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TROPICAL GEOMORPHOLOGY AND LONG-TERM LANDSCAPE EVOLUTION *

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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; BÜDEL, 1982; BIROT, 1968; TRICART and CAILLEUX, 1965; STRAKHOV, 1967). This is what FANIRAN and JEJE (1983) call the "synthetic ap-

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		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

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

proach''. 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 and PAIN, 1981; PAIN and OLLIER, 1984). Strike-slip faulting, gravity sliding and other morphotectonic processes are just as active in the tropics as elsewhere (OLLIER, 1984).

FANIRAN and 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 cases of 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 and 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 climes, and this appears to be generally true. The idea has been carried further, and it is sometimes suggested that regolith is deeper in 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 a, chapter 13). Deep weathering occurs in water-saturated rock, below the watertable, and deep groundwater in any climate has much the same effect. Hydrolisis is the dominant mechanism, and the products of weathering can be removed by ionic diffusion even if there is no flow of water (MANN and OLLIER, 1984). Leaching is intense in the humid tropics, and silica especially tends to be removed from weathering profiles more than in humid temperate climates. Desilicification leads to the formation of kaolin in leached profiles. However, the solute load of tropical streams, which should be carrying away the soluble products of weathering, do not areas where carbonate is precipitated (GOUDIE, 1973; REEVES, This is because the silica is captured in the build-up of montmorillonite clays on lower sites.

Opinions differ on the extent of quartz solubility in tropical weathering profiles. WOLFENDEN (1961) and LELONG (1969) found no evidence for dissolution of quartz; VAN KERSEN (1956) and GRUBB (1983) claim that some quartz is dissolved. If the latter authors are correct, it is in exceptional cases, and it seems to be overwhelmingly true that silica solutions are derived from silicate minerals, and that quartz in almost all profiles is inert.

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 the 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 landscapes 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 usually 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 regions, but JENNINGS and BIK (1962) have shown that some karst landforms commonly attributed to different climates can occur in close proximity, and BROOK and FORD (1978) have described limestone towers up to 125 m high from the North-West Territories of Canada. However, BÜDEL (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 and 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 forest canopy which let in rain, 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 (1968) 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 characterised by the near absence of pebbles and falls within the two size ranges of clays 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". However, FANIRAN and JEJE (1983) write "this position seems to run counter to experiences elsewhere. ...many tropical rivers ... flow ... directly on bedrock, while the depth of the weathered rock increases with distance from such channels to the water divide. In fact tropical rivers show great diversity; the Strickland River in Papua New Guinea, for example, carries a load of huge boulders (Est. I). In the Amazon Basin there are "blackwater" streams, draining swamp forest peats that carry black, acid water but little sediment. This black water contrasts markedly with the muddy water of other streams. In Papua New Guinea the Fly River has a comparatively small sediment load, although murky and opaque, whereas its tributary the Strickland, coming from a more mountainous interior carries a great load in its rapidly flowing turbulent waters. The flood range is important in many tropical rivers (8 m for the Fly, 30 m for the Amazon), but flood ranges can also be high in other climates. The range of landforms in the Fly River floodplain (fig. 2) has been described by BLAKE and OLLIER (1971) and most of the features could be formed in non-tropical climates. The rivers of central Uganda are

