OBAFEMI AWOLOWO UNIVERSITY . ILE-IFE . NIGERIA

Inaugural Lecture Series 81

LANDSCAPE EVOLUTION IN THE HUMID TROPICS AND IMPLICATIONS FOR LAND RESOURCES EVALUATION

By L. K. Jeje

OBAFEMI AWOLOWO UNIVERSITY PRESS LIMITED

L. K. Jeje
Professor of Geography

LANDSCAPE EVOLUTION IN THE HUMID TROPICS AND IMPLICATIONS FOR LAND RESOURCES EVALUATION

by

L. K. Jeje
Professor of Geography

Inaugural Lecture delivered at the University of Ife
(now Obafemi Awolowo University)
on Tuesday, May 13, 1986

Inaugural Lecture Series 81

OBAFEMI AWOLOWO UNIVERSITY PRESS. LIMITED.

ILE - IFE. NIGERIA

ISSN 0189–7845

Printed by
Mustapha Printers (Nig.) Enterprises,
Olorunsogo Off Akanran Road,
Tel: 714190, Ibadan.

1. INTRODUCTION

We are all familiar with the landscape around us; we appreciate it if not for its intrinsic aesthetic values, at least for the associated natural resources among which are soils, vegetation, building materials such as rock chips, gravel and sand, and the various mineral ores.

The unravelling of the mystery surrounding the origin of landscapes is considered to be one of the focal research points in geomorphology. According to Budel (1963), "the aim of geomorphology is to order and interprete the significance of the immense variety of the earth's surface relief." Developments in geomorphology in the early part of this century focused entirely on the explanation of the origin of landscapes in various parts of the earth's surface as witnessed the work of the greatest geomorphologist – William Morris Davis, and other lesser luminaries. Although researches in geomorphology have become more refined in terms of scientific, field and laboratory studies of various geomorphological processes and non dynamic features, however, as observed by Douglas (1980), "the ultimate goal of much the present concern with the study of geomorphic processes is the improvement of our ability to interprete the evolution of landforms, to explain the origin of correlative deposits and to estimate the rate at which segments of the earth's surface evolved".

Given this observation, the choice to explain the origin of landforms in the humid tropical environment, the topic of this lecture, is quite relevant. In fact, it is such as important current geomorphological issue as to warrant the publication of a book in 1985 – *Environmental Change and Tropical Geomorphology* edited by I. Douglas and T. Spencer.

The humid tropical landscape can be resolved into individual landforms depending on their morphostructure and the geomorphic processes operating on them. However, landform recognition is a matter of scale and perspective. For example the entire Chad Basin can be regarded as a landform, however, it contains smaller landforms such as the floodplains of the Yedseram, Logone, Ngadda and Komadugu Rivers, and each of these floodplains contains individual landforms such as river channels, oxbow lakes, backswamp etc. The river channel itself can still be resolved into channel bank, sand dunes, sand bars etc.

The concern in this lecture is not with the origin of these individual landforms, rather the humid tropical environment as defined by Faniran and Jeje (1983) is perceived as a morphogenetic region in which the landforms subject to the constraints of varying lithologies and structure appear to have experienced similar morphogenesis both in terms of palaeo and contemporary geomorphic processes.

In this lecture, the broad landscape morphological characteristics will be examined, and attempts will be made to explain the origin with particular emphasis on the environmental factors of landform evolution. This will be followed by an exposition on the implications for land resource evaluation. Given our limited knowledge of the nature of the landscape and of the palaeo and contemporary geomorphic processes in the humid tropics, the approach is necessarily broad.

1.1 Landscape Morphology

Except for the major landform complexes formed by endogenetic processes in tectonically unstable areas, the landscape of the tropics generally comprises an arrangement of plains at different elevations separated by scarps or broad zones of dissection (King, 1962). The plains which exhibit varying proportions of the weathering front are diversified by different types of river valleys and several positive relief features including tabular laterite-capped hills, low convex hills developed on regolith, rock outcrops, massive corestones, tors, ruwares, different type of rock inselbergs — castle kopjes, bornhardts and whalebacks (Jeje, 1973); conekarsts on limestones and different types of ridges and mountains which may occur individually or in clustered forms.

The number of storeys in any area is a factor of the geological and geomorphological history. For example, the landscape in Guyana and Surinam comprises five storeys separated by scarps (Eden, 1971). This tiered pattern has also been observed by Swan (1970) in Johor, Malaysia where he noted that: "the landscape consists of a bottom storey comprising extensive zones of deposition above which rises a middle storey of dissected lowlands of gentle to moderate steepness with a relative relief within 60m, and a top storey of steep sided mountains, hills and ridges with occasional plateaux and high plains rising above the middle storey". The top storey forms are characterized by faceted slopes comprising the crest, the upper convexity, the free face inclined at more than 45°, the middle debris slope at about 13°, the piedmont slope at around 4.3°, the alluvial toeslope and the stream channel. The middle storey landscape comprising dissected lowlands of gentle to moderate steepness with relative relief up to 61m has slopes ranging from convex through convexo-concave to almost concave especially on regolith derived from granites and argillaceous sediments and of convex form on basic rocks. The bottom storey comprising extensive zones of deposition is predominant along the coast and inland along the main rivers. Generally, the landscape increases in elevation as one moves into the interior of Peninsular Malaysia from the east. The low swampy coastal sedimentary and alluvial plains along the lower river basins are succeeded inland by dissected granitic lowlands which are surmounted by ridges and monadnocks. These are in turn succeeded inland by discontinuous mountain chains.

The tiered landscape is equally ubiquitous in Nigeria both on local and regional scales. Locally, it is evident in the Ibadan area where the Aremo ridge and the Agodi hill standing at 65m above the local footslope constitute the highest storey, the footslopes and the flat to gently convex interfluvial crests constitute the middle storey, while the broad valley floors of the Ogunpa, Ona, Kudeti and Yemetu streams form the lowest storey (Fig. 1). The tiered landscape is particularly well developed in the rolling terrain east of Ilesa (De Swardt, 1953). The top storey comprising steep, unbroken, north-south trending ridges stands at 280m above the footslopes, the middle storey comprises the flat footslopes at the base of the ridges and wide interfluvial crests at 350–365m a.s.l, while the wide aggraded valley floors at 320–335m constitute the lowest storey.

On a regional scale, this pattern is also recognizable in Ado-Iddo Ekiti area where the lowest storey in the upper basin of Upper Ogbese (Elemi) at 364m to 394m is separated from the dissected upper Ero basin at 515m to 576m by a broken rock scarp. The high inselbergs on the latter surface constitutes the third storey. The tiered landscape is also evident on sedimentary rocks particularly on the Cretaceous Upper Coal Measures and Ajali Sandstone in the Nsukka area of southeastern Nigeria. The top storey comprises several erosional residuals in form of laterite-capped tabular, domed, conical and elongated hills and ridges at a general elevation of 535m. The middle storey developed on Ajali Sandstone comprises the footslopes and the interfluvial crests at a general elevation of 435m while the lowest landscape, at a general elevation of 215m to 315m comprises the wide floors of the dry valleys developed on the porous and extremely permeable sandstones. The whole complex is separated from the Cross River Plain to the east by a scarp up to 100m high.

A glance at the relevant SALR imagery of parts of Nigeria will show these series of surfaces and their relationship to one another.

2.0 LANDSCAPE EVOLUTION

Landscape evolution in humid environments has been explained by the application of two main theories: peneplanation (Davis, 1899) and pediplanation (King, 1953; 1957; 1962).

Fig. 1 The tiered landscape around Ibadan (After K Burke, 1967)

As the broad outline of these models is too well known, these will not be repeated here. Suffice it to mention that peneplanation with its emphasis on universal decline of slopes (Fig. 2) cannot account for the gross morphology of the humid tropical landscape, nor can it account for the detailed landform morphology on specific surfaces. The model is thus generally regarded as inapplicable to the humid tropical environment.

As against the decline of slopes emphasized by the peneplanation hypothesis, pediplanation stresses slope retreat and constancy of slope declivity over the landscape (Fig. 3). This theory has been applied in explaining landscape evolution in the humid tropics especially in northern Nigeria by Pugh (1955, 1966), Pugh and King (1952) and Clayton (1958), and world wide by King (1962). While useful in explaining the gross staircase morphological pattern of landscapes especially in the sub-humid tropics,, and while it can also be applied in explaining the development of specific landforms such as tablelands, it is of doubtful validity in explaining the evolution of the detailed landform morphology especially in the more humid and warmer areas where the four prerequisite slope elements described by King are often absent. The model also fails to accommodate the most important geomorphological process in such areas i.e. deep chemical weathering and erosional stripping of the weathered rocks. The model further ignores the effects of structural variations in landscape development. For instance the erosional residuals in parts of southwestern Nigeria attributed by Pugh (1966) to the effects of pediplanation have subsequently been shown to relate to petrological variations in the local geology (Jeje, 1972).

The step-like surfaces characteristic of many parts of the humid tropics which have been eroded one across the other are veritable etchplains, and can thus be explained in terms of the etchplanation concept.

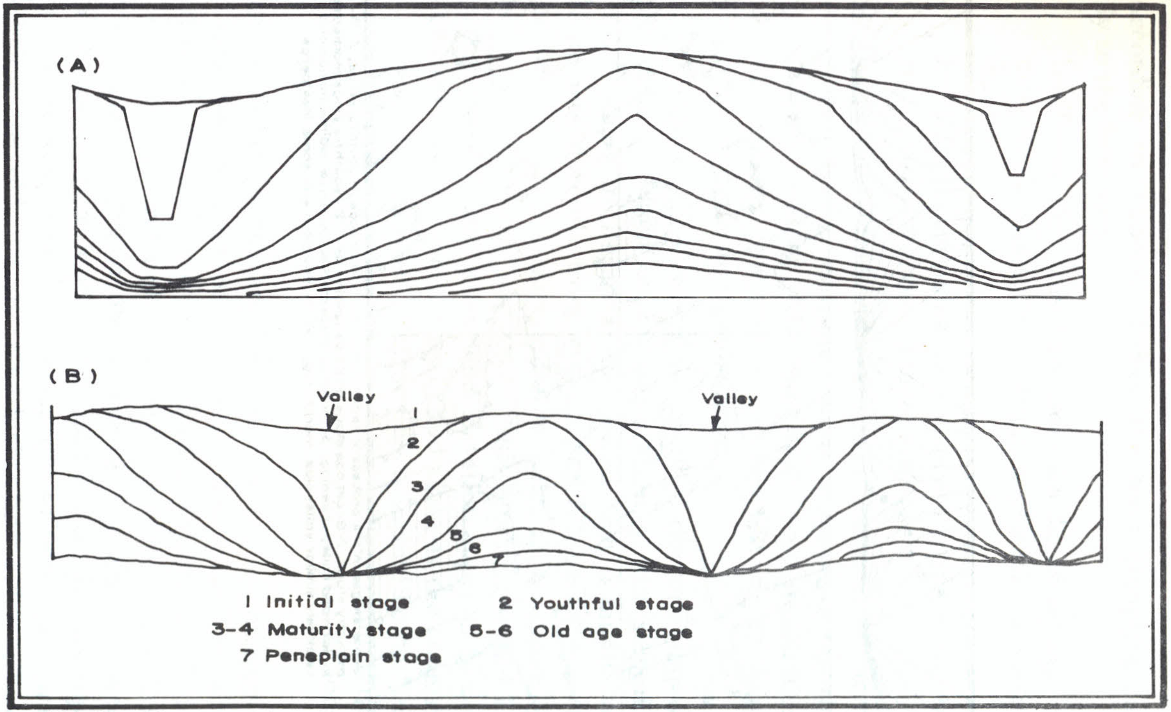


Fig.2: Some stages in the process of peneplanation (Davis 1898, 1912)

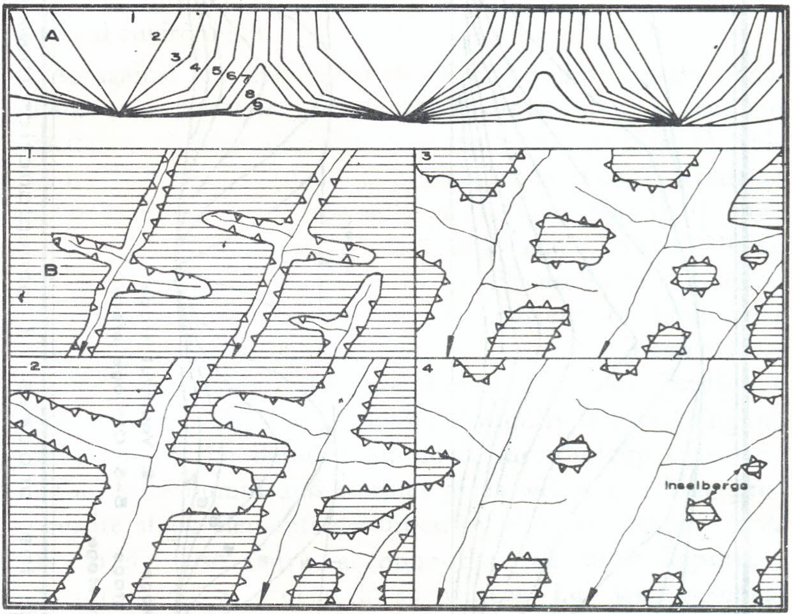


Fig. 3 Some stages in the process of pediplanation. A— 1- initial stage, 2- youthful stage, 3-6- maturity stage, 7-8- old age stage and 9 pediplain. B- 1- 2- youthful stage marked stream incision and valley widening, 3- maturity stage marked by active pedimentation and relatively similar valley side morphology and 4- pediplain with some inselbergs

2.1 Etchplanation

According to Thomas (1984), the term etchplain can apply to the following:

i. landforms that may have been produced by one or more distinct episodes of stripping of a relict saprolite mantle;

ii. landforms continuing to evolve by surface erosion acting on pre weathered materials;

iii. landscapes within which emergent forms coexist with more rapidly evolving forms controlled by the shifting balance between weathering penetration and surface lowering within a system involving active or dynamic etchplanation.

