4. UNIVERSITE DE L'ETAT A LIEGE

1. CLIMATOLOGY, FLUVIAL HYDROLOGY AND TROPICAL GEOMORPHOLOGY AT THE UNIVERSITY OF LIEGE

by J. ALEXANDRE, M. ERPICUM, F. PETIT and J. SOYER*

A. CLIMATOLOGY UNIT

1. Topoclimatology

Topoclimatological research, for the most part, has focused on the spatial or temporal distribution of basic climatic elements such as temperature and precipitation. The repercussions of the components of the geographic environment and of the frequency of weather types on local climates were analysed both for urban and rural zones. The common approach to acquire knowledge of these climates was two-fold :
- an integration of observations made in stations in close proximity;
- a comparison between these observations and those of a station - often an open plain - which are more representative of the regional climate.

1. a) Urban zone. A. LAURANT (1976), A. LAURANT & J. ALEXANDRE (1977) have shown the extent to which urbanisation at recording stations could affect the intensity of rainfall. M. ERPICUM (1977) attempted to show by separate analysis of distinct rainy periods the extent to which the influence of the urban heat island varies from one rainy period to the next, and how water-measurement readings taken at too widely-spaced intervals mask the complexity of the urban effect on rainfall.
Research based on wind records (A. HUFTY, 1965 and A. LAURANT, 1968) and on vertical thermal profiles obtained from telecommunication towers in and out of town (A. LAURANT (1969a and b), A. GRILLI-DELREZ & M. ERPICUM (1984)) have shown how far the wind, indeed the dual effect of temperature inversion on pulsations in the heat island could be indicators of atmospheric pollution in the Liège conurbation. J. ALEXANDRE & C. DAMME (1980) have shown how far the complexity and the modifications of the "warm

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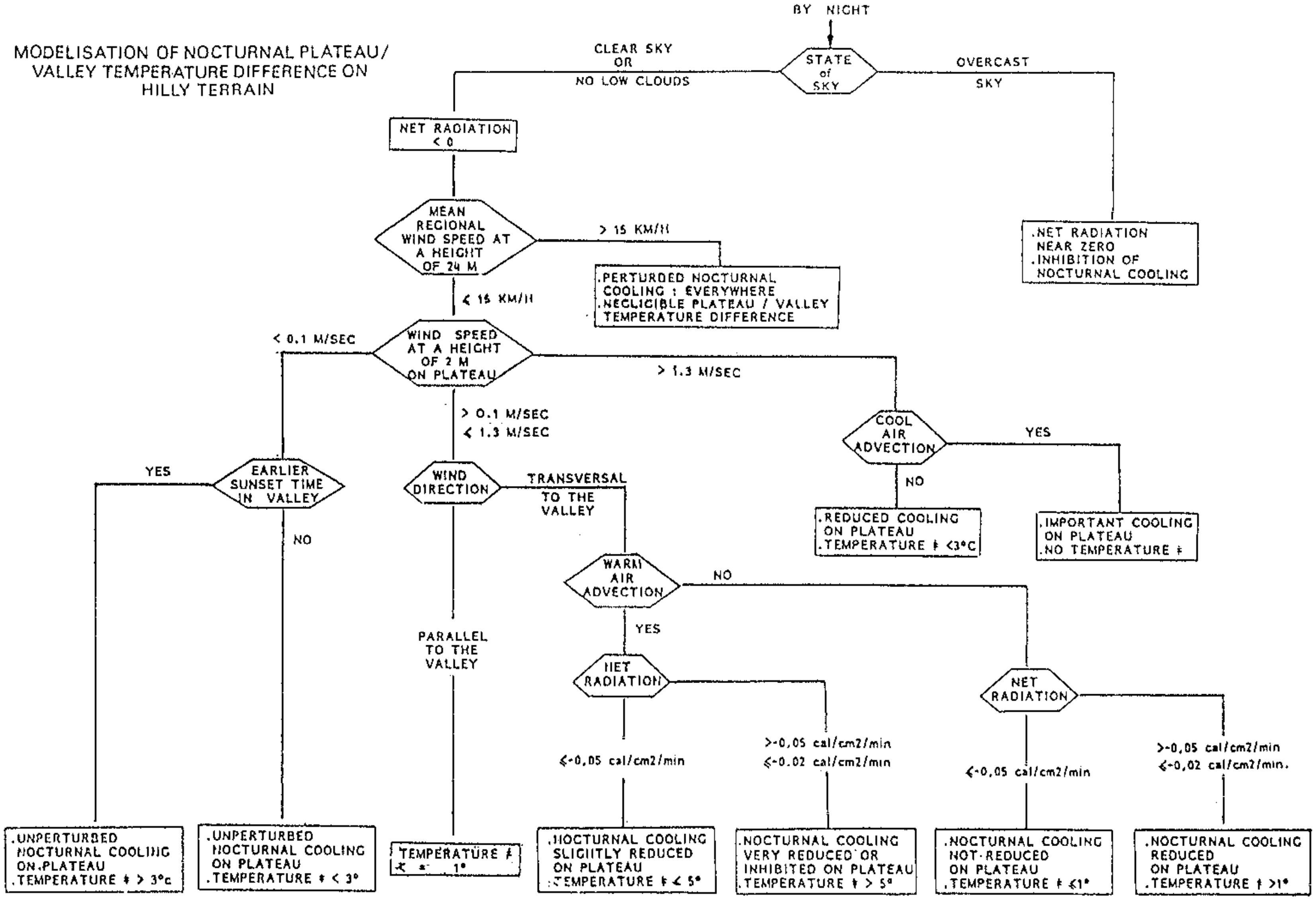