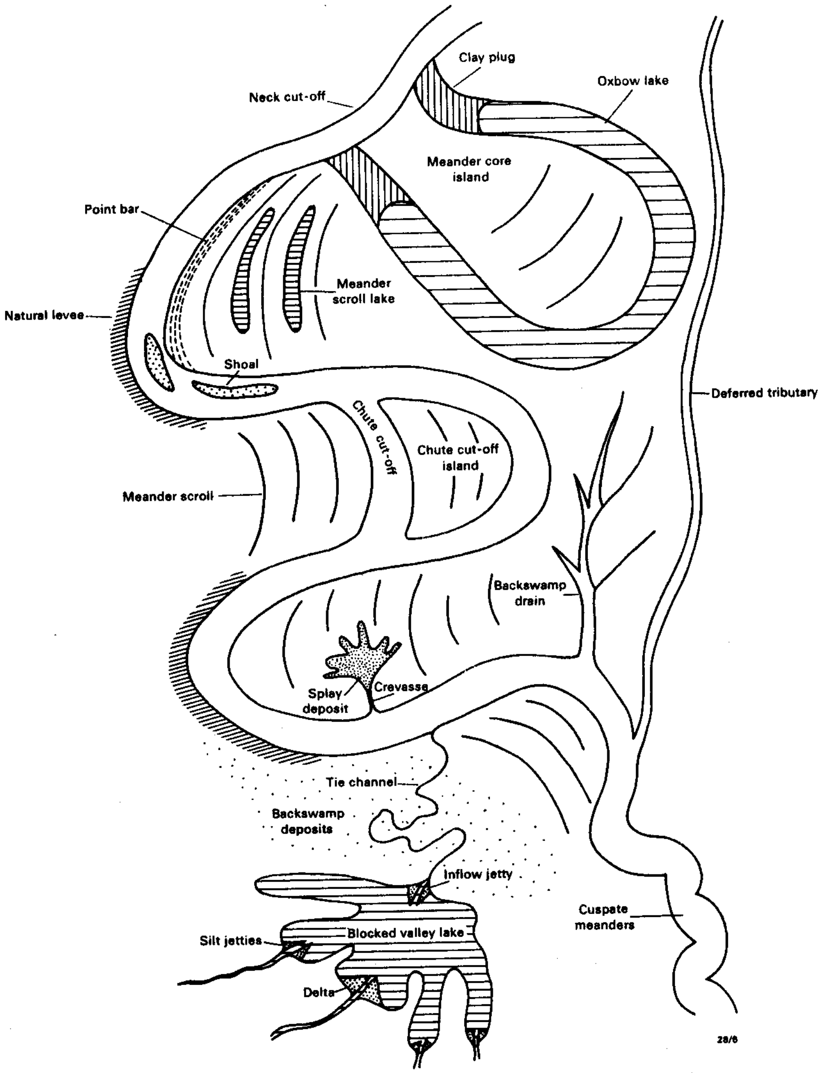


Fig. 2 — Landforms of the Fly River floodplain, Papua New Guinea.

choked with papyrus (except for the Nile itself), but this landscape modifying effect could be matched in non-tropical regions by other kinds of dominant vegetation.

7. *Great Escarpments*

Many landmasses have Great Escarpments separating coastal lowlands from high plateaus (OLLIER, 1984 b). Rivers leave the plateaus by waterfalls. TRICART (1972, p. 59) writes "It has been known for a long time that tropical streams have many rapids. Even powerful rivers have imposing rapids close to their mouths in places where under other climates profiles have long been regularised. The most striking example is the Congo..." Other examples could be cited from tropical South America and Australia. However Great Escarpments are also found in non-tropical southeast Australia, the Western Ghats of India, and elsewhere. They are probably related to tectonics rather than climate.

8. *Rates of geomorphic processes*

There is probably nothing special about the rates of erosion, deposition, weathering, or other geomorphic process in the tropics, and rates are roughly comparable with those from other places. Total denudation reaches a maximum in the semiarid and probably the tropical savanna zones. Solution rates show no clear relationship to temperature or rainfall (SAUNDERS and YOUNG, 1983). Very high rates of erosion have been reported in some areas, such as the 19 000 B from erosion of a young volcano in New Guinea (OLLIER and BROWN, 1971) to very low rates of 1 B or less from parts of Western Australia (B = Bubnoff unit = 1 mm/1000 y). Rainfall intensity and relief are probably the dominant factors, as in other non-extreme climatic regions.

BIROT (1968) has claimed: "Decomposition of rock (chemical weathering) is more rapid than transport on slopes, which is more effective than fluvial erosion". This does not match experience in places like tropical Papua New Guinea where river erosion is dominant, and river beds are often the only place where bedrock is exposed.

9. *Landslides and mass movement*

In rugged tropical landscapes such as mountainous New Guinea recurrent landslides are an important landscape forming process. The same is true, however, of the rugged landscapes of the Himalayas. On low angle slopes there is significant mass movement in tropical areas (MCCALLION, RUXTON and WALTON, 1964), but solifluction has a similar effect in cold areas. It is not possible to say that the intensity or style of landslides and mass movement in the tropics is significantly different from that of other areas.