E. J. Wayland (1934) who first described the formation of "etched plains" based on his observation of the step-like series of plains in Buganda, recognized that a mantle of saprolite would result from vertical penetration of ground water beneath land surfaces of low relief in a seasonally humid tropical climate, and that "this saprolite would be largely removed if and when land elevation supervenes and this process may be repeated again and again as the country rises". By this means, an "etched plain" could be derived from an original peneplain and the land surface maintained at or near base level during spasmodic elevation over long time scales.

Bailley Willis (1936) applied this concept to interprete the Tangayika plateau as an "etched peneplain" widely mantled by residual or transported soils. Mabbutt (1961) also observed that antecedent weathering of the crystalline basement plateau area in the interior of Australia, followed by a change of base level and erosion led to the development of an erosion surface of considerable surficial configuration below the old plateau. The higher and older surface was represented mainly by a laterite-capped plain while the lower and stripped surface comprised the widely exposed basal surface of weathering together with the lower zones of weathering profile, the altitudinal difference between the two depending on the depth of the weathering profile. This process whereby lower surfaces are formed from the weathering profiles of older surfaces which is described as etchplanation has been applied by Budel, (1957, 1965), Wright (1963), Mabbutt (1961), Thomas (1965, 1974), Jeje (1970), Eden (1971), Finkl and Churchward (1973), Finkl (1979), Fâirbridge and Finkl (1980), among others, to explain the evolution of landscapes in many parts of the humid tropics.

An important aspect of this concept which derives from that of the *Doppelten Einebmungslfachen* of Budel (Fig. 4) is that, notwithstanding the Pleistocene-Holocene climatic fluctuations and regional base level changes, most areas in the humid tropics have experienced deep chemical weathering over long geological periods. Weathered rocks in this environment are characterized by dual surfaces of levelling – the weathering front or the basal surface of weathering and the surface of the regolith subject to wash and other types of erosion. The former is characterized by highly irregular surficial configuration resulting from the variable decomposition of the local rocks either along opened joints or related to extremely complex variations in their lithology and composition (Thomas, 1966; Faniran and Omorinbola, 1980).

Depths of weathering in excess of 50m have been found in basement compex rocks underlying deeply weathered sedimentary rocks in southwestern Nigeria (Jeje, 1973). The average weathering depth in the basement compex rocks in Western Nigeria is 15.3m, but in relatively uneroded areas it exceeds 30m as in the Dan Mongu area in the Jos Plateau (Faniran and Omorinbola, 1980). Weathering depths in excess of 90m have been reported in quartz diorite and metamorphic rocks in Colombia, Brazil and the Koidu area in Sierra Leone (Thomas, 1974; Thomas and Thorp, 1985). The weathering front is particularly highly irregular in granitic rocks due to the tremendous influence of joints in

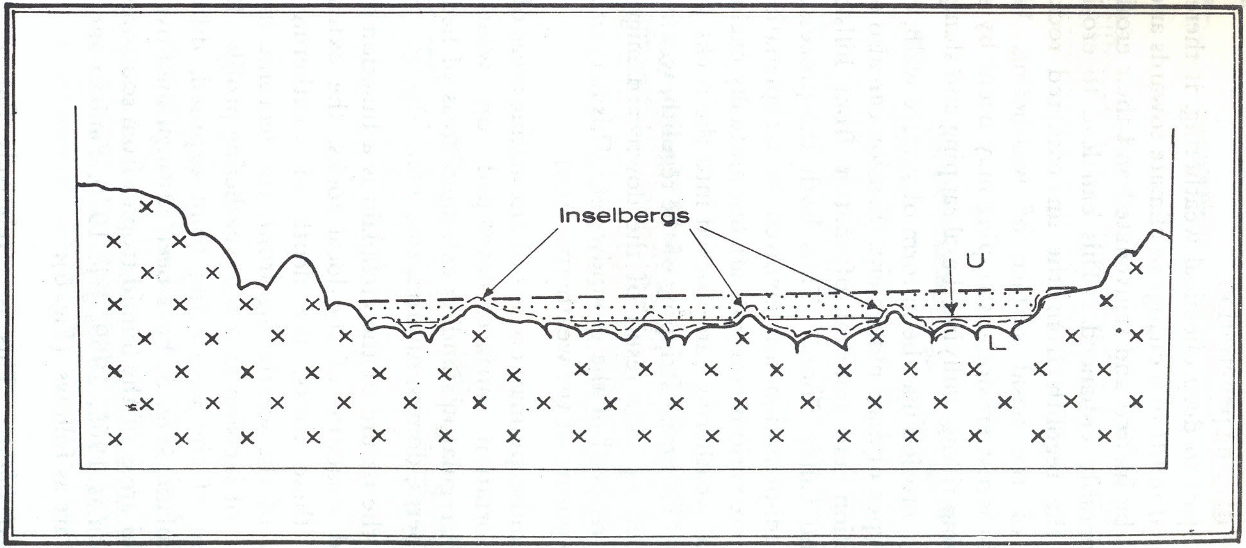


Fig. 4 The dual surfaces of levelling U, upper (subaerial) surface, L, lower (subterranean) surface or weathering front; in the latest cycle, residual unweathered cores of rock have escaped planation and their outcrops have assumed the form of inselbergs (after Budel, 1959)

controlling weathering penetration.

In areas subject to deep chemical weathering, if there is a marked regional uplift or a change in climate towards aridity, the rivers will be incised and rejuvenated and their erosional ability considerably enhanced. This can lead to erosional stripping of the regolith from the unweathered rocks to reveal areas of the basal surface of weathering. Where covered by duricrust erosional stripping may occur by slope retreat involving rilling, gullying, basal sapping and slumping. In other areas, erosion may be in form of surface wash, creep and various types of mass movement. Erosion can also occur through solution and removal of matter from hillslopes, valleysides and valley floors. Thus both the processes of pene- and pedi-planation are involved in etchplanation in which case these various concepts are not mutually exclusive.

As chemical weathering can proceed into the rocks simultaneously with erosional stripping of the regolith, weathering can be speeded up as a result of the downward migration and frequent renewal of the groundwater. This may prevent a complete exposure of the weathering front.

Thus the landscape may consist of alternating areas of low angle transportation surfaces developed on weathered material and irregular upstanding exhumed areas of bedrock forming inselbergs, domes, ruwares, tors etc.

Generally, the nature of the etchplain is a function of the lithology and structure of the local rocks, the extent of exposure of these rocks, the depth of weathering, the configuration of the weathering front, the tectonic history and the depth of incision into the weathering profile. Based on the extent of the weathering front exposed, different types of etchplains (Fig. 5) have been distinguished over the cratonic shield areas of the humid tropics from southwestern Nigeria (Thomas 1965, 1969; Jeje 1970, Faniran and Jeje, 1983). They are as follows (Fig. 6):

The lateritized plain: This is a relatively flat or gently sloping undissected surface underlain by thick regolith in

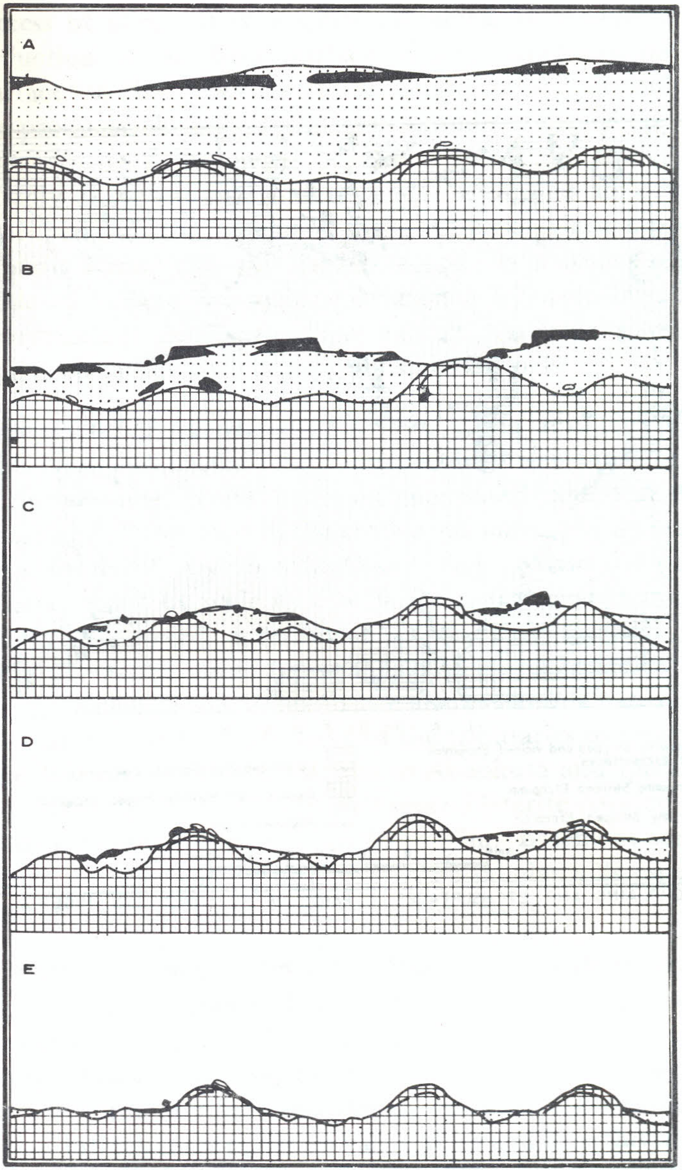


Fig. 5 Different stages in the development of etchplains A, Lateritized etchplains; B, Dissected etchplains; C, Partially stripped etchplains; D, Dominantly stripped etchplains and etchsurfaces and E, Dominantly stripped and incised etchsurface

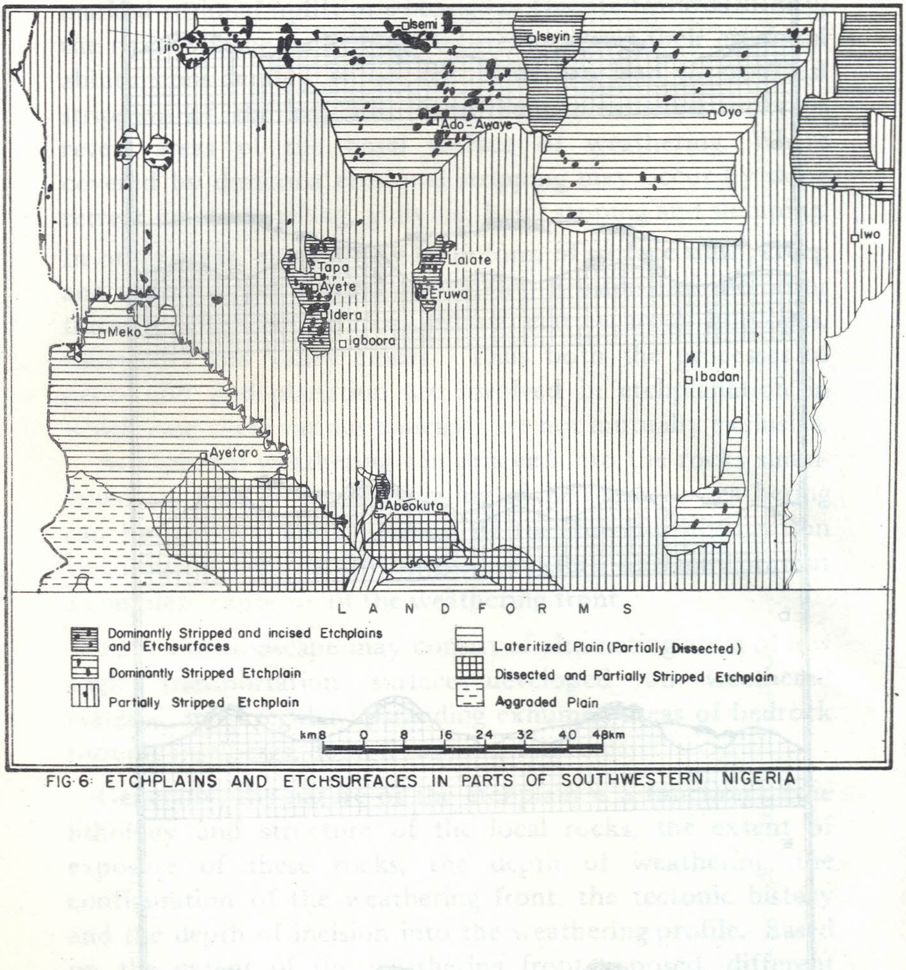
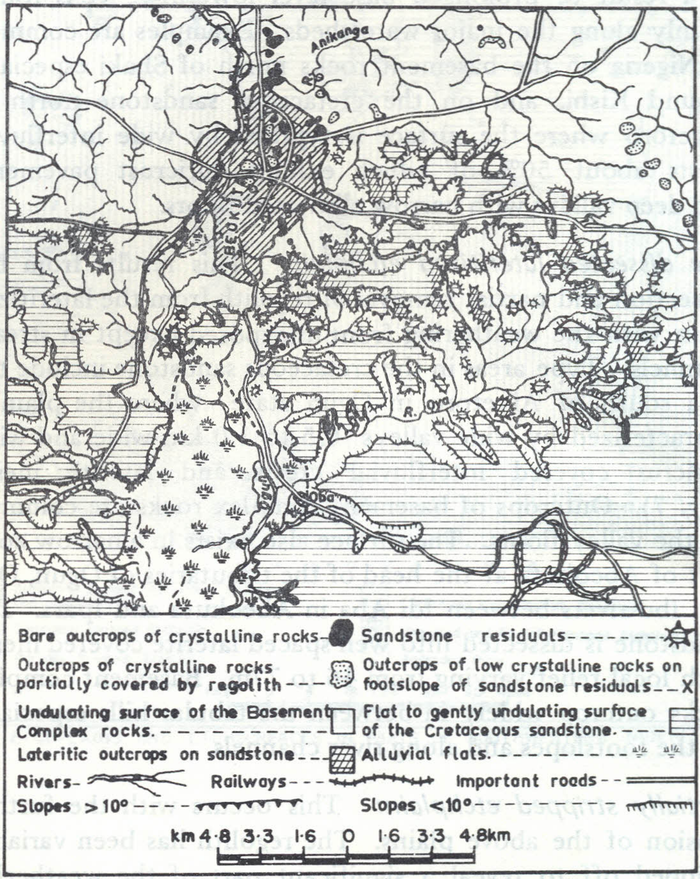


FIG 6: ETCHPLAINS AND ETCHSURFACES IN PARTS OF SOUTHWESTERN NIGERIA

excess of 60m. It is possibly produced by a simultaneor reduction of the basal surface of weathering and the land surface so that few rock outcrops are exposed. It could also be produced during a prolonged sporadic series of uplifts or as a result of prolonged base level lowering. It is found mainly along the major watersheds. Examples are common in Nigeria on the basement rocks north of Shaki especially around Kishi, and on the cretaceous sandstone north of Aiyetoro where the surface is typified by wide interfluvial crests about 50% of which exhibit duricrust pavements and deep valleys with narrow alluviated floors.

