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HILLSLOPE PEDIMENTATION AND STONE-LAYERS IN THE HILLY AREAS OF SOUTHERN CAMEROON

BY

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SUMMARY. – In tropical climates with a short dry season, with highly and deeply weathered soils and a mountainous or a hilly relief, so called hillslope pediments may form ; the pedimentation scarp retreats until it reaches the hilltop (watershed). The height of the pedimentation scarp decreases gradually from the river towards the hilltop. Close to the watershed the scarp disappears.

The stone-layer resulting from hillslope pedimentation is characterized by : (1) a gradually decreasing depth below the soil surface from the valley to the watershed ; (2) a morphological differentiation between the pediment gravel downslope and the stone-line upslope ; (3) a poor sorting of the materials.

The similarity indices calculated on the sand fraction do not provide evidence for the presence of clear lithological discontinuities in the pedisediment. The similarity indices calculated on the gravel fractions on the contrary indicate a sharp lithological discontinuity between the stone-layer and the hill wash cover. All calculated sedimentological parameters prove transport-deposition mechanisms responsible for the formation of the stone-layer and the hill wash cover.

RÉSUMÉ. – *Pédimentation de versant et nappe de cailloux dans les régions de collines du Sud-Cameroun.* – Dans les régions à climat tropical à courte saison sèche, avec un relief de montagne ou de colline et avec des sols très altérés sur une grande profondeur, il peut se former des pédiments de versant ; l'escarpement de pédimentation recule jusqu'au sommet de la colline (partage des eaux). La hauteur de l'escarpement de pédimentation diminue progressivement de façon à disparaître près de la ligne de séparation des eaux. La nappe de gravats qui résulte de cette pédimentation est caractérisée par : 1) une profondeur qui va en diminuant de la vallée vers la ligne de partage des eaux ; 2) une différenciation morphologique entre un gravier de pédimentation vers l'aval et une stone-line vers l'amont ; 3) un faible classement du matériel. Les indices de similarité calculés sur la fraction sableuse ne fournissent

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pas la preuve de l'existence d'une discontinuité lithologique dans le pédisédiment. Calculés sur la fraction graveleuse, ces indices montrent au contraire une discontinuité lithologique nette entre la nappe de gravats et la couverture. Tous les paramètres sédimentologiques calculés convergent pour démontrer que des processus de transport et de dépôt sont responsables de la formation de la nappe de gravats et de la couverture.

SAMENVATTING. – *Helling-pedimentatie en "stone-layers" in de heuvelgebieden van Zuid-Kameroen.* – In gebieden met een tropisch klimaat met een kort droog seizoen, met een berg- of heuvelreliëf met een diep verweerd substraat, kunnen hellingpedimenten gevormd worden. Deze ontstaan door het terugschrijden van de pedimentatiesteilrand tot op de heuveltop (waterscheiding). De hoogte van de steilrand vermindert progressief om te verdwijnen bij de waterscheidingslijn. De "stone-layer" die het gevolg is van deze pedimentatie wordt gekarakteriseerd door : 1) een diepte beneden het wateroppervlak die kleiner wordt van de vallei naar de waterscheidingslijn ; 2) een morfologische differentiëring tussen een pedimentgrint hellingafwaarts en een stone-line hellingopwaarts ; 3) een zwakke sortering van het materiaal. De gelijkvormigheidsindex berekend op de zandfraktie duidt geen uitgesproken lithologische discontinuïteit in het pedisediment aan. De index berekend op de grintfraktie daarentegen, laat een zeer scherpe lithologische begrenzing tussen de "stone-layer" en de deklaag uitkomen. Verschillende sedimentologische parameters duiden op transport-afzetting mechanismen voor de vorming van "stone-layer" en deklaag.