10. *Planation surfaces*

At different times planation surfaces and the processes that form them have been thought to be specific to the tropics. One process was the parallel retreat of slopes to form pediments and eventually pediplains. This idea was first applied to arid geomorphology and was extended to the savanna landscapes and then to the tropics at large. However, LESTER KING, one of the chief proponents of pediplanation believed in a uniformitarian approach to slope development, and thought that pediplains were formed in all non-extreme climates (KING, 1957). Another approach is the etchplain, introduced by WAYLAND (1934) in Uganda. In this system deep weathering alternates with stripping of the regolith. BÜDEL (1982) places great emphasis on the tropical nature of etchplains (*Rumpfflächen*). However, the mechanism has now been reported from many parts of the world outside the tropics, including southwest Australia which is now arid (FINKL, 1979), and from temperate regions in both hemispheres. It is possible that these examples relate to former humid tropical climates, but that is a different argument. No specific type of planation surface can be definitely associated with the tropics.

II. SPECIFIC FEATURES ATTRIBUTED TO THE TROPICS

Even if broad geomorphic topics cannot be related unequivocally to the tropics, it is possible that some specific features and landforms may be so related.

1. *Inselbergs*

Inselbergs were originally related to arid climates, and later to the humid tropics or perhaps savanna landscapes. To some extent the definition of inselberg affects the discussion, but certainly there are many steep granite hills and other isolated hills in non-tropical climates. At this point it is worth stressing that much discussion of tropical climates is too restricted to granite (e.g. THOMAS, 1974; BÜDEL, 1982). It is useful to compare landforms on the same rock in different climates, but it must not be forgotten that there are many rocks in tropical regions besides granite. Certainly many granite landforms commonly attributed to particular climatic effects are found in many different climates. Most inselbergs are on granite or gneiss, but some are not.

2. *Duricrusts*

Duricrusts may indicate the climate at the time of their formation.

Calcrete seems to be normally confined to arid or semi-arid areas where carbonate is precipitated (GOUDIE, 1973; REEVES, 1976). However, B.P. RUXTON (pers. comm.) says that calcretes occur in the Sepik and other areas of humid tropical New Guinea.

Silcrete is a more mysterious deposit which is not climatically distinctive. It is hard to establish any place where it is definitely forming at the present day. It has sometimes been attributed to arid climates (e.g. OLLIER, 1978) but others have demonstrated that it forms in humid climates in association with ferricrete (VAN DE GRAAFF, 1983).

Ferricrete, the iron oxide duricrust, seems to be restricted in its formation to tropical areas, particularly those with a dry season. It is often associated with a Walther profile (ferricrete over mottled zone over pallid zone) to give what is often called a lateritic profile, though the word laterite is sometimes used for the ferricrete itself. Ferricrete is found outside tropical regions, so the relationship to tropical climates is debatable to some extent.

Bauxite (aluminocrete) seems to be restricted in its formation to the perhumid tropics where leaching is intense, and those bauxites now found outside tropical areas can apparently be related to former tropical conditions with confidence.

3. *Coral coasts*

Coral coasts seem to be restricted to tropical climates, and although there are several variations it seems clear that tropical coastal geomorphology has many distinctive features (FANIRAN and JEJE, 1983).

4. *Dunes*

Dunes are common in tropical deserts. They are also common in some non-tropical areas such as Patagonia, so without further information dunes cannot be regarded as a distinctly tropical feature. In the vicinity of Canberra, Australia, for example, there are fossil dunes and sandsheets. It seems that these were formed at the height of the last glacial period, when the climate was akin to that of Patagonia rather than to the tropics.

5. *Catenas*

The regular recurrence of similar topographic sites with similar soils is called a catena, and was first described from the tropics. It is certainly very common in humid tropical regions to find upper slopes with red soils composed largely of kaolin and iron oxides (tropical red earths), and black soils in valleys where montmorillonite has been reconstituted. However the catena concept has now been extended to many other climates, and few generalisations can be made about the nature of catenas in non-extreme climates (OLLIER, 1976). This is because of the role of soil-forming factors other than climate and topography (such as time, parent material, and organisms).

III. POLYGENETIC LANDSCAPES

The concept of climatic geomorphology becomes harder to test if past climates are taken into account. It is possible to rationalise 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 firm evidence and not jump to unfounded climatic conclusions.