The dissected lateritized etchplain: This results from the dissection and partial removal of regolith from the lateritized plain with the weathering front unexposed except in stream channels. Type areas in the cretaceous sandstone include the area south of Aiyetoro in Ogun state where the plain is characterized by wide valleys 0.5 to 1.0 km wide and wide duricrust covered interfluvial crests and laterite mesas (Fig. 7). Outcrops of basement complex rocks are common on the valley floors. The surface also exists in a narrow zone east of Abeokuta at the head of the tributaries of Ogun, Ona and Ibu rivers between Idi Aba in Abeokuta and Ipara. The sandstone is dissected into well spaced laterite covered mesas with local relief varying from 46 to 77m. Basement complex rocks outcrop widely in between the tabular hills especially on the footslopes and along river channels.

Partially stripped etchplain: This occurs with the further erosion of the above plains. The regolith has been variably stripped off to reveal a significant part of the weathering front. Local relief may range from 15—45m. Rock outcrops in the form of ridges, inselbergs, ruwares, corestones, tors, etc., infrequently occur on valley sides and interfluvial crests while tabular hills and lateritic breakaways occur occasionally. This surface covers a large part of the basement complex of southwestern Nigeria with the widest occurrence around Ibadan and Ogbomoso (Fig. 6).



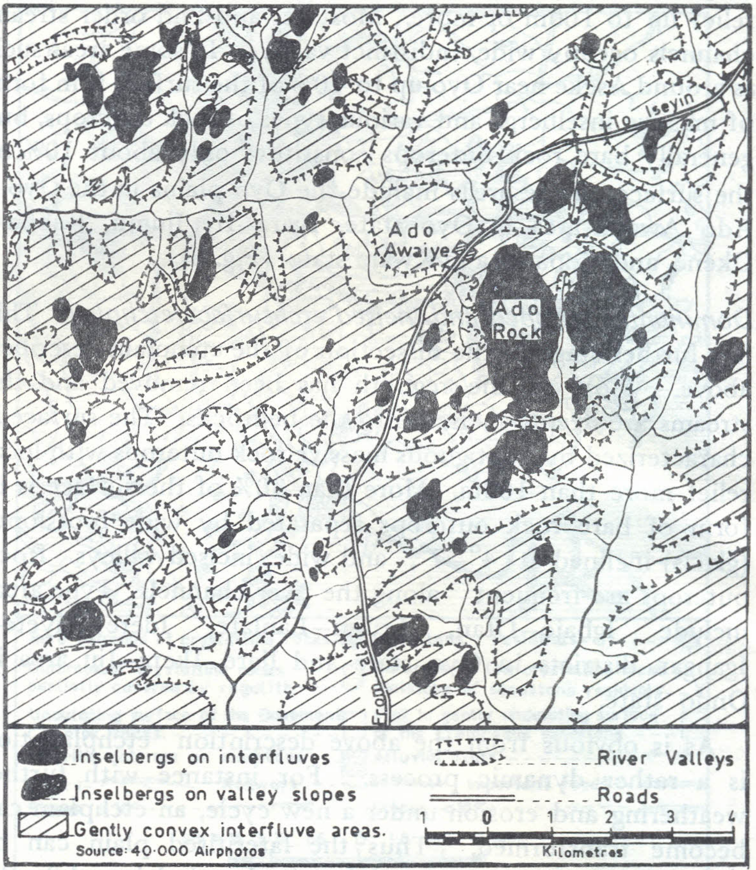
Fig·7· Dissected Lateritised Etchplain near Abeokuta

Dominantly stripped etchsurface/etchplain: This is usually developed on granitic rocks, gneisses and migmatites. Most of the regolith has been removed except for pockets of deep weathering. The plain is highly undulating with local relief up to 100m or more. Most 1st and 2nd order stream channels occupy wide, indistinct valleys. In some areas such as around Aseke near Oyo up to 40% of the surface is in form of massive inselbergs and various types of rock outcrops, but generally bare rock outcrops constitute only about 10% of the surface. Type areas include the Oyo plains in the Oyo–Ado Awaye area in Oyo state, Iyara–Ife Ijumu, Kabba–Okene, and Mopa area in Kwara state (Fig. 8).

Dominantly stripped and incised etchsurface/etchplain: This is a further stage in the dissection of the etchplain described above. Most of the regolith has been removed and the streams are deeply incised into the bedrocks. The surface is characterized by contiguous massive rock outcrops with local relief more than 100m. More than 30% of the surface is in form of bare rock outcrops separated by wide footslopes (glacis) inclined at 4°–7°, and wide, incised valleys. Rock outcrops are frequent along the river channels. Type areas include Igbajo–Otan, Eruwa–Lanlate, Idere–Aiyete–Igangan districts in Oyo state and Ijare–Ikere–Iju area in Ondo state.

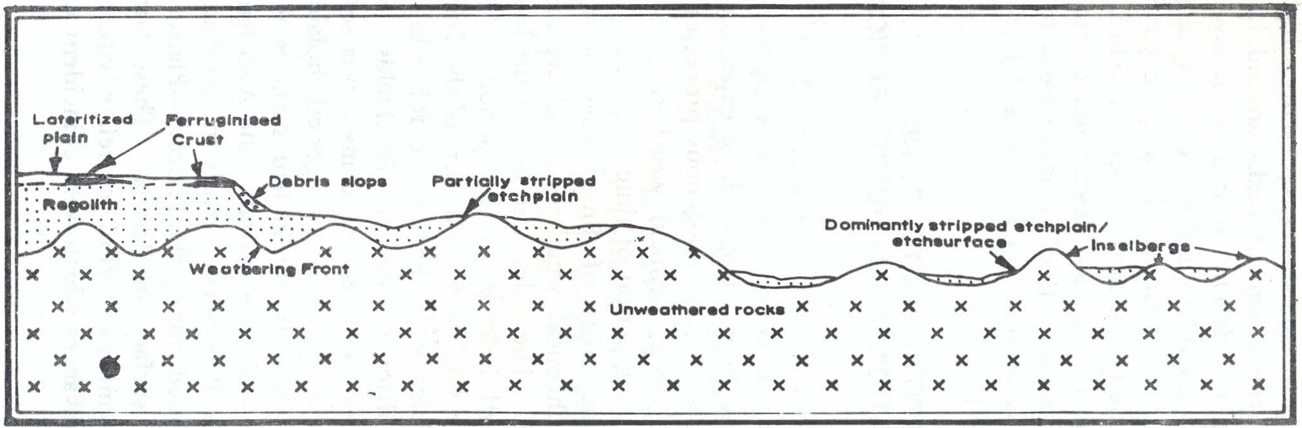
As is obvious from the above description etchplanation is a rather dynamic process. For instance with further weathering and erosion under a new cycle, an etchplain can become transformed. Thus the lateritised plain can be transformed into a dissected laterized etchplain, while the latter can be transformed into partially stripped etchplain.

And with a change of base level involving a regional uplift, a succession of etchplains can occur at different elevations (Fig. 9). Thus while a higher plain may be in form of a lateritized surface, a lower one developing into the older surface may be in form of a dominantly stripped etchplain. This is clearly illustrated around Lokoja where the Agbaja



Source: 40·000 Airphotos

Fig·8· Dominantly Stripped Etchplain / Etchsurface in Ado-Awaye area of Oyo State



Fig·9·A hypothetic succession of various types of etchplains at different elevations on basement complex rocks plateau underlain by sandstones represents a high lateritized plain while on the basement rocks around it, a partially stripped etchplain is developed at a much lower elevation.

As of now, a complete and objective typology of these etchplains cannot be formulated owing to paucity of data on their important parameters such as relief, slopes and drainage. However, detailed description of etchplain morphology and some aspects of drainage basin morphometry on these plains is provided by Faniran and Jeje (1983), and Thomas and Thorp (1985).

3.0 ENVIRONMENTAL FACTORS AND ETCHPLANATION IN THE HUMID TROPICS

Given the sequences of etchplains in the humid tropics, if the etchplanation concept is valid, it appears that most landscapes in the humid tropics have experienced episodic pulses of endogenous and exogenous processes in form of repeated uplift, deep chemical weathering, and erosional stripping over a long period of time. Bigarella (1975) shows that the cratonic areas of Brazil have been subject to repeated deep chemical weathering and erosion since the Devonian period. The oldest and one of the best preserved surfaces in Brazil belongs to this period. According to Bigarella, erosion was the main feature of the Tertiary period in Brazil especially after the Eocene following the uplift, warping and faulting of the cratonic shields. Erosion was especially pronounced when the climate was semi-arid, and this led to the development of younger ethchplains across the older surfaces. Specifically etched surfaces were formed in the Oligocene–Miocene period – the Alto Iguaco surface in Parana and the Palaeocene surface in Sao Paulo area; also another was formed during the Pliocene–Pleistocene period – the Curitiba surface in Parana. These latter surfaces formed during semi-arid periods correlate with earlier end–tertiary glacial advances which were coincident with low sea levels.

The above emphasize the importance of environmental factors such as palaeoclimatic fluctuations and base level changes in the development of landforms, and the need to examine these relative to landform development particularly in the humid tropics. The influences of these factors are so all pervasive on the earth surface especially since the Tertiary period as to induce Thornbury (1954, p. 26) to assert as one of the fundamental concepts of geomorphology that "little of the earth's topography is older than Tertiary and most of it no older than Pleistocene."

The environmental factors considered here include regional base level changes related to the tectonic history and sea level fluctuations, and the palaeoclimatic fluctuations particularly during the quaternary period.

3.1 Tectonic History

Most of the knowledge about the regional pattern of tectonic activities in the shield areas of the tropics derives from denudation chronology supplemented by data from few dated stratigraphic successions. Thus only a relatively sketchy outline of the tectonic history is known, a simplified version of which is presented here.

Most scholars (King, 1962; Richard, 1975; Brown, 1975) agree that the shield areas have only been subject to epeirogenic activities since the Cretaceous, and that in most cases these were contemporaneous with orogenesis in the adjacent fold mountain systems. For example, this was the case for the Australian shield with the Tasman orogeny in the Cainozoic (Richard, 1975), and the Brazilian-Guyana shields relative to the Andean mountain system in the Mio-Pliocene (Harrington, 1975).

Uplifts in the shields were not uniform, axes of maximum upwarp often separated equidimensional basins of lesser rise to produce broad regional domes alternating with regional basins as demonstrated on the African shield (Summerfield, 1985). The domical rises are eroded while the basins (e.g. Chad basin) receive the eroded sediments. The crest of axial upwarp may be greatly uplifted and subject to tension which can lead to rifting as exemplified by the rift valley system in east Africa.

According to King (1962), the cratonic shields were subject to severe disturbances following the final dismemberment of the Gondwana continent in the mid Cretaceous and experienced moderate but widespread uplift of up to 100m. Subsequent to this, and relative to the Alpine orogeny towards the end of the Pliocene, these shield areas also experienced powerful uplifts and warping, which in the interior of Africa involved up to 1300m elevation (King, 1962). However, the amount of uplift in West Africa was rather low. This particular uplift is believed to have been manifested in cymatogenic arching of the coastal areas of west and east Africa, and eastern Brazil. The epeirogenic upward pulses seem to have occurred in succession over a long period in central and south Africa as they are marked by six or seven succession benches separated by 20–30m scarps in the Lulua–Kasai areas of central Africa (King 1962, p. 295) and by five distinct terraces in the Ituri area of Zaire (Ruhe, 1956).

While the main shield areas appear to have been tectonically stable since the end of the Pleistocene (Brown, 1975), some areas adjacent to the Cainozoic mountain systems and parts of the mountain systems themselves are still relatively unstable. For instance the Central Highlands of New Guinea are believed to have been subject to gradual, but continuous uplift since the Miocene, and to have experienced strong uplift in the Holocene (Richard, 1975). Also contiguous areas in south east Asia such as the Sunda Platform are still unstable as evidenced by series of submerged shorelines and elevated beaches around the platform (Tjia, 1970).

These various epeirogenic upward pulses of the cratonic shield can partially account for the staircase arrangement of etchplains/etchsurfaces in most of the humid tropics. In fact, Bremer (1985) and Spath (1985) attribute the staircase morphological pattern of the Sri Lankan landscape solely to these endogenous movements.

Apart from tectonic history, the evolution of humid tropical landforms also seems to have been influenced by the world wide glacio-eustatic sea level fluctuations.

3.2 Pleistocene-Holocene Sea Level Fluctuations

The world wide glacio-eustatic pattern of sea level fluctuation since the end Tertiary is far from being understood. It is still very difficult to establish world wide correlations especially between coastal areas in the high and low latitudes, and between one ocean and the other. Since most of the studies reported in the literature have been carried out in the high latitudes, it is not certain if the findings can in fact apply to the tropics. These studies show that the tectonic and glacio-eustatic sea level fluctuations were so complex that only a very sketchy outline can be attempted here.