Introduction

Stone-layers in Africa are often associated with pedimentation (FÖLSTER 1964, 1969 ; ROHDENBURG 1969, 1982 ; EMBRECHTS & DE DAPPER 1985, 1987). In tropical climates with a short dry season and with highly and deeply weathered soils valley floor pedimentation is active : valley flanks retreat and act as pedimentation scarps. In more or less flat landscape positions a relief is formed characterized by interfluvia having the shape of half oranges and by flat valley bottoms. In a mountainous or in a hilly relief so-called hillslope pediments may develop. The height of the pedimentation scarp decreases gradually from the river towards the watershed (hilltop). Close to the watershed the scarp disappears.

In this paper the characteristics are investigated of a stone-layer and a hill wash cover (the pedisediment) resulting from hillslope pedimentation.

Environmental setting

The studied area is situated near Yaoundé (Cameroon), between the top and the foot of a bornhardt : the Fébé hill. The area is bounded by the latitudes of 3°55' and 3°58' N and by the longitudes of 11°29' and 11°32' E (Fig. 1). The altitude varies between 1,060 m at the top of the hill and 740 m at the bottom of the valleys developed at the foot of the hill.

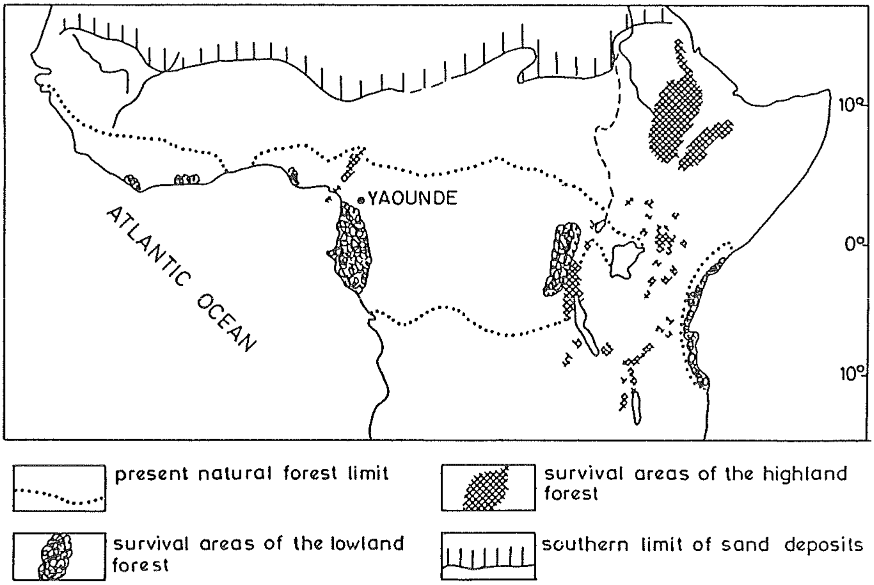

Fig. 1. – Survival areas of the tropical rainforest during drier periods of the Quaternary (HAMILTON 1976) and situation of the study area.

The substratum is a migmatised gneiss with biotite and garnet. The mean annual rainfall is about 1,600 mm, the mean air temperature is 23.4°C. A long dry season extends from the mid of November till the end of February, a short dry season is present in part of July and in August. Semi-deciduous forest, degraded forest with fallow, gallery forests and tree savannahs are the main vegetation types in the area. During the dry periods of the Quaternary the rainforests of West and Central Africa survived in some isolated coastal areas characterized by a monsoon system (AUBRÉVILLE 1962, HAMILTON 1976). The map (Fig. 1) shows that during the drier climatic phases the Fébé-area probably belonged to an extensive savannah zone at relatively short distance of the forest survival area of the Cameroonian and Gabonese coasts.

The present landscape of the Fébé area is the result of the action of successive cycles of erosion on a hard massive rock (EMBRECHTS 1985). Local differences in resistance to weathering were at the origin of the formation of bornhardts. Soil profiles and road cuts were studied in each of the geomorphological units characterising a substructural slope of the Fébé bornhardt (Fig. 2).