Fig. 1. Modelisation of nocturnal plateau-valley temperature difference on hilly terrain.

air bubble" could be deduced from readings taken at ground level dependent upon the judicious location of these recording points along the slope.

J. GILLMANN (1972) and J. ALEXANDRE (1980) analysed the distribution of atmospheric pollution (smoke and SO_2) and proposed a method of cartography for it based on the example of the Liège conurbation. Previously, A. HUFTY (1968) hat proposed a synthesized map of the climatic sectors of the Liege area, and subsequently R. TERCAFS & M. ERPICUM (1966) have looked into the usefulness of computer processing of topography in terms of its contribution to automatic cartography of microclimates.

1. b) Rural zone. M. ERPICUM (1979) studied the climate of a small valley in Southern Belgium as a function of weather-types. Analysis of "plateau-valley" thermal contrasts and an interpretation based on concomitant reading of the radiative balance, on wind velocity and direction, as well as on short vertical thermal profiles (ground-level to 5 m) were carried out by M. ERPICUM (1982) (fig. 1). Thermal behaviour patterns in the heart of this small valley were able to be confirmed and extrapolated in Upland Belgium based on the use of daily extremes of temperature and the identification of the site of each station (M. ERPICUM, 1984). Cumulatively these investigations resulted in a modelisation of the differentiation in noctural temperatures in regions of accidented relief (M. ERPICUM, 1980, 1984, 1986).

1. c) A Method of classification for annual pluviometric regimes was proposed by H. LAGIEWKA (1981) based on Fourier harmonic analysis of monthly norms in the Belgian pluviometric pattern. From the same data, principal component analysis brought out the topoclimatic factors in the precipitation regime (M. ERPICUM & H. LAGIEWKA, 1987). In addition, M. ERPICUM & J. ALEXANDRE (1981) have proposed a detection-method for intra- and inter-annual variability in daily temperature extremes from the example of Uccle (Belgium).