In the 1930's it seemed a reasonable assumption that the glacial periods of the highter latitudes would be matched by rainy periods — "pluvials" — 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 also suggests that in general 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. BÜDEL (1951) 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 probable, with limited movement 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 of perhaps 20 alternating colder and warmer periods (fig. 3). Any correlation between these and the old four glaciations is purely coincidental. Furthermore if the geomorphic history of the tropics extends back beyond the Quarternary a great deal more climatic change becomes available. The question of landscape longevity therefore becomes critical in assessment of tropical landforms.

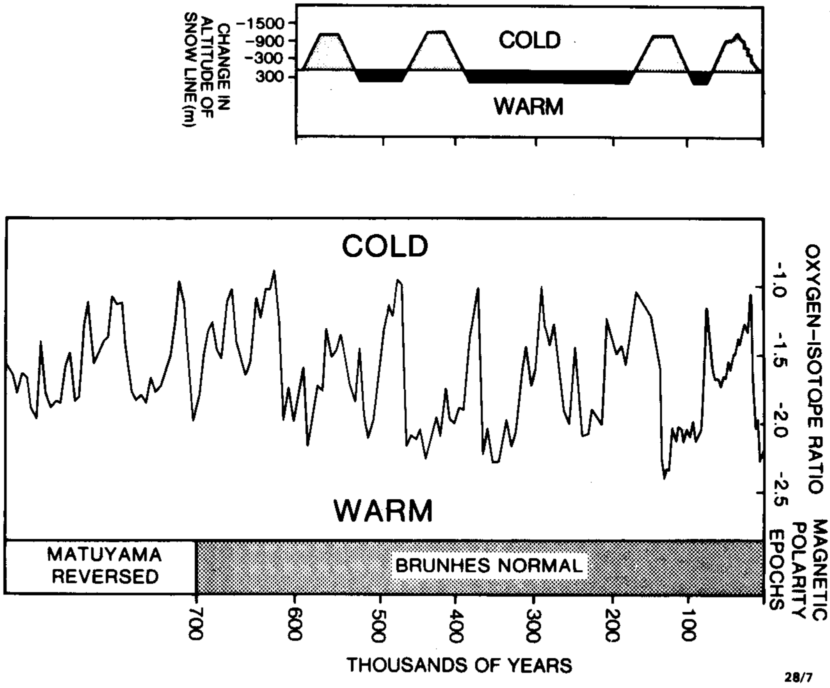


Fig. 3 — The old four-glacial model and the modern view of Quaternary climatic fluctuations.

IV. 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". The 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 Quatenary 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 100 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 and 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 dryer 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. PLAIN and OLLIER (1981), for exemple, describe a landscape formed on a Pliocene granite in which rapid rates of uplift coupled with rapide 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.

V. DISCUSSION

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, 1968). STODDART traces the history of many aspects of climatic geomorphology, and concludes that while climatic factors may be important, they are not necessarilly 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 the 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.

CONCLUSION

There are a few landforms and landscape forming processes that are distinctive of the tropics, but because of many complications in climatic and geological history it is usually very difficult to isolate tropical features from features that could be formed in other climates. Since climatic change is the norm rather than the exception, this complexity cannot be ignored. In the present state of knowledge an interpretation of internal evidence is more valuable than inductive interpretations based on climatic theories. In the words of FANIRAN and JEJE (1983) "One important feature... of the humid tropical environment is that of an insufficient data base".

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

REFERENCES

BIROT, P. 1968. *The cycle of erosion in different climates.* (Trans. C.I. JACKSON and K.M. CLAYTON).

BÜDEL, J. 1951. "Die Klimazonen des Eiszeitalters" (Trans. H.W. WRIGHT), *Intern. Geol. Rev.*, 1, 72-76.

BÜDEL, J. 1982. *Climatic Geomorphology* (Trans. L. FISCHER and D. BUSCHE), Princeton Univ. Press, Princeton, N.Y.

BLAKE, D.H. and OLLIER, C.D. 1971. "Alluvial plains of the Fly River, Papua". *Z. Geomorph.*, NF., Suppl. Bd., 12, 1-17.

BROOK, G.A. and FORD, D.C. 1978. "The origen of labyrint and tower karst and the climatic conditions necessary for their development". *Nature*, 275, 493-6.

COTTON, C.A. 1961. "The theory of savanna planation". *Geography*, 46, 89-101.

FANIRAN, A. and JEJE, L.K. 1983. *Humid Tropical Geomorphology*. Longman, London.