Based on world wide morphogeological evidences, it has been deduced that the sea level fell intermittently during most of the Tertiary period (King, 1974). This eustatic pattern related to several factors among which were widespread crustal uplift in association with the Alpine orogeny, local orogenesis and volcanic actions. For instance, as a result of isostatic crustal rebound following the erosion of the Mesozoic fold mountain systems, especially the Appalachian system, the sea level dropped for about 50m between late Cretaceous and early Tertiary at a mean rate of 0.7m/1000 years over a period of about 70 million years (Tanner, 1968).

Towards the end of the Tertiary, there is evidence to suggest eustatic falls of sea levels in relation to glaciation especially from the late Miocene. However, the pattern of glacio-eustatic sea level oscillation was highly complex due to the intricate relationships between crustal subsidence resulting from ice coverage and the varying rate of isostatic rebound at different locations especially in the higher latitudes.

As a result of the growth of the Antarctic and Greenland ice sheets, the sea level dropped by about 72m during the Pliocene – Pleistocene period (Mercer, 1968). Tannar (1968), however, put the drop at 75m and the period at the Miocene – Pliocene. While the total glacio-eustatic sea level changes have been estimated to range between +200m (Fairbridge, 1961) and –160m (Shepard and Curray, 1967) since the Pleistocene, the actual pattern of sea level movements is far from being resolved as illustrated in Table 1 and Fig. 10).

TABLE 1

Pattern of Sea Level Movement since the Upper Pliocene

Period	*Valentin (1952)*	*Fairbridge (1961)*
Upper Pliocene	+ 100m	+ 200m, + 130m
Gunz glacial advance	– 20m	– 10m
Gunz-Mindel interglacial	+ 60m	+ 100m, + 80m
Mindel glacial advance	– 90m	– 40m
Mindel-Riss interglacial	+ 30m	+ 55m, + 30m
Riss glacial advance	– 110m	– 55m
Riss-Wurm interglacial	+ 15m	+ 18m, + 8m, + 3m
Wurm glacial advance	– 95m	– 100m
Post Wurm	–	– 2m

In addition, several different estimates of the maximum sea level fluctuation in association with the Pleistocene glacial advances have been suggested. As shown by King (1974), p. 263), Antevs (1928) suggested a value of 93m for the last glaciation and 120–130m for the maximum; Daly (1934) gave values of 75m and 90m respectively; while Donn *et. al.* (1962) estimated the maximum value at between 137.4 and 159.3m, and King (1974) estimated it at 100m.

Shepard and Curray (1967) and Veeh (1966) believe that the sea level was slightly higher than now between 100,000 and 150,000 years ago, and that it fell to –120m between 50,000 and 60,000 years ago.

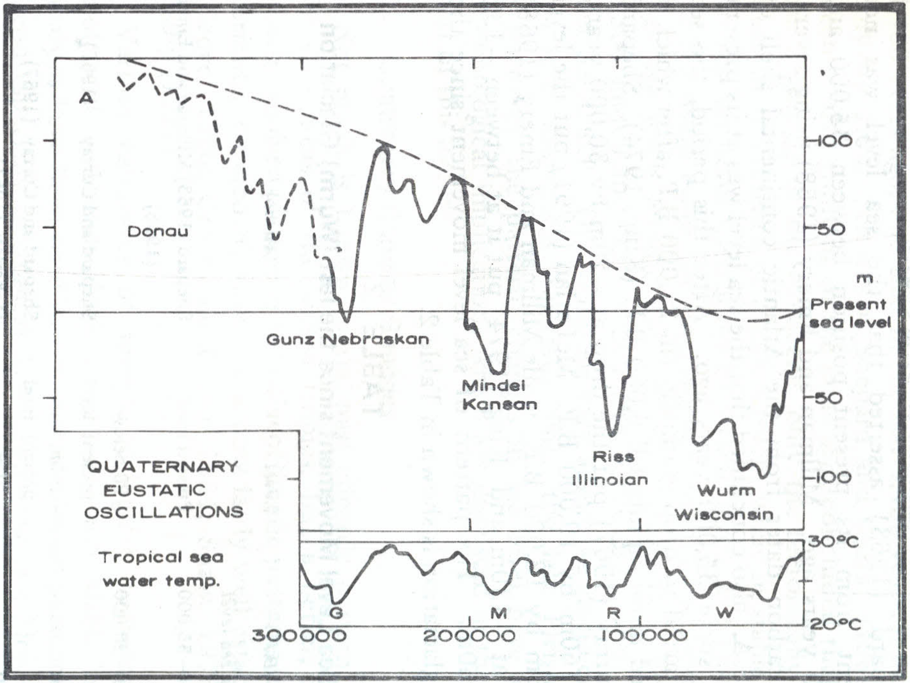


Fig.10: Changes of sea level during the Pleistocene period (After Fairbridge, 1961)

The pattern of sea level change since the last glacial period had been well documented, but it is still not easy to establish correlations even between coastal areas in the high latitudes, much less to establish such correlations between the latter and the tropical coasts.

Shepard (1963) asserted that the sea level was not different from its present position between 35,000 and 30,000 years ago. Millman and Emery (1968) using several radio carbon dates from the Atlantic continental shelf of the U.S.A. also concluded that the sea level was at its present height some 35,000 years ago. After this period, the sea level started to drop gradually till 21,000 B.P. after which it dropped more rapidly till 6,000 B.P. (King, 1974). Shepard and Curray (1967) put the drop at −20m by 30,000 years, and −160m by 19,000 B.P. McFarlan (1961) put the level at −76m by 18,000 B.P., while Millman and Emery (1968) put it at −130m and King (1974) put it at between −132 and −60m. The pattern of sea level movement since the Wurm glaciation is shown in Table 2.

TABLE 2

Sea Level Movement since the last (Wurm) Glaciation

Time (B.P.)	*Level*	*Author*
Falling sea level		
30,000–35,000	**Present level**	**Shepard (1963) Millman and Emery (1968)**
21,000–30,000	**−20 below present level**	**Shepard and Curray (1967)**
19,000	**−160m present level**	**Shepard and Curray (1967)**
18,000	**− 76m**	**McFarlan (1961)**
18,000	**−130m**	**Millman and Emery (1968)**
18,000	**−132 – −60m**	**King (1974)**
Rising sea level		
14,000 – 4,400	**−4.4m**	**Scholl and Struver (1967)**
3,400	**−2.8m**	**Scholl and Struver (1967)**
3,400	**−3.4m – +3.4m**	**Fairbridge (1961)**

The sea level started to rise as from 14,000 B.P. The rise was rapid till 7,000 B.P. after which it continued at a slower rate till 4,000 B.P. (King, 1974). Studies based on the stable crustal area of Florida by Scholl and Struver (1967) suggest that the sea level was 4.4m below the present level some 4,400 years ago, and that in the last 3,400 years, it has risen only by 1.6m. However, Shepard and Curray (1967) and Veeh (1970) studying in the same area concluded that since the beginning of the Holocene, only the tectonically active areas show evidence of high sea levels, while in stable areas, the sea has never risen above its present level. But Tjia *et. al.* (1977) using radio carbon evidence established periods of high sea levels around the Malaysian peninsula at between 8,300 and 9,500 B.P., 4,200 and 5,700 B.P., and 2,500 and 2,900 B.P. Thus opinions vary about the glacio-eustatic sea level movement especially since the late Pleistocene. Whatever the pattern, changes in sea level have several morphological implications which are discussed in the latter part of this lecture.

3.3 Quaternary Climatic Changes

Not much is known of the past climatic pattern in the forested areas of the humid tropics, but a better, if still poorly resolved picture of the palaeoclimatic patterns in areas currently covered by savannas is now fairly well established (Grove, 1958; Grove and Pullan, 1964; Shaw, 1976; and Selby (1977).

Various categories of morphogeological, topographical, biological and archeological evidence and stable isotope analysis have been used to establish the broad palaeoclimatic trend especially in tropical Africa since the late Pleistocene. Table 3 reflects the uncertainties about these events and the dates.

The evidences adduced by some of these authors are already outlined and discussed (Jeje, 1980).

Opinions vary about the nature of the palaeoclimate in the forested humid tropics during the Pleistocene – Holocene

TABLE 3

The Broad Outline of Climatic Fluctuations in Tropical Africa since the late Pleistocene

Climatic event	*Period (B.P.)*	*Author*
	36,000 – 20,000	Thomas and Thorp (1980)
	C 31,000	Burke and Durotoye (1971)
Wet phase	30,000 – 20,000	Street and Grove (1979)
	C 21,000	Talbot et al. (1984)
	C 20,000	Shaw (1976)
	"	Servant and Servant – Vildary (1980)
Dry phase	26,000 – 14,500	Wijmstra (1978)
	25,000 – 18,000	Maley (1981)
	22,000 – 13,000	Pastouret et. al. (1978)
	20,000 – 18,000	Burke et. al. (1971)
	20,000 – 17,000	Servant and Servant – Vildary (1980)
	" "	Williams et. al. (1980)
	20,000 – 13,000	Kolla et. al. (1979)
	–	Fredoux (1978)
	15,000 – 12,500	Kendal (1969)
Wet phase	15,000 – 7,000	Burke et. al. (1971)
	13,500 – 10,500	Hall et. al. (1985)
	13,500 – 10,000	Pastouret et. al. (1978)
	C 13,000	Maley (1981)
	13,000 – 8,000	Talbot and Delibrias (1980)
	12,500 – 10,000	Kendal (1969)
	12,500 – 7,800	Thomas and Thorp (1980)
	12,000 – 8,000	Fredoux (1978)
	11,000 – 8,000	Servant and Servant – Vildary (1980)
	10,500 – 7,000	Talbot et. al. (1984)
	C 10,560	Wijmstra (1978)
	9,000 – 5,000	Shaw (1976)
	8,000 – 6,500	Maley (1977, 1981)
Dry phase	7,000 – 5,000	Burke and Durotoye (1971)
	7,000 – 3,300	Thomas and Thorp (1980)
	5,000 – 4,000	Oliver (1972)
	5,000 – 3,450	Shaw (1976)
	4,500 – 4,000	Talbot and Delibrias (1980)
	4,500 – 3,000	Talbot (1981)
Wet phase	5,000 – 3,000	Burke et. al. (1971)
	3,750 – 1,000	Talbot and Delibrias (1980)
	3,500 – 780	Brooks (1948), Shaw (1976)

	3,300 – 1,750	Thomas and Thorp (1980)
	C 3,250	Shaw (1976)
	C 3,000	Hall et. al. (1985)
	2,750 – 2,450	Oliver (1972)
	1,170 – 780	Gribbin and Lamb (1978)
Dry phase	780 – 530	Brooks (1948)
	C 480	Shaw (1976)
	430 – 130	Gribbin and Lamb (1978)

glacial and interstadial periods. According to Williams (1985), during the glacial periods in the higher latitudes, the climate in the low latitudes especially in the inter tropical areas was colder, drier and windier than today, while in the interglacial period the climate was characterized by very high temperature and rainfall.

Aubreville (1962) and also Schwarzbach (1963) put the extreme limit of arid areas during Wurm glacial maximum at between latitude 8°N and 10°N in Nigeria, all places southward to the coast being covered by woodland savanna with bastions of forest surviving along the coast in Liberia, Ivory Coast, Ghana and in Cameroon and Gabon. Selby (1977) and Sowunmi (1981) also showed that areas south of latitude 10°N in West Africa were covered either by woodland or tall grass savanna and that they have not experienced arid conditions since the late Pleistocene. Although as indicated by Wickens (1975) and Grove and Warren (1968), during the Wurm maximum glacial advance, rainfall in the present rain forest areas declined by 15–20 percent, this was still possibly sufficient to support woodland savanna. Also as emphasized by Lamb (1969) and Gribbin and Lamb (1978), the temperature range between the last glacial and interstadial periods was 6°C in the tropics so that the effect of a decrease in rainfall during the dry period was possibly counter balanced by a decrease in evaporation in which case the vegetation of the present rainforest zone would have been only slightly affected. Thus it is quite possible that the margin of most of the present rainforest area was covered by wooded savanna (Thomas, 1974, p.274). However, Sowunmi

(1981), based on palaeobotanical evidence from the Niger delta suggested an invasion of savanna tree and grass in an area currently covered by thick rainforest.

3.4 Implications of Base Level and Climatic Changes for Landform Evolution

If it could be established that the late Tertiary witnessed widespread uplift of the cratonic shields and the adjacent areas, this could possibly have occurred simultaneously with the Pliocene-Pleistocene glacial advances and the associated low sea levels. These could also have been coincident with climatic oscillations in the tropics where it has been suggested that the glacial periods possibly synchronized with relatively dry phases and the interstadial periods with relatively humid phases (Fairbridge, 1961, 1964; Emiliani, 1955; Bonatti and Gartner, 1973). This simultaneous occurrence would have elicited extremely complex but interrelated geomorphic responses with several implications for the evolution of both the gross and detailed morphology of landscapes. As these effects are still not fully resolved, it may be difficult to examine them simultaneously. They are therefore discussed concurrently.

3.4.1 Base Level Changes

With the lowering of the sea level either through crustal uplift or glacial advances, rivers will be rejuvenated and become incised, the depth of incision at any location depending on the amount of uplift involved, the nature of the bedrock, the depth of weathering into the bedrock and distance from the regional base level. With the uplift of a deeply weathered terrain underlain by a highly irregular basal surface, erosional stripping will be most intense very close to the base level at the lower parts of the river basins, the regolith will be removed first from the valley bottom and subsequently, through creep, slope wash, rilling, gullying, basal sapping and mass slumping, from the interfluvial areas. Thereafter erosional stripping will proceed towards the upper parts of the basins. Thus landscapes in the remote interior of the continents and on regional watersheds particularly in West Africa not subject to repeated erosional stripping are characterized by lateritized plains which have survived in their present form since the Tertiary subject to continuous chemical weathering and without any serious erosion. In contrast, the stair case like surfaces closer to the coast have experienced repeated deep weathering and erosional stripping of the weathered material with the subsequent exposure of wide areas of the weathering front on the different surfaces. In such landscapes, with channel incision, the water table can migrate downwards, and where it is frequently renewed, weathering penetration especially beneath the interfluves is facilitated. As a result the current weathering front is not parallel with the surface configuration, but is deeper under the interfluves and relatively shallow under the river channels (Fig. 11) as observed in many parts of West Africa (Ruddock, 1967, Thomas 1966, 1974; Jeje 1970, 1973, 1982; Faniran and Omorinbola, 1980).