2. Intertropical climatology

Research in intertropical climatology has, in the main, been conducted in collaboration with researchers in the Geography Department of Lubumbashi University. It has been concerned as much with the intensity of rainfall in Lubumbashi (KALOMBO, K., 1979) as its spatial variability (J. SOYER & NTOMBI, M.K., 1982). It has also been concerned with fixing the date of the start of the rainy season in Lubumbashi (NTOMBI, M.K., 1982) and additionally with the evolution of the water content of the air in promixity to the ground

in the Lubumbashi region during transition periods before and after the rainy season (MBENZA, M., 1982).
The stock of water in the Upper Lufira basin and effective evapotranspiration were estimated from readings taken above and in the soil (J. ALEXANDRE, 1977; J. ALEXANDRE & NZENGU, J., 1973).
The interpretation of satellite pictures obtained from METEOSAT, has enabled M. ERPICUM (1985) to show the high degree of complexity in the evolution of convective cloud masses over tropical Africa in the course of a single day and from one day to the next.

B. HYDROLOGY AND RIVER GEOMORPHOLOGY UNIT

1. Climatic factors in the water stock of small forest basins

The main location for the siting of recording instruments in the field is the Hautes-Fagnes plateau and its wooded slopes. The distribution of precipitation was studied here with the aid of a dense network of rain gauges and pluviographs (P. DEGEE & F. PETIT, 1981) enabling local effects to be distinguished from regional effects studied separately (H. LAGIEWKA, 1981).
The interception of precipitation by the forest cover and the stemflow were studied - according to the type of precipitation and its intensity - in experimental plots (beech and spruce at different stages of growth). Evaporation rates thus obtained are significant, and they even, in certain climatic conditions, exceed potential evapotranspiration rates calculated by the Penman method from observations in a meteorological park as well as those obtained from evaporation pans also positioned in a meteorological park (F. PETIT & KALOMBO, K., 1984). This is mainly caused by advection of warm air which contributes to provide complementary energy (J. ALEXANDRE & F. PETIT, 1983).
The evolution of the snow cover (thickness and intensity) was traced, particulary in relation to changes in weather, as well as its interception by differing forest cover (F. PETIT, 1985). It was thus provided that, in a forest environment, a far from negligible quantity of snow was sublimated, and, particularly subsequent upon the soaking of the tree-tops when the snow slides off, evaporated. Various controls were carried out, notably in respect of the evolution in temperatures and densities in the very heart of the snow cover.
Effective evapotranspiration was calculated by following the method involving the measurement of the latent heat flow in the total energy stock. Various initial tests were performed in a meteorological park, then recording of measurements was intensified in coniferous

forest, particulary at tree-top level, with the aid of a specially equipped mast. At this height, convection, but mainly turbulence resulting from the increased roughness of the evaporation surface, play a predominant part in the renewal of air, thus aiding evaporation (F. PETIT & M. ERPICUM, 1983). Controls were carried out with evaporation pans installed in tree canopy and by comparative study of the hydrological stock of small wooded and non-wooded drainage basins (MBUYU, N. & F. PETIT, 1987).

2. Discharge response to precipitation. Frequency of floods

The frequency of certain discharges at flood level, especially at bankfull stage, was analysed in rivers in Upland Belgium as a function of the lithology of hydrographic basins and the land use (F. PETIT, 1986a; 1987a), but also as a function of the morphology of the channel. Thus in a medium sized Ardenne river characterised by a heavy pebble-load and relatively weak competence, accumulation riffles build up to relatively high levels in the minor bed. This encourages it to burst its banks at relatively weak levels of discharge, thus increasing the frequency of discharge at full-bank stage (its recurrence period being 0.4 per annum). This results in frequent cutting-off meanders by overflow. However where thick herbaceous vegetation occurs on the alluvial plain as in the case of former mowed meadow land, the cutting-off process of the meander by individual channel formation does not speed up until 'scaloping' of the vegetation cover occurs, requiring considerable preparatory work by burrowing animals. On the other hand, where the cover consists of small shrubs such as the natural vegetation in the bottoms of valleys, but also in the case of conifer plantations, the formation of individualised channels by short-circuiting is greatly facilitated (F. PETIT, 1984). Such modifications in the vegetation on the alluvial plain would therefore tend to make the bed subrectilinear and allow swifter transmission of floodwaters.
Such modifications with regard to the transmission of floodwaters were studied in greater detail by G. MABILLE & F. PETIT (1986) in a river in Middle Belgium which had undergone numerous developments, not only at the hydrographic basin level (changes in farming methods, impermeabilisation of the basin due to urbanisation), but also in the case of the river bed (straightening and deepening of the minor bed). Where sequences of identical rainfall occur, peaks of floodwater increase and the response-time shortens, resulting in an increase in the frequency of full-bank discharge and flooding of the land in the unstraightened zones downstream. Furthermore, analysis of flood discharge at different stations brought out the knock-on effect of overflow on the transmission of floodwaters.