FINKL, C.W. 1979. "Stripped (etched) surfaces in southern Western Australia". *Aust. Geogr. Studies*, 17, 35-52.

GARNER, H.F. 1968. "Tropical weathering and relief". *The Encyclopedia of Geomorphology* (ed. R.W. FAIRBRIDGE), 1161-73. Reinhold, New York.

GARNER, H.F. 1983. "Large-scale tectonic denudation and climatic morphogenesis in the Andes mountains of Ecuador". pp. 1-17 in *Mega-geomorphology* (eds. R. GARDNER and H. SCOGING), Clarendon Press, Oxford.

GOUDIE, A. 1973. *Duricrusts in tropical and subtropical landscape*. Clarendon Press, Oxford.

GRUBB, P.C.L. 1983. "Weathering and leaching patterns associated with some gibbsitic soils in southern Africa" in *Leaching and Diffusion in rocks and their weathering products* (ed. S.S. AUGUSTITHIS), Theoprastus, Athens, 321-343.

JENNINGS, J.N. and BIK, M.J. 1962. "Karst morphology in Australian New Guinea". *Nature*, 194, 1036-8.

KING, L.C. 1957. "The uniformitarian nature of hillslopes". *Trans. Edin. Geol. Soc.*, 17, 81-102.

LELONG, F. 1969. "Nature et genèse des produits cristallines dans climat tropicale humide (Guyane Française)". *Sciences de la Terre*, Mem. 14, 1-188. Nancy.

McCALLIEN, W.J., RUXTON, B.P. and WALTON, E.K., "Mantle rock tectonica". *Bull. Overseas Geol. & Min. Res.*, 9, 257-294.

MANN, A.W. and OLLIER, C.D. 1984. "Chemical diffusion and ferricrete formation". *Catena*, (in press).

OLLIER, C.D. 1974. "Jungles and Rain Forests". *Encyc. Britannica*, 10, 336-42.

OLLIER, C.D. "Catenas in different climates". Ch. 5 in *Geomorphology and Climate* (ed. E. DERBYSHIRE), Willey, London.

OLLIER, C.D. 1978. "Silcrete and weathering". Ch. 2 in *Silcrete in Australia* (ed. T. LANGFORD-SMITH), Univ. New England, Armidale.

OLLIER, C.D. 1981. *Tectonics and Landforms*, Longman, London.

OLLIER, C.D. 1984 a. *Weathering* (2nd Ed.) Longman, London.

OLLIER, C.D. 1984 b. "Morphotectonics of continental margins with Great Escarpments" in *Tectonic Geomorphology* (eds. M. MORISAWA and J.J. HACK), Proc. 15th Geomorphology Symposium, Binghamton, N.Y. (in press).

OLLIER, C.D. and HARROP, F.J. 1971. "The caves of Mont Hoyo, Eastern Congo Republic". *Bull. Nat. Spel. Soc.*, 25, 73-8.

OLLIER, C.D. and BROWN, M.J.F. 1971. "Erosion of a young volcano in New Guinea". *Z. Geomorph.*, 15, 12-28.

OLLIER, C.D. and MACKENZIE, D.E. 1974. "Subaerial erosion of volcanic cones in the tropics". *J. Tropical Geog.*, 39, 63-71.

OLLIER, C.D. and PAIN, C.F. 1981. "Active gneiss domes in Papua New Guinea: new tectonic landforms". *Z. Geomorph.*, 25, 133-45.

PAIN, C.F. and OLLIER, C.D. 1981. "Geomorphology of a Pliocene granite in Papua New Guinea". *Z. Geomorph.*, 25, 249-258.

PAIN, C.F. and OLLIER, C.D. 1984. "Drainage patterns and tectonics around Milne Bay, eastern Papua New Guinea". *Rev. Geomorph. Dyn.*, (in press).

PELTIER, L.C. 1950. "The geographic cycle in periglacial regions as it is related to climatic geomorphology". *Ann. Assoc. Amer. Geogr.*, 40, 214-36.

PITTY, A.F. 1982. *The Nature of Geomorphology*. Methuen. London.

REEVES, C.C. 1976. *Caliche: origin, classification, morphology and uses*. Estacado, Lubbock.

RUXTON, B.P. 1967. "Slopewash under mature primary rain forest in northern Papua" in *Landform Studies from Australia and New Guinea* (eds. J.N. JENNINGS and J.A. MABBUTT), 85-94. ANU Press, Canberra.