As shown by Thomas (1965), two patterns of uplift which can produce different results can be envisaged; rapid but periodic uplifts, and slow but continuous uplift.

Given the tectonic movements and the cymatogenic warping, tilting and uplift of the coastal margins of continental shields during the Pliocene (King, 1962), landscapes in such areas would be subjected to repeated deep chemical weathering and erosional stripping so that they would be characterized by bare exposed rocks in between zones of deep weathering. With this geomorphological history, the rock outcrops in the form of inselbergs, tors etc. will become more and more emphasized but some through fluvial erosion, exfoliation and collapse following the opening up of formerly tightly closed joints will be destroyed.

As emphasized by Wayland (1947), under conditions of slow but continuous uplift, erosional stripping can proceed at equal pace with intense chemical weathering so that while

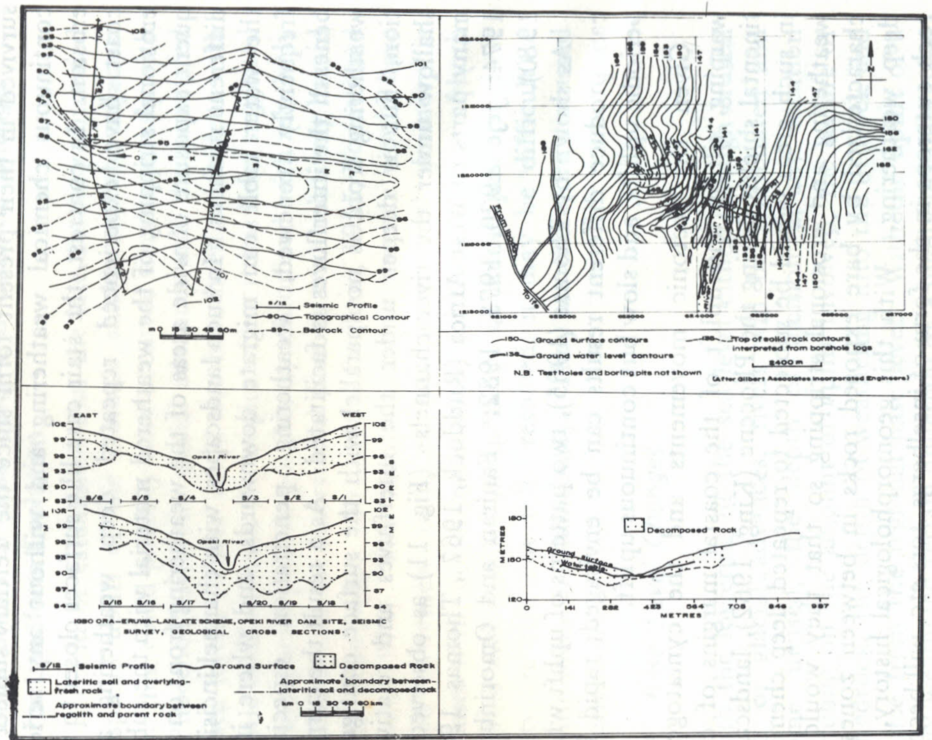


Fig. 11 Pattern of deep weathering in the basement rocks Southwestern Nigeria

the entire terrain undergoes a general lowering, few rock outcrops will be evident, and the landscape may exhibit thick laterite cover as envisaged by Trendall (1962) and De Swardt (1946) in explaining the occurrence of thick laterite cover in the humid tropics. Both scholars concluded that most of the iron in the laterites has been derived *in situ* from rocks removed in the process of surface lowering either as a result of solution at depth and physical erosion at the surface (De Swardt) or through eluviation and flushing out of materials from the pallid zone leading to a slow and imperceptible settling of the laterite over long periods of time (Trendall). However, as shown by Thomas (1965), since surface erosion would be at the expense of the laterite crust, this would inhibit the thickening of the laterite from below; also the mechanism for any significant removal of material from beneath the laterite sheets by soil water is difficult to envisage. It is therefore hard to see how the hypotheses of Trendall (1962) and De Swardt (1964) can be sustained.

If however the arguments of Trendall and De Swardt are valid, the implications are that the lateritized plains in the continental interiors which are believed to have been preserved in the absence of serious fluvial erosion could have formed as a response to falling base level occasioned either by gradual uplift or slow, sea level withdrawal in which case, such plains with their overlying laterites may represent products of several phases of uplift and still stand, during which the laterite deposit has survived over wide areas to impose, as observed by Thomas (1965 p. 128), a deceptive simplicity on a complex landscape. That this situation may not be readily achieved, however, is indicated by Thomas's (1965) reference to the presence of more than 90m of weathering beneath ridges capped by laterites standing 61–91m above the stream channels in parts of Serro do Navio district of Brazil, evidence of the persistence of laterite deposits and their survival without marked lowering during phases of down cutting in adjacent stream valleys.

Deep weathering may or may not always keep pace with increased rates of surface erosion following repeated uplifts, so that varying proportions of the weathering front especially in the cratonic shields may be exposed in many areas. The pattern of differential exposure controls the distribution of laterites and as seen earlier results in a variety of types of etchplains (Fig. 12) (Thomas, 1965, 1974; Jeje, 1970; Faniran and Jeje, 1983).

The genetic relationship between these plains is well demonstrated in parts of western Nigeria (Fig. 12) (Thomas 1965, p. 138, 1969 p. 138). The highest and oldest laterized plains lying between 450 and 530m and between 600 and 680m are well preserved on the watershed between the Niger and the Gulf of Guinea. The progressive stripping of the plains during later erosional cycles appears to have been accelerated by the cymatogenic arching and tilting of the southern part of the area towards the coast in the Pliocene-Pleistocene. This together with the Pleistocene-Holocene climatic changes has possibly led to the evolution of different types of stripped etchplains at lower levels ranging from 390m to 180m and below all over south western Nigeria. The particular type formed in any locality depends on the lithology.

3.4.2 Climatic Changes

It is generally believed that the warm humid periods with high incidence of rainfall was marked by 'biostasy' characterized by deep chemical weathering, pedogenesis involving the development of soil profiles, faunal pedoturbation, mobilization of iron and other elements, recementation of lateritic crust and gravel, fluvial erosion in channels and the evacuation and or reworking of pre-existing alluvial deposits and the scouring of bedrocks where exposed. A change towards aridity which is normally characterized by a decline in vegetal cover gives rise to 'rhexistasy' marked by disequilibrium, instability and surface erosion through widespread rejuvenation, gullying, erosional stripping of valley

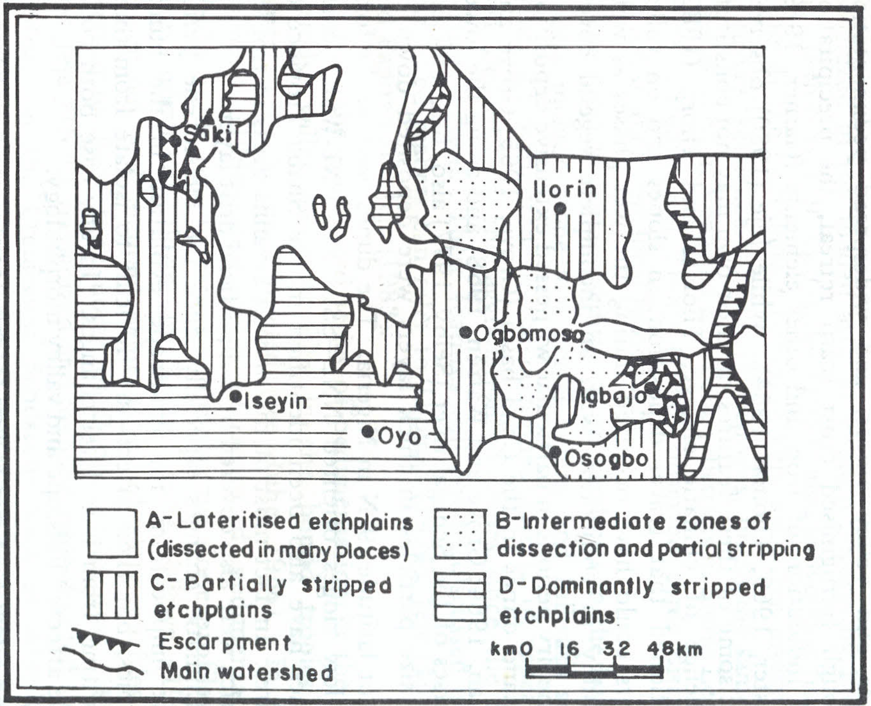


Fig.12: Varieties of Etchplains around the primary watershed in South-western Nigeria

sides and hillslopes to reveal core boulders, rock slabs and inselbergs, disruption of lateritic crusts, deposition of colluvial and alluvial sediment on hillfoot sites, hillslopes, valley heads and valley floors, and widespread pedimentation through ferruginised crust scarp retreat, the precipitation and induration of iron and other elements (Garner, 1969; Folster, 1969, Thomas 1984). While Jeje (1980) observed that some of these features on their own may not constitute evidence of climatic change, Thomas and Thorp (1980) cautioned that gravel deposition on slopes and on valley floors could have occurred during the wet phases as well, possibly in conjuction with an incomplete vegetal cover.

The dry periods in particular witnessed extensive deposition of sand dunes in the Chad basin (Grove, 1965; Grove and Pullan, 1964; Grove and Warren, 1968) and along the lower courses of the Senegal river (Selby, 1977) also, fine sand and silt size particles in thick layers were deposited down to about latitude 9°N in Nigeria. The dunes were in the form of low ridges oriented NNL–SSW and ENE-WSE. Such dunes have also been identified in the Shaba Province of Zaire. In fact most of the present savanna areas in tropical Africa were also covered by a superficial drift layer.

Climatic changes especially since the Pleistocene period have implications for landscape evolution in the humid tropics, but their effects are difficult to isolate from those resulting from base level changes. In any case both could have affected hillslope and valley morphology.

3.4.3 Hillslope and Valley Morphology

The repetition of slope degradation and aggradation due to changes in either climate or base level has led to the accumulation of several sequences of deposition on hillslopes and on lower flat surfaces. Butler (1959) recognized six such strata on hillslopes in south eastern Australia while the stratigraphy of an exposed soil at the head of a bog burst at Chelinda in Malawi reveals about the same number (Shrodder, 1976). De Villiers (1965) recognised five distinct strata in Natal. About the same number was recognised north of the Niger-Gulf of Guinea watershed in western Nigeria by Folster (1969). Bruckner (1955), however, recognized only three distinct strata in the lateritic deposits of south eastern Ghana, more or less the same number recognized in the Ibadan area of western Nigeria by Burke and Durotoye (1971). Garner (1968) also shows that floodplains in the Cordillera Oriental in Peru are often underlain by several sequences of alluvial deposits, much the same as those studied in Yengema and Tongo districts in Sierra Leone where Thomas and Thorp (1980) observed three distinct alluvial strata in the local floodplains.

The most important sediments on hillslopes in the humid tropics include stone and gravel layers, and hillwash sediment, all attributed to the combined effects of repeated past degradation and aggradation of slopes since the late Tertiary period. These features will not be discussed here. Interested readers can refer to Thomas (1974), Jeje (1980), and Faniran and Jeje (1983).

Given the postulated series of pedimentation in the dry periods, valley slope profiles in the humid tropics are expected to be multi-faceted (see Ruhe, 1956). In fact Folster's (1969) description of repeated pedimentation ideally leads one to expect multi-concave slope profiles in areas north of Ilorin in Kwara state. Wigwe (1966) recognized and mapped these types of slope profiles on Cretaceous Sandstone north of Ilorin, while Moss (1965) and Jeje (1970) recognized and mapped multi-faceted slope profiles on the Cretaceous Sandstone west of Abeokuta (Fig. 13). These slope profiles contain up to 5 slope units. Of those measured, the slope segment next to the stream channel is 15–40m long and inclined at 16°–45°. The succeeding valley bench often covered by detrital ferruginous crust and other colluvial material is 80–170m long and inclided at 1°–6°. This is followed by another slope unit 120–210m long, inclined at 2°–7° which is in turn followed by a steep debris slope inclined at 10°–20°. The

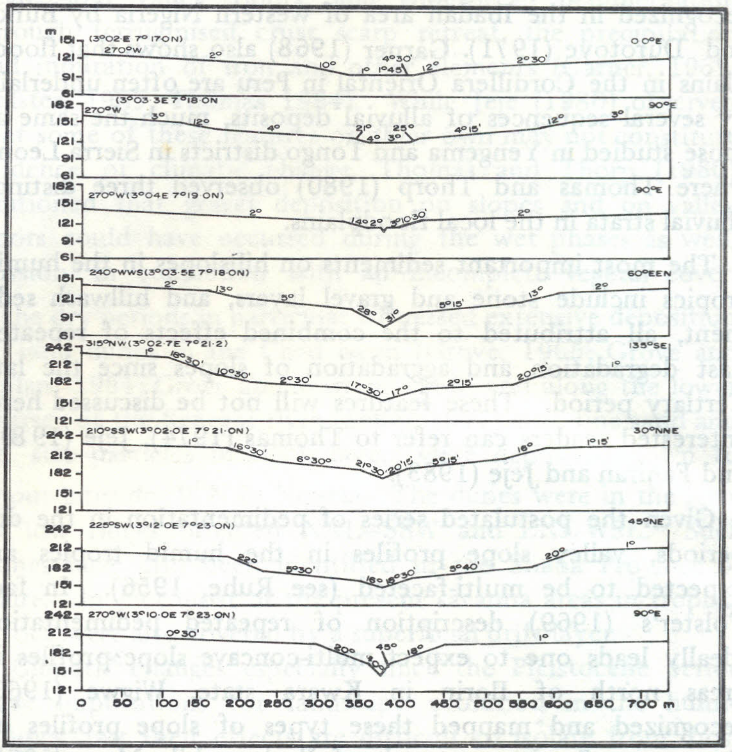


Fig. 13 Valley cross sections, Ayetoro area, southwestern Nigeria(Jeje 1970)

upper part is marked by outcrops of ferruginous crust up to 15m thick (Fig. 14). The crest is typically flat. De Swardt (1953) recognized such multi-faceted valley slopes along the Kaduna River.