3. Geomorphology of river beds

Studies carried out in the non-regulated sectors of this same river in Middle Belgium have shown that alluvial sedimentation is considerable, particulary in the shelter zones of meanders, but also in counter-current cells where, nonetheless, flow velocities are relatively high (F. PETIT, 1975). Sedimentation is actually fostered by the formation of aggregates linked to the abundance of organic matter. These deposits are subject to little displacement, resisting floods near or exceeding full-bank stage and they are at the origin of secondary low-lenght meandering (S. ALEXANDRE-PYRE & F. PETIT, 1979).

The shaping of river beds and the transport of the bedload were subjected to special investigation in rivers in Upland Belgium. Morphological modifications were related to dynamic factors such as the velocity and organisation of the flow as well as to the degree of shear stress evaluated by a variety of methods. Numerous experiments conducted mainly with marked pebbles made it possible to establish that shear stress calculated from the energy slope and the hydraulic radius was a reliable criterion in explaining erosion and the transport of the pebble load (F. PETIT, 1986b): Furthermore the influence of natural phenomena (vegetation, imbrication of the pebbles, the heterogeneous nature of the materials) which assist or conversely hinder the initial movement of river-bed particles was shown (F. PETIT, 1987b). In an Ardenne river with a pebble bed load, shear stresses vary from site to site depending on the degree of discharge (fig. 2). Thus in the case of low discharge (close to the mean), shear stresses are weak in pools, allowing accumulation of fines elements, but also of pebbles derived from erosion occurring downstream of riffles where shear stresses are high. Floods close to or exceeding full-bank stage produce shear stresses which are at their highest in the bottom of pools - this is where the maximum competence of the river occurs - allowing the displacement of pebbles which may have been laid down at times of lower rates of discharge. Upstream of riffles, shear stress is weaker and these riffles appear as barriers which only very small elements can pass beyond. These elements thus represent the effective competence of the river and the size of the elements which carpet the riffles provide an additional assessment of it.

Material transported in the form of bed-load was measured by means of the placement of sediment traps. In this river, the bed-load is rather small since the dynamic conditions necessary for transport in all the sites on the river occur only infrequently. Conversely in a river in Belgian Lorraine with a mainly sandy load, shear stress is sufficient in all sites of the bed to permit transport of the load, even in the absence of high discharge. So much so that the quantity

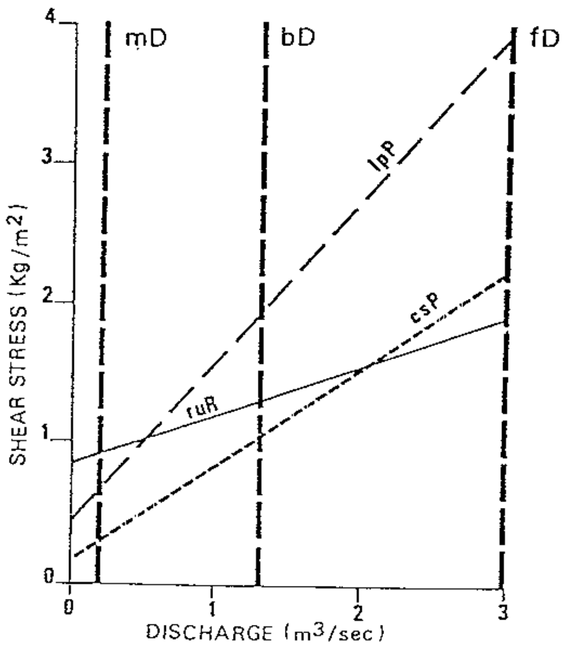

Fig. 2.
Evolution of mean shear stress as a function of discharges in different sites :
a) csP, counter-slope pools
b) lpP, lowest point of pools
c) ruR, reach upstream of constructed riffles.
mD, bD and fD are median, bankfull and annual flood discharge.