SAUNDERS, I. and YOUNG, A. 1983. "Rates of surface processes on slopes, slope retreat and denudation". *Earth Surf. Proc. and Landforms*, 8, 473-501.
STODDART, D.R. 1969. "Climatic geomorphology: review and re-assessment", in *Progress in Geography*, Volume 1 (eds. C. BOARD, R.J. CHORLEY, P. HAGGETT and D.R. STODDARTT), 159-222. Edward Arnold, London.
STRAKHOV, N.M. 1967. *Principles of Lithogenesis*. Vol. 1. (trans. J.P. FITZSIMMONS). Oliver and Boyd, Edinburgh.
THOMAS, M.F. 1974. *Tropical Geomorphology*, Macmillan, London.
THOMAS, M.F. 1976. "Criteria for the recognition of climatically induced variations in granite landforms" in *Geomorphology and Climate* (ed. E. DERBYSHIRE). Wiley, N.Y., 411-45.
THORNBURY, W.D. 1954. *Principles of Geomorphology*. Wiley, New York.
TRICART, J. 1972. *The landforms of the humid tropics, forests and savannas* (trans. C.J.K. DE JONGE). Longman, London.
TRICART, J. and CAILLEUX, A. 1965. *Introduction à la geomorphologie climatique*. S.E.D.E.S. Paris.
TWIDALE, C.R. and HARRIS, W.K. 1977. "The age of Ayers Rock and the Olgas, Central Australia". *Trans. R. Soc. S. Aust.*, 101, 45-50.
WAYLAND, E.J. 1934. "Peneplains and some other erosional platforms". *Ann. Re. Bull. Uganda Geol. Surv. Dept.*, 1933, 77-9.
WENTWORTH, C.K. 1943. "Soil avalanches on Oahu, Hawaii". *Bull. Geol. Soc. Am.*, 53, 53-64.
WOLFENDEN, E.B. 1961. "Bauxite in Sarawak". *Econ. Geol.*, 56, 972-981.
VAN DE GRAAFF, W.J.E. 1983. "Silcrete in Western Australia: geomorphic settings, textures, structures, and their genetic implications" in *Residual deposits: surface related weathering processes and materials* (ed. R.C.L. Wilson), Blackwell, UK.
VAN KERSEN, J.F. 1956. "Bauxite deposits in Suriname and Demerara (British Guiana)". *Liedse Geol.*, 21, 249-373.

RESUMO

Geomorfologia tropical e evolução da paisagem a longo termo — O Autor discute o conceito de "geomorfologia tropical" que supõe um conjunto de processos e de formas de relevo peculiares das regiões tropicais, diferentes, de certo modo, dos das regiões extra-tropicais, através da revisão de um certo número de premissas em que se baseia tal conceito. É minimizado o papel do clima, tão importante na chamada geomorfologia climática — as variedades entre os trópicos de Câncer e de Capricórnio são reduzidas a um único tipo geral de condições quentes e húmidas — para demonstrar que há outro factor, a longa duração da evolução das paisagens, que dá às regiões tropicais a maioria das suas diferenças significativas, quando comparadas a outras regiões. Na maior parte das vezes o leitor é remetido para textos do Autor, não porque ele os considere melhores que