Such series of complex slope profiles are also fairly common on the basement complex rocks at least in the forest area of south western Nigeria. Field measurements in the Opa basin in the Ife area on an undulating plain underlain by weathered basement complex rocks show that 36 percent of the measured valley slopes are dominated by simple profiles while the rest are multi-faceted except that the changes in slope angles are no more angular (Jeje, 1976). Also of the 82 valley and hill slopes measured in the Xavantina and Cachimbo areas of Brazil by Young (1970) about 40 percent are multi-faceted. Kessel (1977) also observed that valley slopes in the savanna area of Rupununi in Guyana are multi-concave and multi-faceted. Kadomura (1977) observed much the same features in the savanna area of the Cameroon Republic.

However, as already indicated, it is possible that these multi-faceted valley slopes could have resulted from the combined effects of climatic change, lowering of the regional base levels, and the rapid incision of the streams as a result of the world wide low sea levels associated with the major glacial advances. In fact, Moss (1965) attributed such multi-faceted profiles on the sedimentary rocks of south western Nigeria to repeated base level lowering during the Pleistocene.

4.0 RELATIONSHIPS BETWEEN PRESENT LANDFORMS AND CONTEMPORARY PROCESSES – LANDFORM STABILITY AND INSTABILITY

Certain landforms resulting from deep chemical weathering and subsequent erosion, such as tors, corestones, inselbergs, duricrust capped hills, pediments, duricrust pavements, although generally characteristic of the tropics, have also been observed in other climatic zones ranging from the temperate to the arid. Since there is evidence to suggest that

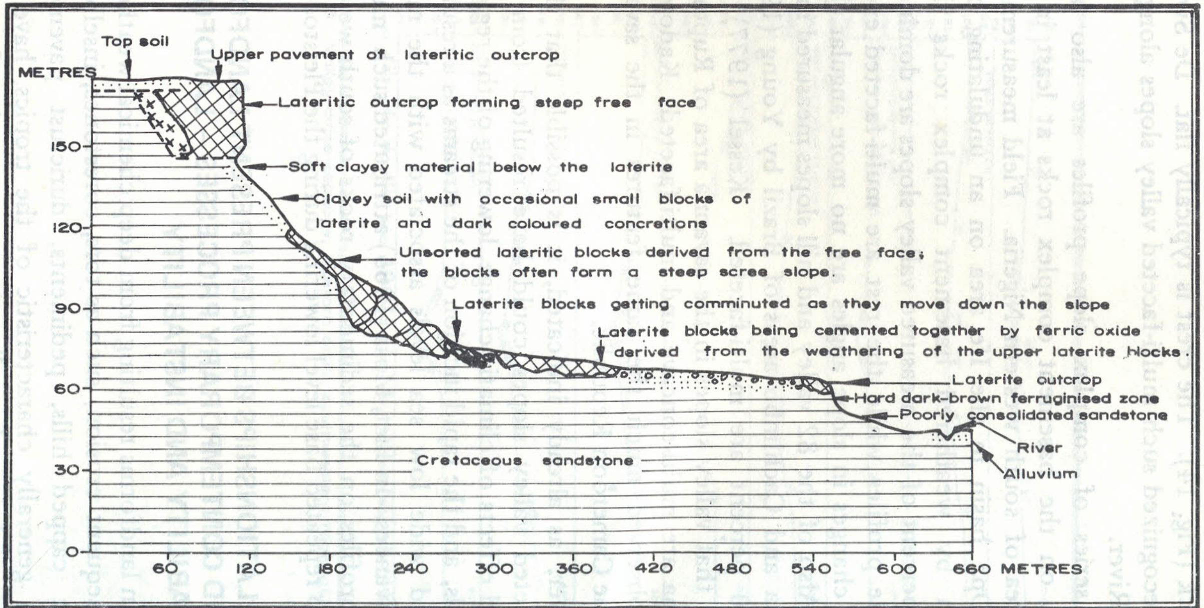


Fig. 14 Hillside morphology and occurrence of ferruginised crust in Ayetoro area of southwestern-Nigeria

climate has changed several times in all the present climatic zones through the Tertiary into the Quaternary, it is uncertain under which climate these landforms evolved either in the tropical or extra-tropical areas. If they evolved under past dry climatic conditions, they can be regarded as relict landforms under the present humid warm climatic conditions.

The wide saucer-shaped, alluviated, marshy valleys with poorly defined river channels observed in Malaysia (Swan, 1970), in Malawi and in the Mato Grosso area of Brazil (Young, 1969, 1970) and in parts of south western Nigeria (Wigwe, 1966 and Jeje, 1970), are also believed to have been formed under past drier conditions. If this is the case, the implication is that most landforms in the humid tropical environment are indeed relict, and are thus inherited features which are now adjusting to the present climatic conditions.

However, it has also been contended that some of these landforms evolved under climatic conditions not exactly dissimilar from those of today. Features such as corestones, tors, and inselbergs though they can be formed through deep chemical weathering and erosion, are azonal, and relate more to structure than climate; hence they do not serve as indicators of the climate under which they were formed. Also valley form is not a good climatic indicator. For instance Bik (1966) observed V-shaped valleys supposedly formed under humid conditions in close contiguity to saucer-shaped wide valleys putatively formed under semi-arid conditions in an area in New Guinea. Recent investigations in various climatic environments have also shown that pediments can be formed under any type of vegetal cover. Bik (1966 p.41) reports that in parts of New Guinea covered by rainforest, slopes are actively wasting back both in volcanic terrain and in areas of arenaceous and argillaceous rocks so that pediments are actively developing under the forest. Backwearing and pedimentation appear to be active at the base of the forest-covered Cretaceous scarp in south western Nigeria (Jeje, 1972). These processes are also very active in the dry forest in the Mato Grosso in Brazil where the sandstone overlying shale is being actively eroded and subject to parallel backwearing (Townshend, 1970, pp. 394-396). In fact backwearing appears unconfined to the tropical environment as it has been observed by Dury (1972) in the humid temperate environment of southern England under a forest cover. King (1957) even conceeded that pedimentation can take place under any climatic condition including the rainforest climate provided the required conditions were satisfied. Thus pediments in the humid tropics are not necessarily relict.

Much has been written about the morphology and formation of laterites (ferricretes) with the emphasis that they are formed under alternating periods of humidity and aridity, and are thus relict wherever they are found under the rainforest. The formation of laterite will not be discussed in detail here, suffice it to observe along with Young (1976, pp. 154-155) that "it is not true as is sometimes held, that a savanna climate is necessary for laterite formation. Whilst some laterites of the rainforest may be relict, others are forming at present". While the process of iron mobilization and precipitation in the soil is undoubtedly favoured within the zone of groundwater fluctuation in the savanna zone, or as a result of climatic fluctuations, it is equally true that the rainforest area is not a zone of static water table so that it can also favour the formation of laterites.

Thus both Scrivenor (1909) and Harrison (1934) showed that laterites could form where the rainfall is continuous throughout the year provided the rains are separated by short dry spells. Young (1976) doubts the hypothesis that iron deposition and hardening are simultaneous in which case the short dry seasons prevalent in the rainforest area could be sufficient for the formation of laterite. Townshend (1970) shows examples of contemporary formation of laterite in a part of the Mato Grosso of Brazil in a horizontally bedded Palaeozoic sanstone dissected by valleys. Near the upper margins of the valley sides, steps and benches occur on which laterite is continuously outcropping as the valley is eroded. On tracing the laterite back to the plateau with an auger, it disappeared within 20m of the edge of the outcrop. The contemporary formation of groundwater ironstone observed by Folster (1969) and Smyth and Montgomerry (1962) in parts of western Nigeria also shows that laterites in the forest areas are not necessarily relict features.

Thus it is possible that most landforms in the humid tropics, though exposed to the Pleistocene-Holocene climatic fluctuations, have evolved under climatic influences not entirely dissimilar from those occurring today. If the landforms were affected by these climatic fluctuations, they have since adjusted to the present warm humid conditions.

In the absence of any serious contemporary tectonic activities, rapid base level lowering and drastic changes in the prevailing climatic conditions, the landscape appears to be in a delicate equilibrium with the present climatic environment. Deep weathering now possibly exceeds regolith removal through the various agencies of chemical and physical denudational processes. Most hillslopes covered by dense vegetation whether forest or savanna are only experiencing very slow geological erosion. Duricrust scarps, blocks and rubble on hillslopes are immobilized and colonized by dense vegetal cover as evident on valley slopes in many areas. Old gullies are also stabilized and colonized by dense vegetation. Most exposed rock outcrops are experiencing thin sheeting induced by hydro-thermal influences. Linear erosion except very locally is rather weak as tropical rivers are not exactly noted for their erosional ability due to the absence of large amounts of coarse sediments. This arises from the thorough decomposition of the rocks so that the sediments reaching the rivers through the process of slopewash and creep are often completely devoid of coarse load (Thomas, 1974, pp. 119-121; Twidale, 1976, p. 273).

This stability, however, has been shattered wherever there have been serious anthropological interferences with the vegetal and soil cover. The most important anthropological factors include heavy population pressure on the land and the consequent devegetation, overcultivation, overgrazing, poor cultivation techniques and very poor engineering work. All these have combined to trigger severe gullying and slope failure in many parts of the humid tropics, and to cause landscape instability. About 16,700 km^2 is affected by serious forms of accelerated erosion in eastern Nigeria alone. Severe gullying have also been reported from Kenya, Malawi, Zimbabwe, Tanzania, the heavily populated island of Java and Malaysia. Douglas (1967a and b) shows the effect of vegetal cover on sediment yield in the Cameroon Highlands of Peninsular Malaysia. In a catchment where 94 percent of the natural vegetation was intact, sediment yield was 21.1m^3/km^2/yr, but was 103.1m^3/km^2/yr in a catchment with 64 percent vegetal cover. Identical results were obtained from the Owena basin in south western Nigeria (Ogunkoya and Jeje, in press).

As already indicated, obviously relict landforms are important elements in the present savanna areas all over the humid tropics. Such landforms include lateritic scarps on hillslopes, series of transverse dunes and an extensive cover of medium to fine sand drift. The latter features which were produced under obviously drier climates being basically unstable under present climatic conditions are experiencing serious transformations. The dunes which have been subject to repeated humid conditions are undergoing weathering and the development of lateritic profiles. They are now colonized by thickets and shrubs with a ground flora of tufted grasses. Where the vegetation cover has been removed they have been seriously eroded. The drift covered areas are now subject to intense sheet and gully erosion in several parts of northern Nigeria, most especially in the Kubani basin in the Zaria area where veritable badland terrains are very common. The drift materials are also subject to intense gullying in Shaba Province of Zaire.

5.0 IMPLICATIONS FOR MANAGEMENT

The modes of landscape evolution in the humid tropics have practical implications for land resources evaluation and management. The humid tropical region is among the least developed areas in the world but many of its countries are in a hurry to develop. In the absence of clear and detailed information about its natural resources, development plans are often based on guesses and estimates. In most of these countries, for example Nigeria, emphasis is on the improvement of agriculture and ancilliary facilities such as roads and water supply. In order to plan a rational land development programme, land evaluation studies are often commissioned.

Land evaluation is the term used to describe the process of assessing the productivity and potential of land for agriculture, foresty, water resource development, settlement and resettlement schemes, and recreation. The word 'land' embraces rocks, landform, soils, climate, vegetation and water. Extensive studies of the land with a view to its evaluation for resource exploitation have been carried out by the British Directorate of Overseas Surveys, Land Resources Development Centre in Nigeria, Malawi, Kenya, Botswana, Solomon Islands, Fiji, and Vanuatu; and by the Australian C.S.I.R.O. Division of Land Research and Regional Survey in parts of Australia and Papua New Guinea. These surveys which adopted the landscape approach of terrain classification were based on different sizes of land units – the land element, the land facet, the land system, the land region, the land province, the land division and the land zone. The land systems and facets are the most widely used units.

The land system is defined as "an area or group of areas throughout which there is a recurring pattern of topography, soils, and vegetation" (Christian and Stewart, 1953, p. 76) recognizable on medium scale aerial photographs and mappable at 1:250,000 to 1:1,000,000 scales. In emphasizing the geomorphological base, Christian (1957 p. 76) remarked that "a simple land system is a group of closely related topographic units usually small in number that have arisen as the products of a common geomorphic phenomenon. The topographic units thus constitute a geographically associated series and are directly and consequently related to one another". In general, the land system approach views the entire terrain with regard to the whole range of possible land use interests. Thus Bawden and Tuley (1966) recognized and mapped thirty land systems in the Sardauna Province of Nigeria and described the geology, physiography, soils, climate, vegetation and the current use in each land system, and then assessed the land's suitability for various agricultural development. Aitchison *et. al.* (1959) also recognized five land provinces in north eastern Nigeria and subdivided them into land regions and then into land systems each of which was described in terms of geology, physiography and soils, and the resource potential with regard to agricultural development.

Some scholars, however, believe that the land facet is a more appropriate unit for terrain evaluation than the land system (Beckett and Webster, 1965). The land facet is defined as "one or more land elements grouped for practical purposes, part of a landscape which is reasonably homogenous and fairly distinct from surrounding terrain" (Christian and Stewart, 1964). It is mappable at 1:10,000 to 1:80,000 scales. The land facets are believed to have distinctive patterns of slope, vegetation types and ground tones on aerial photographs which are an indication of internal soil-drainage conditions. Thus as a result of its uniformity, the land facet is often preferred as a basis for soil mapping. Murdoch *et. al.*(1976) applied it in mapping soils in the savanna area of western Nigeria.