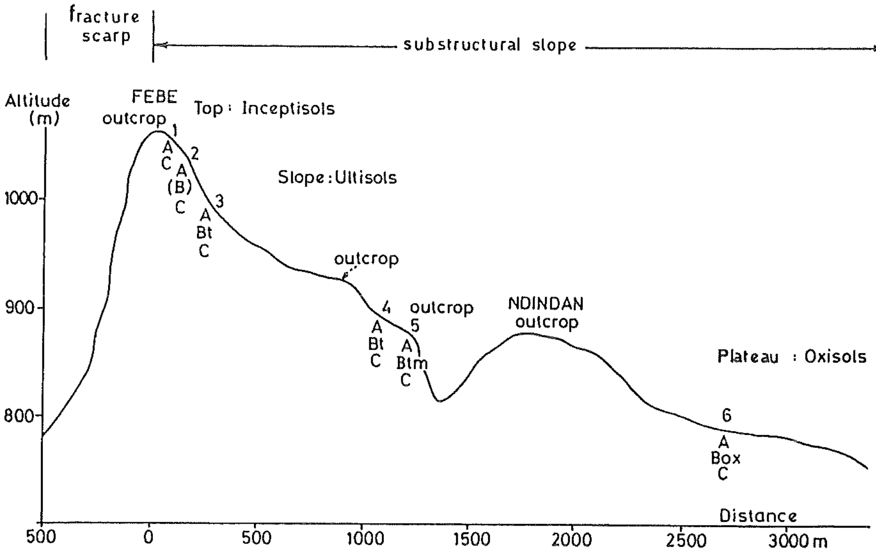

Fig. 2. – Localization of selected pedons on the substructural slope (vertical exaggeration 5/1).

Methods

Roundness and Shape of Quartz Grains

Petrographic sized thin sections (50 × 30 mm) were prepared out of undisturbed soil samples. Classification of the quartz grains in the relative scale of Powers (1953) was carried out using a magnification of 40 × .125 to 150 grains were counted on each thin section.

Grain size analysis

Grain size distributions were determined with the pipet method after pretreatments with H_2O_2 and HCl 0.2N and using Na-metaphosphate as dispersing agent. The sand was fractionated using standard sieves of 47, 105, 250, 500, 1000 and 2000 μm sieve opening.

Similarity Index

The similarity index (Langohr *et al.* 1976) was determined on the sand and gravel fractions of adjacent horizons and on the sand fractions of the top horizon and successive subsoil horizons of the same soil profile.

SEDIMENTOLOGICAL ANALYSIS

According to VISHER (1969) each subpopulation of a sediment is characterized by the mean, standard deviation, skewness and curtosis of its normal distribution.

Results

1. MORPHOLOGY OF THE STONE-LAYER

An important morphological difference between the soils near the top of the Fébé hill and the soils of lower elevations is the nature of the coarse material present in the stone-layer. Above the altitude of 850 to 900 m a stone-line primarily composed of more or less weathered stone fragments and quartz gravel is present, below this elevation pediment gravel is observed. Fig. 3 shows a section of the hillslope illustrating the position of the fresh rock, saprolite, stone-line and pediment gravel.