of material evacuated is relatively significant (approaching 0,2 t km^{-2}) (F. PETIT, 1986a).

C. UNIT OF TROPICAL GEOMORPHOLOGY

Research in the field of tropical geomorphology was conducted principally in Southern Shaba in close collaboration with the Geography Department of the University of Lubumbashi. Southern Shaba is a region enjoying two contrasting seasons of roughly equal length; the natural vegetation is open forest (miombo) with scattered remains of dense forest (muhulu) and a few areas of edaphic savannah.

1. Present-day processes

a) Landslips and ravinements are exceptional in this tropical region (J. & S. ALEXANDRE, 1964). Linear erosion requires sharp slopes of the order of 15°. The repeated movement of livestock on a sandy substratum may cause gullies, but their damp microenvironment with its dense vegetation produces stabilisation in a relatively short time (S. ALEXANDRE, 1978).

b) The degree of impact of rainsplash was compared in a regressive series in conjunction with anthropic degradation of the vegetation. Readings obtained from splash captors have shown that in the climatic formation of the region which comprises dry dense forest (muhulu), the annual turn-over of mineral particles in the soil represented a mere 3.1 $t.ha^{-1}$, thanks to the permanency of the vegetative cover, the multi-strata structure and the presence of a thickly matted ground-cover (MITI et al., 1984). In the open forest (miombo), the displacement of earth already reaches 7.2 $t.ha^{-1}\ y^{-1}$. On the savannah and land lying fallow, the annual turn-over is of the order of 30 $t.ha^{-1}\ y^{-1}$, with wide variability bound up with the density of the vegetation left behind after the passage of bush-fires, depending of whether they are early or late (J. ALEXANDRE, 1967). The monoculture of maize is accompanied by splash erosion of 170 to 206 $t.ha^{-1}\ y^{-1}$ (J. SOYER et al., 1982).

c) Superficial soil creep was calculated by measurements of the movements of T plates positioned from the summit of an inselberg to its base, and also on a surface of denudation in characteristic biotopes of the Shaba. Creep is distinctly seasonal with the most significant differential movements near the surface occurring at the beginning and end of the rainy seasons. The effects of successions of showers were verified by rain simulation experiments (J. SOYER, 1985). Alternate soaking and drying-out may cause lateral displacement of the order of one cm per annum in the upper soil horizons of surfaces of denudation as demonstrated by deformations of Rudberg ring columns.

d) Burrowing animals (termites, worms, ants, mole-rats) play an important part in the erosion of hillsides by bringing to the surface from lesser or greater depths an earthy material which they abandon without protection to the effects of rain and wash (J. ALEXANDRE, 1967). An first evaluation was made in the case of earth moved by termites of the genus Cubitermes building up fields of small termite-mounds which can represent a mass of 24t. of earth left above the surface of the soil. Destruction and renewal of epigeous material can be effected in a cycle of about 8 years. The activity of these termites implies that a layer of earth 24 to 37 cms thick would be brought to the surface in 1,000 years (ALONI, K. & J. SOYER, 1987). The destruction of the giant mounds of Macrotermes falciger involves an accumulation of the order of 1.5 cm per 1.000 years. The overall activities of burrowing animals can finally account for the formation of stone - lines in certain cases. (ALONI, K. et al., 1987).

e) In the case of rivers, two factors involved in channel dynamics were studied. A parallel drawn between the behaviour of the Lualaba and the Lufira highlighted the importance of the bedload; which is sandy in both cases, but more abundant in the former. Here the channel is shallow, cluttered with islands at low water and its sinuosity is limited since it is confined between two large natural levees built up at times of flood with a fraction of the bedload.