However, this approach to terrain classification poses several problems. The most important is that as land system mapping is on the basis of pattern recognition from aerial photographs, in the absence of no clear cut diagnostic features for recognising the different land systems, mapping cannot be successfully replicated; as many versions of the land system map of the same area will be produced as there are operators. Also in the absence of any rigid criteria for defining and delimiting these land systems, they are often arbitrarily defined according to the scale of the survey, thus units recognised in the field vary in complexity from simple land elements to more complex land systems such as a whole mountain system (Thomas, 1969). Thus the conceptual basis of land system mapping, especially the problem of defining and mapping these units of the environment, is still to be clearly resolved.

The geomorphic principles of land system mapping by the C.S.I.R.O. as summarised by Mabbutt and Stewart (1963) include:

morphologic –	based upon external form, relief and slope categories in particular;
genetic –	based on common origin, usually according to lithology in erosional systems or to a common process in depositional systems;
chronologic –	the relative and possibly absolute ages of land surfaces are recognized, and inherited features of former conditions are identified;
dynamic –	the mode and rate of landscape change and the recognition of dominant formative processes.

In reality, these principles are not easy to follow and applying them is extremely tedious and time consuming. In fact, it is doubtful if they can be followed on the scale of land system mapping at 1:500,000. For example, the precise measurement of form is only possible on large scale maps, as the level of generalization on small scale, maps will be unacceptable.

The above emphasizes the need to establish fundamental principles that will govern terrain classification. The first step in setting up such principles is to select one distinct element of the environment for mapping. Such an element must have a high degree of correspondence with the other elements of significance to land development, or the correspondence must be predictable from a knowledge of the chosen element. As the landform is the only element that fulfils these conditions, "a correct interpretation of the landform in terms of its genesis and sequence of development provides the understanding whereby the form units within an area may be related to another in terms of its formative processes" (Thomas, 1969, p. 114). Having decided on these geomorphological entities, the next stage is to define them so rigorously and in such a clearly circumscribed manner that they can be readily recognized at different places (as attempted by Thomas, 1969, p. 118). Their genesis and relations with neighbouring landforms should also be clearly defined.

This was the approach adopted by Mabbut (1962) in his study of Alice Springs Area in Australia where, basing his classification on lithology and geomorphic history, he recognized four main classes of land units:

1. Erosional Weathered land surface
2. Partially Dissected Erosional Weathered Land Surface
3. Erosional Surfaces formed below Weathered Land Surface
4. Depositional Surfaces.

Eighty-eight land systems were recognised within these categories and grouped at a lower level of complexity according to their dominant morphological or lithological characteristics.

This type of classification not only establishes relationships between adjacent land systems, it also enhances a certain degree of prediction between the land systems, the soils, and other properties of the land surfaces. It also facilitates the mapping of genetically defined and related landform units at various scales. The system can be applied in the humid tropics wherever it is possible to recognize such genetically related landform systems which if once defined and described from particular areas (see Thomas, 1965, 1969; Jeje, 1970), can be recognized on the basis of similar criteria elsewhere.

5.1 Etchplains and Soils

As already emphasized in this lecture, deep chemical weathering and the development of duricrust are important elements of the geomorphology of the humid tropics especially in areas associated with crustal stability. Also as already indicated such deeply weathered terrain can be subject to erosional stripping following base level or climatic changes to produce a suite of distinctive landform systems which can be related, morphologically described and classified in specific terms. Thus based on this reality of deep weathering and subsequent stripping a variety of etchplains have been recognized on the basement complex rocks of south western Nigeria which can also be recognized in similar areas in the humid tropics. As already described, these are:

Lateritized etchplains
Dissected, lateritized etchplains
Partially stripped etchplains
Dominantly stripped etchplains/etchsurfaces
Dominantly stripped and incised etchsurfaces

The aggraded etchplain can be recognized where the plain is covered by aeolian drift or by alluvium. These etchplains and etchsurfaces can be recognized partially on the basis of lithology, because while the acidic igneous and metamorphic rocks give rise to rocky terrains with pockets of deep weathering zones between the outcrops, and thus form stripped etchplains, basic rocks which are readily lateritized often form lateritized plains. Similarly the ferruginised sandstones readily give rise to lateritized plains.

Based on this observation, and on the work of Moss (1968), and the soil mapping exercise by Smyth and Montgomery (1962), as a first approximation the following relationship in Table 4 can be suggested between soils, lithology and etchplains in Central Western Nigeria.

TABLE 4

Tentative Association between Soils, Lithology and Etchplains in Central Western Nigeria

Catena type (Moss (1968)	*Lithology*	*Soil Association* Smyth and Montgomery, 1962)	*Type of etchplain*
Catenas with rock outcrops	Quartzite and quartz schist	Okemesi	Dominantly stripped
	Sericite schist	Mamu	Dominantly stripped
	Coarse grained granitic rocks and coarse grained gneisses	Iwo	Dominantly stripped and incised
	Medium grained granitic rocks and medium grained gneisses	Ondo	Partially stripped
Catenas with hard laterites	Amphibolites and different types of basic rocks	Itagunmodi	Dissected
Catenas without rock outcrops or hard a laterite	Fine grained biotite gneisses and schists	Egbeda	Partially stripped
Soil associations on relatively flat land at high levels associated with lateritized plains covered or uncovered by drift, and at low levels associated with alluviated surfaces	Different acidic basement rocks overlain by widespread ferruginised crust	Gambari series	Lateritized
	Flood plain alluvium	Jago	Aggraded

With further refinement, this scheme can be applied in mapping the broad land units and soils in most areas of the humid tropics.

6.0 CONCLUSION

The organization of landforms into land systems on the basis of genetic factors such as lithology and formative processes like deep weathering and erosional stripping of the weathered material to form a related series of etchplains appears to constitute an important principle in a broad classification of the humid tropical terrain into mappable units; more so where such units can be shown to have associations with soil development and the other elements of the land. Such maps which can be produced from various imageries where topographic mapping at a medium scale is still unaccomplished can be very useful for development and land management purposes.

Although Nigeria is fairly covered by 1:50,000 topographic maps and 1:40,000 airphotos, land unit mapping with the aim of evaluating the units for various development purposes has not been carried out in any systematic manner. Up till now, efforts have only been concentrated in Gongola State and parts of the Benue and Plateau States by the British Directorate of Overseas Surveys Land Resources Development Centre and other local and foreign agencies. As these agencies based mapping on field work and aerial photograph analysis both of which are extremely tedious, progress has of necessity been very slow. However, this inadequacy can now be remedied by the use of S.L.A.R. (Side Looking Airborne Radar) imagery recently procured by the Federal Department of Forestry. As this imagery with its synoptic perspectives can provide more information on the geology and landform complexes than the topographic maps and the available airphotographs, the task of carrying out a systematic land unit mapping and the evaluation of the productive capacity of all parts of the country is made easier. This poses a challenge which all indigenous geomorphologists and related scientists must take seriously so that at no distant date, the land unit and land evaluation maps of Nigeria will become available for various planning purposes.

7.0 ACKNOWLEDGEMENT

I want to express my posthumous but deep gratitude to the late Prof. H. A. Oluwasanmi who initiated the staff training and development programme through which the foundation of my career in this University was laid. I am also grateful to members of my nuclear family for their forbearance and tolerance.

REFERENCES

Aitchison, P. J. and Glover, P. E.: *The Land Resources of North East Nigeria, 3.* The Land Systems, L.R.D./D.O.S. Tolworth, Surrey, England.

Antevs, E. (1928): *The Last Glaciation, American Geographical Society Research Series* 17.

Aubreville, A. (1962; Savinisation tropicale et glaciations quarternaires, *Adansonia,* N. S. 2(1): 16–24.

Bawden, M.G. and Tuley, P. (1966): *The Land Resources of Southern Sardauna and Southern Adamawa Provinces, Northern Nigeria,* LRD/DOS,2, Tolworth, Surrey England.

Beckett, P. H. T. and Webster, R. (1965): *A Classification System for Terrain,* Report Military Engineering Experimental Establishment 872, Christchurch.

Bigarella, J. J. (1975): *'Brazil' in The Encyclopedia of World Regional Geology, Part I, Western Hemisphere,* R. W. Fairbridge (ed), J. Wiley, London.

Bik, M.J.J. (1966): Structural geomorphology and morphoclimatic zonation in the Central Highlands, Australia, New Guinea. in: J. N. Jennings and J. A. Mabbott (eds.), *Landform Studies from Australia and New Guinea,* Cambridge University Press, Cambridge.

Bishop, W. W. (1966): Stratigraphic geomorphology: A review of some Eastern African landforms, in G. H. Dury (ed.) *Essays in Geomorphology,* Heinemann, London, 139–176.

Bonatti E. and Gartner, S., (1973): Carribean climate during Pleistocene Ice Ages, *Nature,* 244, 563–565.

Bremer, H. (1985): Soil and slope development in the wet zone of Sri Lanka, in I. Douglas and T. Spencer (eds) *Environmental Change and Tropical Geomorphology,* George Allen & Unwin.

Brooks, C. E. P. (1948): *Climate through the Ages,* Dover, New York, N. Y. 2nd ed., 329–341.

Brown, D. A. (1975): "Australia' in R. W. Fairbridge (ed) *op. cit.*

Bruckner, W. D., (1955): The mantle rock (laterite) of the Gold Coast and its origin, *Geologie Rundschau,* 43; 307–327.

Budel, J. (1957): Die *Doppelten Einebnungsflachen* in den feuchten Tropen, *Zeitschrift fur Geomorphologie,* N. F. 1, 201–228.

Budel, J. (1965): Die relief typen der Flachensput-zone Sud-Indiens am Ostabfall Dekans gegen, Madras. *Coll. Geog.* Bonn. 8.

Burke, K. and Durotoye, A. B. (1971): Geomorphology and superficial deposits related to late Quaternary climatic variation in South Western Nigeria, *Zeitschrift fur Geomorphologie,* 15(4) 430–441.

Burke, K., Durotoye, A. B., and Whiteman, A. J. 1971): A dry phase south of the sahara 20,000 years ago, *Archaeology,* 1, 1–8.

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

Christian, C. S. (1957): The concept of land units and landsystems, *Proc. 9th Pacific Scientific Conference,* 1957, 20, 74–81.

Christian, C. S., and Stewart, G. A. (1953): *Survey of the Catherine–Darwin Region,* 1946, Land Resource Series C.S.I.R.O. Australia, I.

Clarke, J. I. (1966): Morphometry from maps in G.H. Dury (ed.) *op. cit.*

Clarke, J. I. and Orrell, K. (1958): *An Assessment of some Morphometric Methods,* Dept. of Geog. Durham Colleges, University of Durham, Occasional Papers, Series, No. 2.

Clayton, W. D. (1958): Erosion surfaces in Kabba Province, Nigeria, *Journal West African Science Association* 4, 141–9.

Daly, R. A. (1934): *The Changing World of the Ice Age,* Yale University Press, New Haven.

Davis, W. M. (1899): The geographical cycle, *Geographical Journal,* 14, 481–584.

Davis, W. M. (1900): Glacial erosion in the valley of the Ticino, *Appalachia,* 9, 136–156.

Davis, W. M. (1905): The geographical cycle in an arid climate, *Journal of Geology* 13, 381–407.

De Villiers, J. M. (1965): Present soil forming factors and processes in tropical and substropical regions. *Soil Science* 99; 50–57.

De Swardt, A.M.J. (1946): The recent erosion history of the Kaduna valley near Kaduna township, *Annual Report Geological Survey of Nigeria,* 33–45.

De Swardt, A. M. J. (1953): The geology of the area around Ilesha, *Geological Survey of Nigeria,* Bulletin 23.

De Swardt, A.M.J. (1964): Laterisation and landscape development in parts of equatorial Africa. *Zeitschrift fur Geomorphologie,* 8, 313–333.

Donn, W. L., Farrand, W. L. and Ewing, M. (1962): Pleistocene ice volumes and sea level lowering, *Journal of Geology,* 70, 206–214.

Doornkamp, J. C. and King, C.A.M. (1971): *Numerical Analysis in Geomorphology,* Arnold, London.

Douglas, I. 1967a): Natural and man made erosion in the humid tropics of Australia, Malaysia and Singapore, in *Symposium on River Morphology,* General Assembly of Bern.

Douglas, I (1976): Man, vegetation and the sediment yields of rivers, *Nature,* 215 (No. 5104), 925–928.

Douglas, (1980): Climatic geomorphology. Present-day processes and landform evolution: Problems of interpretation. *Zeitschrift fur Geomorphologie* NF suppl. 36, 27–47.

Douglas, I. and Spencer T. (1985): *Environment Change and Tropical Geomorphology* George Allen & Unwin ppl 378.

Dury, G. H. (1972): A partial definition of the term *'pediment'* with field tests in humid climate areas of southern England, *Transaction Institute of British Geographers,* 57, 139–152.

Eden, M. J. (1971): Some aspects of weathering and landform in Guyana (formerly British Guiana), *Zeitschrift for Geomorphologie,* N.F. 15(2) 181–98.

Emiliani, C., (1955): Pleistocene temperatures, *Journal of Geology,* 63, 538–578.

Eyles, R. J. (1971): A classification of West Malaysia drainage basins, *Annals Association of American Geographers,* 61, 460–7.

Fairbridge, R. W. (1961): Eustatic changes in sea level, *Physics and Chemistry of the Earth,* Series 4, 99–185.

Fairbridge, R. W. (1964): African ice age aridity, in A.E.M. Nairn (ed.). *Problems in Palaeoclimatology* Interscience, London, 356–360.

Fairbridge, R. W. and Finkl., C. W. Jnr. (1980): Cratonic erosional unconformities and peneplains. *Journal of Geology* 88, 69–86.

Faniran, A. and Jeje, L. K. (1983): *Humid Tropical Geomorphology,* Longman, London.

Faniran, A. and Omorinbola, E. O. (1980): Evaluating the shallow groundwater reserves in Base Complex areas: A case study of south western Nigeria, *Journal of Mining and Geology,* 17(1), 65–79.

