a system with 27 cooling phases over the past 3.5 million years. Since the geomorphic history of the tropics extends back beyond the Quaternary a great deal more climatic change becomes available. The question of landscape longevity therefore becomes critical in assessment of tropical landforms.

III. LANDSCAPE LONGEVITY

Geomorphology first developed in North America and Europe, and most work continues to come from these atypical places. They are atypical because they suffered a glaciation in Quaternary times that was of such severity that it often provided a new start for landscape development. The Quaternary bias in landscape studies, the Eurocentric view, has become a tacit assumption in much work, and is occasionally stated clearly, as by THORNBURY (1954) who enunciated his 6th Principle as "Little of the earth's topography is older than the Tertiary and most of it no older than Pleistocene". This traditional view lingers on, even though it is quite clear that large areas of the world, including most of the tropics, did not suffer Quaternary glaciation, and have landscape histories that can be traced well beyond the Quaternary.

In Australia, for instance, it was the Permian glaciation that provided a new start for landscape evolution, equivalent in kind to the Quaternary glaciation of Europe but more than a hundred times older. Much of Australia has been land since Permian times. Some individual valleys can be shown to have existed in the Permian very much as they do today. In examining Australian landscapes the long time scale must be taken into account. Many ferricretes have been dated by palaeomagnetism at 25 m.y., but others give various younger and older dates back to about 60 m.y. Ayers Rock could be described in simple terms related to its present climate, or postulated past climates. However, on the plain surrounding the Rock lacustrine sediments have been found which show that the plain (and therefore the Rock) were in existence in Palaeocene times (TWIDALE & HARRIS, 1977). The Rock has therefore had approximately its present appearance for 70 million years, and the present climate is almost irrelevant.

Thus we see that the time scale for landscape evolution in Australia is the same long time scale that is appropriate for biological evolution, plate tectonics and continental drift. The last topic opens a new possibility - could the continents have drifted through a range of different latitudinally defined climatic zones?

In Australia the answer is a definite "No!". In Early Tertiary times the climate was generally warm and moist, despite a high latitude, and as Australia drifted north the climate remained much the same. Some periods were drier than others, but real aridity with salt lakes and desert dunes did not begin until the Quaternary. Northern Australia did not drift through an arid belt before reaching the latitude of the humid tropics. Instead, Australia drifted north while climates were warm and wet, and aridity set in after it had reached its present position. Northern Australia has never been arid.

Similar scenarios relate to South America, Africa and India. In tectonically mobile areas, such as island arcs where uplift can bring about altitudinal climatic changes, the geological complications to any climatic evolution are even more complex.

The effect of the time scale all comes down to a matter of rates. If a feature can be formed in a few hundreds or thousands of years then the long time scale is not relevant. Such features may well be in equilibrium with present day climate. It is also possible for dynamic equilibrium to enable landscape persistence over a long period. Pain & Ollier (1981), for example, describe a landscape formed on a Pliocene granite in which rapid rates of uplift coupled with rapid weathering rates result in a persistent landscape of angular (feral) relief with deep weathering on all slopes and ridges but fresh rock exposed in stream beds.

The only safe course seems to be to determine the landscape history and climatic history independently, and then see if there are any correlations. It seems unwise to assume that climate, especially that of the present day, can be related directly to landforms anywhere. It is particularly unwise to make this assumption in the tropics, where landscape histories are often very long.

IV. DISCUSSION AND CONCLUSIONS

Several authors have discussed climatic geomorphology in general, and noted several deficiencies. Stoddart (1969) pointed out that Davis first described a "normal" cycle of erosion, and then described the arid and glacial cycles, schemes that in the present paper are related to "extreme" climates. Only later were cyclical schemes devised for the savanna landscape (Cotton, 1961) and other landscapes (e.g. Birot, 1970). Stoddart traces the history of many aspects of climatic geomorphology, and concludes that while climatic factors may be important, they are not necessarily dominant - to isolate a single group of factors such as climate is unrealistic and distorting. Even Thomas (1974, 1976) with his great experience of the tropics, takes a cautious line like Stoddart, and does not try to isolate specific "tropical" features. He writes (1976, p.440) "... few granite landforms can be unambiguously associated with closely defined climatic environments. It would therefore be mistaken to attempt a climatic classification of granite landforms".

In another review, Pitty (1982, p.82) concludes that climatic geomorphology is an example of a concept of low explanatory power, which he thinks is brought about by four factors - complexity of climatic influences, palaeoclimates and palaeoforms, multizonal processes and forms, and convergence of landforms. All this seems to be very true of tropical geomorphology.

There are a few landforms and landscape forming processes that are distinctive of the tropics, but because of many complications in climatic and tectonic history it is usually very difficult to isolate tropical features from features that could be formed in other climates. Since climatic change is the exception rather than the norm this complexity can not be ignored. Geomorphic evolution in old flat continents such as Africa is very different from that in tectonically active environments such as the island arcs of Indonesia and New Guinea. Models derived in one area should not be extended to the whole "tropics".

Probably the most significant factor in the geomorphology of tropical regions is that they escaped Quaternary glaciation, and therefore they have a very long geomorphic history.

Fig. 1 - Simple relationship between climatic factors and landscape forming processes

		PROCESS		
		WEATHERING		MASS MOVEMENT
CLIMATE	COLD	Frost Reduced chemical effects (low temp)		Rock glacier Solifluction (wet) Scree slopes
	HUMID	Chemical dominant weathering	*Deep weathering*	Creep Landslides
	ARID	Salt weathering (heat)		Rockfalls

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