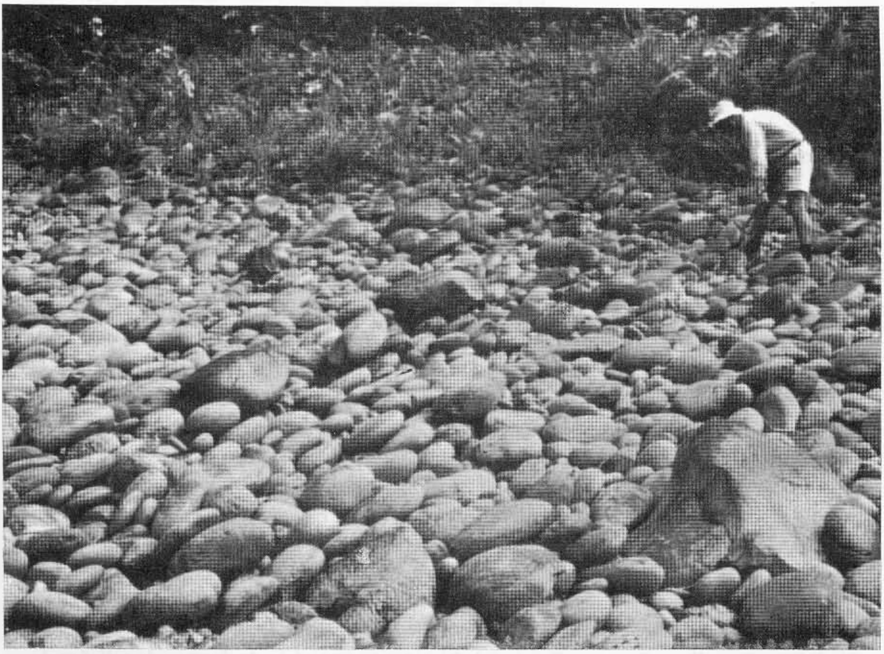
os de outros, mas porque desse modo evita possíveis acusações de incorrecta interpretação de ideias de outros investigadores.

O texto abrange cinco partes fundamentais: I. Tópicos de geomorfologia tropical (processos tectónicos; vulcões; meteorização e solos; carso; *sheetwash*; rios; grandes escarpas; intensidade dos processos geomórficos; deslizamentos e movimentos de massas; superfícies de aplanação). II. Aspectos específicos atribuídos às regiões tropicais (*inselberge*; crostas ou couraças; costas coralígenas; dunas; catenas). III. Paisagens poligénicas. IV. Longevidade dos relevos. V. Discussão. Para o Autor haverá umas quantas formas de relevo e de processos de evolução das paisagens que são característicos das regiões tropicais mas, por motivo das muitas complicações da história climática e geológica, em regra geral é difícil distinguir as que são mesmo tropicais das que se poderão ter desenvolvido noutros climas. E, uma vez que as modificações climáticas são mais a norma que a excepção,

RÉSUMÉ

Géomorphologie tropicale et durée de l'évolution du paysage — L'auteur discute le concept de "géomorphologie tropical" qui présuppose un ensemble de processus et de formes de relief particuliers aux régions tropicales, différent de ceux des régions extratropicales, en passant en revue un certain nombre de prémices sur lequel se base un tel concept. Le rôle du climat, si important dans la géomorphologie dite climatique, est minimisé au point que les types de formes qu'on relève entre les deux tropiques sont réduits à un seul et unique de régions chaudes et humides. Cette démarche prétend démontrer qu'il y a un autre facteur à prendre en compte: la durée d'évolution des paysages qui donne aux régions tropicales un cachet si particulier. La plupart du temps, le lecteur est invité à se reporter à d'autres textes de l'auters, non pas parce qu'il les considère les meilleurs mais parce qu'ainsi il évite les accusations toujours possibles d'interprétations incorrectes des idées des autres chercheurs.

Le texte comprend cinq parties principales: I. Sujects de géomorphologie tropicale (tectonique; volcans; altération et sols; Karst; *sheetwash:* écoulement en nappe; fleuves; grands escarpements; intensité des processus morphogénétiques; glissements et mouvements de masse; surfaces d'érosion). II. Aspects spécifiques attribués aux régions tropicales, (inselbergs, croûtes et cuirasses; côtes coralliennes; dunes; séquences pédologiques). III. Paysages polygéniques. IV. Durée des reliefs. V. Discussion. Pour l'auteur, il y aurait bien toute une série de formes de relief et de processus d'évolution des paysages caractéristiques des régions tropicales mais, en règle générale, à cause de nombreuses complications dans l'histoire climatique et géologique, il est difficile de distinguer celles qui sont réellement tropicales de celles qui auraient pu se développer sous d'autres climats. Puisque les modifications climatiques sont plus la norme que l'exception, cette complexité ne peut plus être ignorée. L'auteur ajoute encore que, dans l'état actuel de nos connaissances, une interprétation de ce qui paraît évident est plus riche d'enseignements que les interprétations inductives fondées sur les théories climatiques et que, le facteur le plus significatif de la géomorphologie des régions tropicales reste probablement la constatation que les formes ont échappé aux glaciations du Quaternaire. Par conséquent, elles ont une histoire bien plus longue.



Est. I — Imbicate structure in pebbles on a shoal, Strickland River, Papua New Guinea.