Finkl, C. W. Jnr. (1979): Stripped (etched) land surfaces in south western Australia. *Australian Geogr. Studies* 17 (1) 33–52.

Finkl, C. W. Jnr and Churchward, H.M. 1973): The etched landsurfaces of south western Australia. *Journal Geol. Society Australia* 20, 295–307.

Folster, H. (1969): Slope development in south western Nigeria during late Pleistocene and Holocene: *Gottinger Bodenkundlische Berichte,* 10, (3) 3–56.

Folster, H., Moschrefi, N. and Ojanuga, A. G. (1971): Ferralitic pedogenesis on metamorphic rocks, south western Nigeria, *Pedologie* 21 (1); 95–124.

Fredoux, A. (1978): *Pollens et spores d' especes actuelles et Quaternaries des regions peri-langunaires de la Cote d' Ivoire,* thesis, Montpellier.

Garner, H. P. (1968): Tropical weathering and relief in R. W. Fairbridge (ed) *Encyclopedia of Geomorphology,* Reinhold, New York.

Geyl, W. F. (1961): Morphometric analysis and the world wide occurrence of stripped erosion surfaces, *Journal of Geology,* 69; 388–416.

Gribbin, J. and Lamb, H. H. (1978): Climatic change in historical times, in, J. Gribbin (ed): *Climatic change,* Cambridge University Press, Cambridge, 68–82.

Grove, A. T. (1958): The ancient erg of Hausaland and similar formations of the south side of the Sahara. *Geographical Journal* 125, 528–533.

Grove, A. T. and Pullan, R. A. (1964): Some aspects of the Pleistocene Paleography of the Chad Basin, in F. C. Howell and F. Bouliere (eds), *African Ecology and Human Evolution,* London University Press, London, 230–245.

Grove, A. T. and Warren, A. (1968): Quaternary landforms and climate on the south side of the sahara *Geographical Journal,* 134, 144–208.

Hall, A. M.; Thomas, M. F., and Thorp, M. B. (1985): Late Quaternary alluvia placer development in the humid tropics, the case of the Birim Diamond Placer, Ghana, *Journal Geological Society of London, 142, 777–787.*

Harrington, H. J. (1975): 'South America' in R. W. Fairbridge (ed), *op. cit.*

Harrison, J. B. (1934): *The Katamorphism of igneous rocks under humid tropical conditions,* Imperial Bureau of Soil Sciences, Harpenden.

Jeje, L.K. (1970): *Some aspects of the geomorphology of southwestern Nigeria,* Thesis, University of Edinburgh, Edinburgh (unpublished).

Jeje, L. K. (1972): Landform development at the boundary of sedimentary and crystalline rocks, in south western Nigeria. *Journal of Tropical Geography,* 34, 25–33.

Jeje, L. K. (1972): Pediments, *Nigerian Geographical Journal* 15 (1) 79–82.

Jeje, L. K. (1973): Landforms on the sedimentary rocks of south western Nigeria, *Journal of Tropical Geography,* 36, 31–41.

Jeje, L. K. (1976): Slope profiles from a humid tropical environment, the example of Opa Basin in Ife area, *Bulletin of the Ghana Geographical Association.* 18, 52–67.

Jeje, L. K. (1980): A review of geomorphic evidence for climatic change since the late Pleistocene in the rainforest areas of southern Nigeria, *Palaeogeography, Palaeoclimatology.* Palaeoecology, 31, 63–86.

Jeje, L. K. (1982): Some aspects of the geomorphology of Nigeria, in J. S. Oguntoyinbo, O. O. Areola, and M. O. Filani (eds.), *A geography of Nigerian Development.* 2nd edition, Heinemanns, Ibadan.

Kadomura, H. (1977): *Geomorphological studies in the forest and Savanna Areas of Cameroon,* an interim report of the Tropical African Geomorphology Research Project 1975/76, Sapporo, Japan.

Kendal, R. L. (1969): An ecological history of the Lake Victoria Basin, *Ecological Monograph* 39(2), 121–76.

Kessel, R. H. (1977): Slope runoff and denudation in the Rupununi savanna, Guyana. *Journal of Tropical Geography.* 44, 33–42.

King, L. C. (1953): Canons of landscape evolution, *Bulletin Geological Society of America.* 64, 721–51.

King, L. C. (1957): The uninformitarian nature of hillslopes, *Transactions Edinburgh Geological Society* 17, 81–102.

King, L. C. (1962): *The Morphology of the Earth,* Oliver & Boyd, Edinburgh.

King, C. A. M. (1974): *Introduction to Marine Geology and Geomorphology,* Arnold, London.

Kolla, V., Biscaye, P.E. and Hanley, A. F. (1979): Distribution of quartz in late Quaternary Atlantic sediments in relation to climate, *Quaternary Research* 11, 261–77.

Krook, L. (1975): 'Surinam' in R. W. Fairbridge (ed) *op. cit.*

Lamb, H. H. (1969): Climatic fluctuations, in: H. Flohn (ed): *General Climatology, 2 World Survey of Climatology* Elsevier, Amsterdam, 173–249.

Mabbutt, J. A. (1961): A stripped land surface in western Australia, Transactions Institute of British Geographers, *29, 101–14.*

Mabbutt, J. A. (1962): Geomorphology of the Alice Springs area in Perry, A. A. et. al. 1962, *Land of the Alice Springs Area, Northern Territory,* 1956–57, Land Resource Series CSIRO Australia, 6, 163–178.

Mabbutt, J. A. and Stewart, G. A. (1963): The application of geomorphology to resources surveys in Australia and New Guinea, *Revue Geomorphologie Dynamique,* 14, 97–109.

Macfarlane, M. J. (1969): *Lateritization and landscape development in parts of Uganda:* Thesis, University College, London.

Pugh, J. C. and King, L. C. (1952): Outline of the geomorphology of Nigeria, *South African Geographical Journal,* 24, 30–7.

Rhodenburg, H. (1969): Slope pedimentation and climatic change as principal factors of planation and scarp development in tropical Africa. *Giessener Geographische Schr.* 20, 127–133.

Rich J. L. (1938): Recognition and significance of multiple erosion surfaces; *Bulletin Geological Society of America* 49, 1695–1722.

Rickard, M. J. (1975): Australasia – regional review in, R. W. Fairbridge (ed) *op. cit.*

Ruhe, R. V. (1956): Landscape evolution in the High Ituri, Belgian Congo. Publications de *L'Institut National pour L'Etude Agronomique du Congo Belge* (INEAC), Serie Scientifique, 66.

Scholl, D. W. and Stuiver, M. (1967): Recent submergence of south Florida; a comparison with adjacent coasts and other eustatic data. *Bulletin Geological Society of America,* 78, 437–54.

Schwarzbach, M. (1963): *Climates of the Past,* Van Nostrand, New York, N. Y. 340 pp.

Scrivenor, J. B. (1909): The use of the term 'Laterite': *Geological Magazine,* 6, 574.

Selby, M. J. (1977): Pluvials in northern and east Africa and their relations to glacial climates in Europe. Environment Studies. *Dept. of Geography and Environmental Studies, University of Witwaterstrand, Johannesburg. Occasional Paper,* No. 19.

Servant-Vildary, S. (1978): *Stude des diatomees et paleolimnologie du bassin du Tchad an Cenozoique superieur Trav. Doc. ORSTOM* 84 vols I & II

Servant, M. and Servant-Vildary, S. (1980): L'environment Quaternaire du bassin du Chad, in M.A.J. Williams and H. Faure (eds), *The Sahara and the Nile,* Balkema, Rotherdam.

Shaw, B. D. (1976): Climate, environment, and prehistory in the Sahara. *World Archaeology,* (8/2); 133–149.

Shepard, F. P. (1963): Thirty-five thousand years of sea level, in, T. Clements (ed), *Essays in Marine Geology in Honour of K. O. Emery,* University of California Press.

Shepard, F. P. and Curray, J. R. (1967): Carbon 14 determination of sea level change in stable areas, in, M. Sears (ed), *Progress in Oceanography,* 4, i Quaternary History of the Ocean Basins. Oxford, Pergamon.

Shrodder, J. F. (1976): Mass movement in Nyika Plateau, Malawi, *Zeitschrift fur Geomorphologie* N.F. 20 (1), 56–77.

Smyth, A. J. and Montgomery, F. F. (1962): *Soil and Land Use in Central Western Nigeria,* Govt. Printers, Ibadan.

Spath, H. (1985): Relief generation and soil in the dry zone of Sri Lanka, in Douglas, I. and Spenceer T. (eds), *op. cit.*

Street, F. A. and Grove, A. T. (1979): Global maps of lake level fluctuations since 30,000 B.P. *Quarternary Research,* 12(1), 83–118.

Summerfield, M.A. (1984): Tectonic background to long term landform development in tropical Africa in Douglas, I. and Spencer, T. (eds) *op. cit.*

Swan, S. B. St. C. (1970): Land surface mapping, John, West Malaysia, *Journal of Tropical Geography,* 31, 91–103.

Talbot, M. R. and Delibrias, G. (1980): A new late Pleistocene-Holocene water-level curve for Lake Bosumtwi, Ghana. *Earth and Planetary Science Letters,* 47, 336–44.

Talbot, M. R. (1981): Holocene changes in tropical wind intensity and rainfall: evidence from south east Ghana, *Quaternary Research 16, 201–20.*

Talbot, M. R., Livingstone, D. A., Palmer, P. G., Maley, J., Melack, J.M., Delibrias, G. and Gullicksen, S. (1984): Preliminary results from sediment cores from Lake Bosumtwi, Ghana, in Coetzee, J. A. and Van Zinderken Bakker, E. M. (eds) *Palaeocology of Africa,* 16, 172–201.

Tanner, W. F. (1968): Tertiary sea level symposium – introduction and multiple influences on sea level changes in the Tertiary. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 5, 7–14, 165–71.

Thomas, M. F. (1965): An approach to some problems of landform analysis in tropical environments. In, Whittow, J. B. and Wood, P.D. (eds) Essays in Geography for Austin Miller, Reading, *118–44.*

Thomas, M. F. (1966): Some geomorphological implications of deep weathering patterns in crystalline rocks in Nigeria. *Transactions Institute of British Geographers,* 40, 173–93.

Thomas, M. F. (1969): Geomorphology and land classification in tropical Africa, In, M. F. Thomas and G. Whittington (eds), *Environment and Landuse in Africa,* Methuen, London.

Thomas. M. F. (1974): *Tropical Geomorphology: a study of weathering and landform development in warm climates.* Macmillan, London.

Thomas, M. F. and Thorp, M. B. (1980): Some aspects of the geomorphological interpretation of Quaternary alluvial sediments in Sierra Leone, *Zeitschrift fur Geomorphologie,* N.F. Suppl. Bd. 36, 140–61.

Thomas, M. F. and Thorp, M.B. (1985): Environmental change and episodie etchplanation in the humid tropics of Sierra Leone: the Koidu etchplain, in Douglas I and Spencer, T. (eds) *op. cit.*

Thornbury, W. D. (1954): *Principles of Geomorphology,* Wiley & Toppan.

Tjia, H. D. (1970): Quaternary shorelines of the Sunda Land, south-east Asia, *Geologie Mijnbouw* 49(2), 135–44.

Tjia, H. D. Fujii, S., Kigoshi, K., (1977): Radio carbon dates of Holocene shorelines in Peninnsular Malaysia, *Sains Malaysia,* 6(1), 85–91.

Townshend, J.R.G. (1970): Geology, form and slope process, and their relation to the occurrence of laterite. *Geographical Journal,* 136, 392–399.

Trendall, A. F. (1962): The formation of apparent peneplains by a process of combined lateritization and surface wash. *Zeitschrift fur Geomorphologie* N. F. 6, 183–97.

Twidale, C. R. (1976): *Analysis of Landforms,* J. Wiley, New York.

Valentin, H. (1952): *Die Kusten der Erde, Petermanns Geog. Mitt. Erganzungsheft,* 46, Justus Perthes, Gotha.

Veeh, H. H. (1966): Th 230/U 238 and U 234/U 238 ages of Pleistocene high sea level stands. *Journal of Geophysical Research* 71 (14), 3379–86.

Wayland, E. J. (1934): Peneplains and some other erosional platforms. *Bulletin Geological Survey of Uganda, Annual Report Notes,* 1, 74, 366.

Wayland, E. J. (1947): The study of past climates in tropical Africa, *Proceedings Pan African Congress Pre-history, 59–66.*

Wickens, G. E. (1975): Quaternary plant fossils from Jebel Marra volcanic complex and their palaeochmatic interpretation. *Palaeogeography, Palaeoclimatology and Palaeoecology* 17, 109–122.

Wigwe, G. A. (1966): *Drainage composition and valley forms in parts of northern and western Nigeria* Ph.D. thesis, University of Ibadan.

Wijmstra, T. A. (1978): . Palaeobotany and climatic change, In, J. Gribbin (ed), *Climatic change,* University Press, Cambridge.

Williams, M.A.J., Adamson, D.A., Williams, P.M., Morton, W.H., and Parry D.E. (1980): Jebel Massa Volcano: A link between the Nile valley and Central Africa: in M.A.J. Williams and H. Faure (eds): *The Sahara and the Nile* Balkema, Rotherdam.

Williams, M. A. J. (1985): Pleistocene aridity in tropical Africa, Australia and Asia: in Douglas, I and Spencer, T. (eds) *op. cit.*

Willis, B. (1936): *East African Plateaus and Rift Valleys* Studies in Comparative Seismotology, Carnagie Institute, Washington.

Wright, R. L. (1963): Deep weathering and erosion surfaces in the Daly river basin, Northern Territory, *Journal of the Geological Society of Australia,* 10, 151–65.

Young, A. (1969): Natural resource survey in Lalawi, some considerations of the regional method in environmental description, in, M.F. Thomas and G. Whittington (eds) *op. cit.*

Young, A. (1970): *Slopes,* Oliver & Boyd, Edinburgh.

Young, A. (1976): *Tropical Soils and Soil Survey,* University Press, Cambridge.