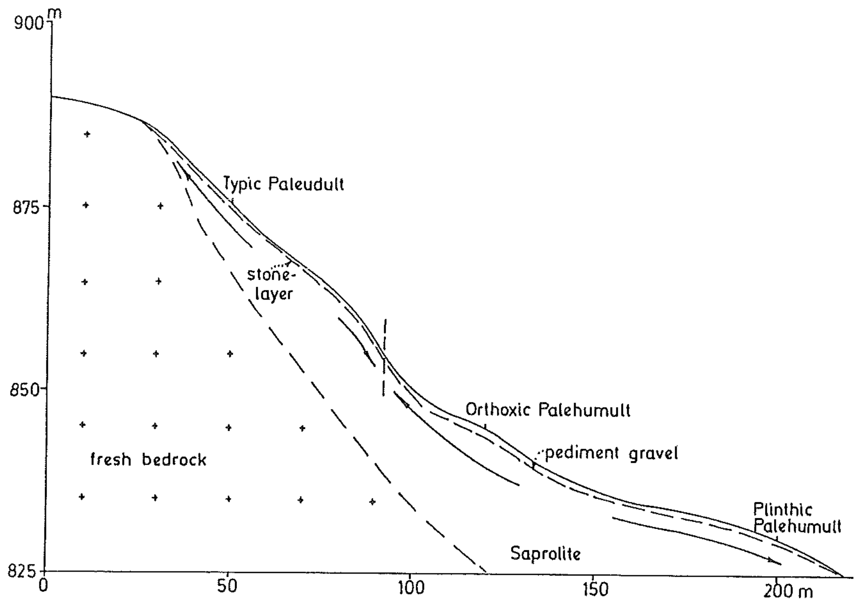

Fig. 3. – Section through a slope showing the position of the stone-line, the pediment gravel and the situation of some soils (vertical exaggeration 2/1).

The stone-line is present on linear or on slightly convex slopes of about 40%. The upper boundary of the stone-line is situated at about 10 to 50 cm depth. The coarse elements are more or less rounded rock fragments and quartz gravels varying in diameter between 2 mm and about 30 cm.

The pediment gravel is 1 to 2 m thick on slopes of 30 to about 5% and is 3 to 4 m thick in flatter landscape positions. On the slopes the pediment gravel starts at a depth of 120 to 200 cm ; at the foot of the hill the pediment gravel is found at 150 to 300 cm depth.

The main constituents of the pediment gravel are Fe-nodules, quartz and rock fragments and petroplinthite blocks :

a) Fe-nodules are predominant in the pediment gravel. They have a diameter ranging between 2 mm and 2.5 cm, they cannot be broken by hand and they have a dark brown patina, the interior is black. Some nodules contain inclusions mainly of quartz. Microscopically most of these nodules correspond to garnet pseudomorphs formed by alteration in the saprolite (EMBRECHTS & STOOPS 1982). Nodules composed of isotropic Fe-nodules and included mineral grains are rather scarce, they may be inherited from the saprolite.

b) Quartz and rock fragments are found in small amounts. Quartz fragments generally have a diameter smaller than 2 cm. They are often hard but can sometimes be broken by hand. Quartz fragments are angular or slightly rounded. The rock fragments present in the pediment gravel have a diameter smaller than about 5 cm but larger diameters may occasionally occur. The individual minerals and the stratification are clearly visible in hand specimens. Many fragments are impregnated with Fe- or Mn-oxyhydroxides. Rock fragments are angular or slightly rounded. Most rock fragments of the pediment gravel are less altered than the underlying saprolite.

c) In the pediment gravel also imperfectly rounded blocks of petroplinthite are present with a diameter varying between 0.25 and 3 m. These blocks are composed of small Fe-nodules cemented by Fe-oxyhydroxides.

The undulating character of the upper and lower boundaries of the pediment gravel is clearly visible in deep road cuts (Fig. 4). In a lateral section quartz veins present in the saprolite do not continue in the pediment gravel. At the contact between a quartz vein and the pediment gravel many quartz fragments are found in the lower part of the pediment gravel.

In the depressions at the upper boundary of the pediment gravel a local bifurcation of the gravel is sometimes observed : a thin layer of fine material separates the two layers of pediment gravel (Fig. 4). Sometimes a layer of finer nodules is present, the fine and the coarse nodules being separated from each other by a clear discontinuity (Fig. 4).

In the vicinity of a core stone (Fig. 4) in the saprolite on the slope a relatively large number of angular, relatively fresh rock fragments mixed with other constituents of the pediment gravel is present. These rock fragments have a diameter which is normally smaller than 5 cm. The number of these fragments decreases with increasing distance from the core stone.

The clay fraction, constituting 30 to 65% of the fine earth (< 2 mm) of both the stone layer and the hill wash cover is present as stable crumbs mainly of sand and silt size.