Along the Lufira with its deep narrow channel, the meanders are well developed and migrate continually, eliminating the natural levee of the concave bank (J. ALEXANDRE, 1962).
The vegetation on the banks protects them in various ways. Tall trees of the forest-gallery are ineffective and topple in the bed of the watercourse. Conversely certain shrubs adapted their morphology to the undermining and remain well anchored despite deviation of the trunk. Thus they form groynes which divert the current from the banks, but increase the likelihood of overflow. Other shrubs such as large graminaceae with offshoots and suckers encourage sedimentation and subsequently protect it (A. LEQUARRE, 1978).

2. Terraces and rock bars

Rivers in the Shaba are presently subjecting certain sectors to limited vertical erosion whereas the alluvial sheets of the terraces were built up in two different morphoclimatic environments (S. ALEXANDRE-PYRE, 1971; S. ALEXANDRE & G. SERET, 1969; J. ALEXANDRE & A. STREEL-POTELLE, 1979) :

a) On the one hand rather poorly-classified sediments except in certain lenses, with poor-rounded coarse sediments, occasionally of a nature liable to weathering, with a fine matrix of local origin which retains ochre or red colouration inherited from weathering on the slopes; gravel lenses were sometimes indurated at a later date by ferruginous compounds. Such deposits are attributed to a drier climatic phase than presently obtained.

b) On the other hand sediments of distinctly finer medium composition containing at times well-rounded pebbles which have come away from potholes, with an appreciable organic content giving rise to black, grey or white colouration by leaching. These alluvia are characteristic of the lowest terrace, the "graviers sous berge" (under-bank gravels), which is a residual formation previous to sedimentation in an often sub-marshland environment, bearing witness to a wetter climatic phase than at present day. Certain C_{14} dating indicate that this latest terrace dates from circa 7,000 years B.P. There are also in existence a few earlier terraces of this type.
The rock bars dotted along the water courses of the Shaba ensure, by virtue of the low erosive power of these courses, a permanency in local or regional base levels (J. ALEXANDRE, 1973). This permanency aids the formation of coatings (ferruginous, manganesiferous or siliceous) and complex deposits of calcium carbonates (travertines and karst encrustments) which enable the recent history of the rocky riffle and the waterfall which follows to be retraced (J. ALEXANDRE & A. LEQUARRE, 1978).

3. Surface of Denudation

In the Southern Shaba, a certain degree of tectonic stability was conducive to the development of multiple surfaces of denudation of two very distinc types, pediplanation and peneplanation (S. ALEXANDRE, 1967, 1969, 1971; J. & S. ALEXANDRE, 1970).

a) Piedmont-sited glacis are constituted by the juxtaposition of very depressed rock fans the coalescence of which has created the surface. The hydrographic network has retained the imprint. They are covered by a shallow (2 to 3 m) layer of dissipating area materials more or less respected by later chemical weathering. The slopes related to the competence of the running water (gully or small river) which formed the dissipation area : they evolve from 18° (elements of 40 cms diameter) to 2° (2-3 cms diameter). The glacis are recent and relate to zones where water courses are still causing vertical erosion between the denudation phases.

b) The plateaux are themselves covered with plane surface due to erosion. The slopes are less than on the glacis. The pebble pavement which is broadly, but not exclusively, developed results from a phase of removal of fine particles by areal wash, providing an indication as to the origin of the surface : erosion, on gentle slopes, of chemically weathered products in the substratum by rain wash. The "Inselberge" would result in this case from zones subjected to little or poor weathering and progressively cleared in a distant past (Tertiary).
None of the types of denudation occurs currently in the present day. Surfaces are today incised and superficial deposits are covered over with earth (in particular, stone-line complex). The shaping of surface either by dissipation and lateral erosion (pediplanation) or by areolar wash (peneplanation) would be facilitated by a landscape featuring sparse vegetation of a type similar to that presently found on the steppes. In theory, the shaping by these two processes could have occurred simultaneously. Peneplanation surfaces require previous chemical weathering for which a wet phase is more favorable. Therefore they form the most characteristic surfaces in regions at present covered by savannah and open forest where such climatic alternation occurred.