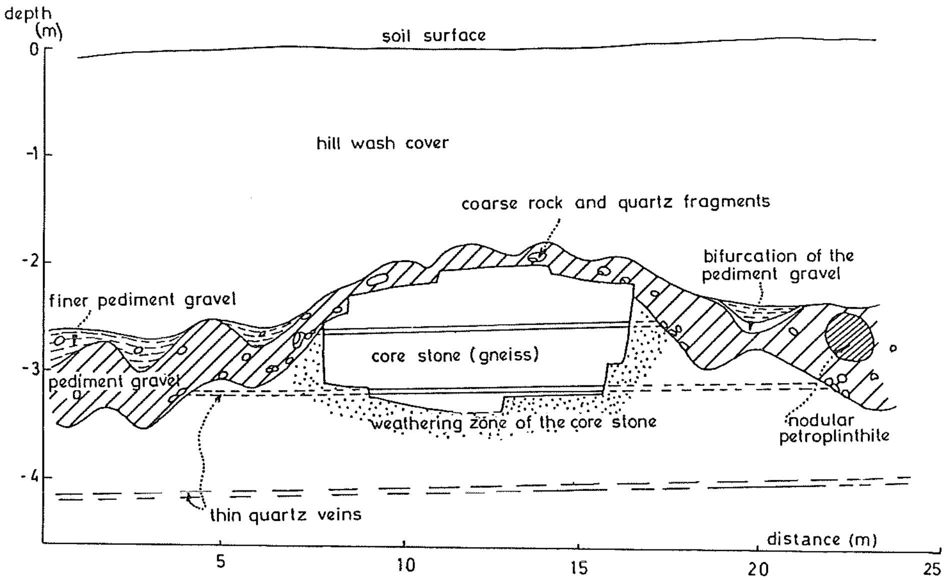

Fig. 4. – Schematical representation of the elements of the pediment gravel in a section perpendicular to a substructural slope.

2. Sedimentology of the Pedisediment

Classification of the quartz grains according to their roundness and shape (Powers 1953) proves that fragmentation in horizons close to the soil surface is negligeable. Furthermore the classification does not indicate rounding due to transportation or to chemical weathering (Embrechts & De Dapper, 1985).

The similarity index (LANGOHR *et al.* 1976) calculated on the gravel fraction of a horizon belonging to the hill wash cover (very few coarse fragments) and a horizon of the stone layer is near to O. A gradual decrease is noticed of the similarity index of the sand fractions calculated between the top horizon and horizons of increasing depths (EMBRECHTS & DE DAPPER 1985).

The grain size distribution of the pedisediment (Fig. 5a) exhibits a break-point around 2 phi (250 µm). This point marks the lower limit of the traction population.

In the horizons of the hill wash cover the upper limit of the fine traction population corresponds to the upper limit of the very coarse sand (2 mm). In the horizons of the stone layer the upper limit of the fine traction population is determined by the onset of a coarser population (fig. 5b). In both cases - 1 phi (2 mm) is an acceptable upper limit of the fine traction population.

In the pedisediment the mean diameter decreases from the bottom (stone layer) to the top (surface horizons). The sorting is more or less constant in the stone layer but increases from the bottom to the top in the hill wash cover. The finest and the best sorted horizons are found near the surface of the profiles situated at the greatest distances from the watershed (EMBRECHTS & DE DAPPER 1985).

The deposition circumstances of the pedisediment are presented in Fig. 6.

Calculations of the mean diameter of the traction population of the stone layer indicate that the coarsest material is present in the deepest horizons of the stone layer (EMBRECHTS & DE DAPPER 1985).

The evolution of skewness and kurtosis confirms the observations made on mean diameter and sorting (EMBRECHTS & DE DAPPER 1985).

Linear relations exist between sedimentological parameters of some reference soil horizons and the distance to the present watershed (Table 1).

Discussion

The rounded form of most of the rock fragments present in the stone layer may indicate transportation, but when these elements contain weatherable minerals, the rounding may also be due to alteration in situ. The rounding of quartz fragments may point to transportation.

The garnet pseudomorphs of the pediment gravel have conserved the dodecahedric shape of the original cristals and their slightly rounded form does therefore not indicate transportation.

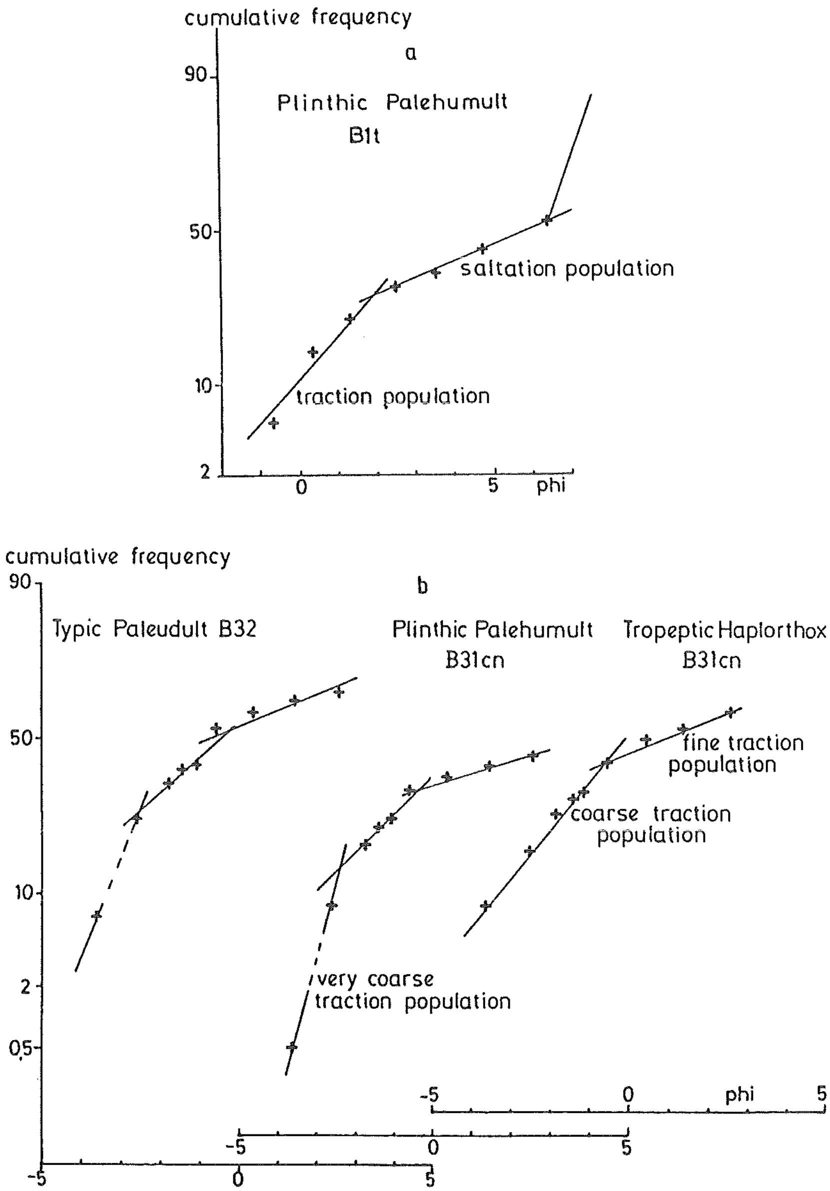

Fig. 5. – Boundaries of the fine traction population a) without coarse elements ; b) coarse elements included.