4. The Geomorphological importance of lateritic ferricrete

Gritty ferricretes which are the most widespread in the Shaba, result from a succession of processes which imply climatic oscillations. The successive phases in their formation are as follows (J. ALEXANDRE, 1978) :

a) The formation in a shallow horizon, about one metre, of ferruginous nodules. This concretisation requires a damp climate producing the organic material necessary for the mobilisation and dehydration of iron hydroxides.

b) Mechanical concentration of the nodules on the surface of the ground by means of erosion by areolar wash, favoured by a drier climate of the type which presently prevails on the steppes.

c) A covering of the pavement composed of the ferruginous chippings and a cementation of the matrix between the grit under conditions differing little from those involved in the formation of nodules.

d) The disposition on a denuded hardpan of a ribboned coating, part of the external layers of which are comparable to a desert varnish at least for the earliest hardpans (J. ALEXANDRE & TSHIDIBI, N. ya B., 1985).

If it was possible for the first three phases to occur in one and the same cycle, the same is not true for the last which is unique. The desert climate seems to have "frozen" the system, hardpan and associated surface, before the advent of a new erosion cycle. It is on this count that the ferruginous coatings are precious in the working-out stratigraphy based on continental formations.

Laterite hardpans (cuirasses) thus contribute not only to the protection of ancient surfaces but also to their dating thanks to the nature and especially the colour of the coatings. With the aid of a stepped altimetric arrangement and geometric relation to other continental formations, hardpans of successive ages were able to be identified : a thick zonal coating of dark colour (late secondary or early Tertiary), a purplish-red fine (mid-Tertiary), a zonal coating ending with a shiny dark brown layer affected with cracks most of which have been sutured (late Tertiary), a matt beige coating (very end of the Tertiary), a purplish-red or dark brown very thin (Quaternary) (fig. 3).

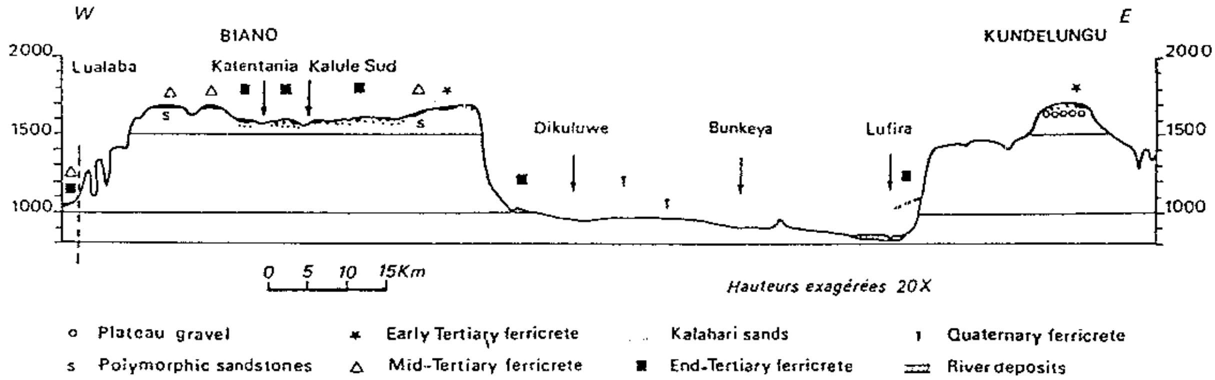

Fig. 3. Topographical profile through the southern High Shaba near the paralell of 11°30' S.

With the aid of this stratigraphy, the broad outlines of geomorphological evolution in Upper Shaba were able to be traced (J. ALEXANDRE & S. ALEXANDRE-PYRE, 1987).

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