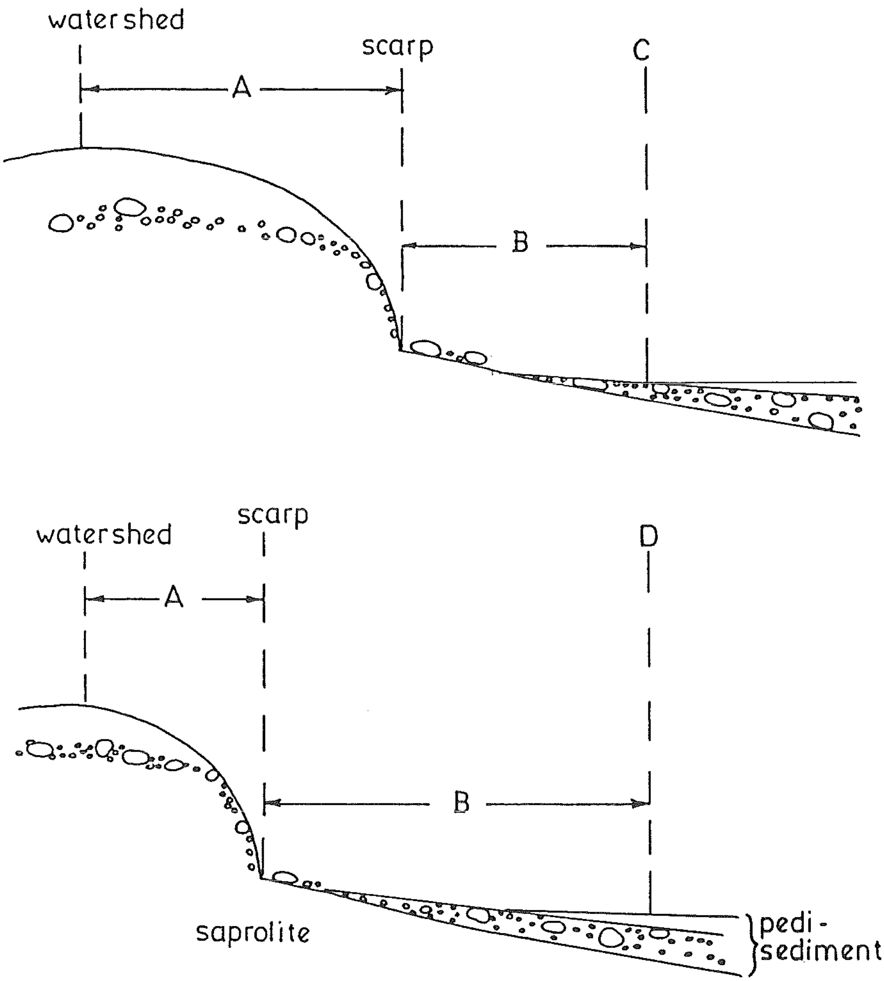

Fig. 6. – Deposition of the pedisediment with retreating scarp. The stone-layer is deposited at the foot of the scarp. The fine material is : (A) transported by sheet wash and gully erosion ; (B) transported over the stone-layer without important deposition or take up of material ; (C) deposited after transportation over a *short* distance over the stone-layer (basis of the hill wash cover) ; (D) deposited after transportation over a *long* distance over the stone-layer and the hill wash cover (top) and hence after a relative increase of the amount of fine grains and an improvement of the sorting with regard to situation (C).

Table 1

Correlation coefficients of the linear relations (Parameter = A + B × Distance) between sedimentological parameters and the distance to the watershed and corresponding probability levels

Horizon	Mean	Sorting	Skewness	Kurtosis
Top horizon n = 10	0.93 P > 0.1%	- 0.90 P > 0.1%	- 0.88 P > 0.1%	- 0.95 P > 0.1%
Basis of hill wash n = 10	0.93 P > 0.1%	- 0.60 P > 10%	- 0.92 P > 0.1%	0.62 P > 10%
Top of stone layer n = 8	0.41	0.63 P > 10%	- 0.69 P > 10%	- 0.17

The blocks of petroplinthite found in the pediment gravel are remnants of a (petro-)plinthite formed locally in the pedisediment during a former period of soil formation. At present secondary nodular plinthite is formed in the pediment gravel in places where a convergent water flow exists (EMBRECHTS 1985).

The undulating character of the upper and lower boundaries of the pediment gravel, the observations of the quartz veins, the local bifurcation of the pediment gravel, the presence of layers of finer gravel in depressions of the upper boundary of the pediment gravel and the observations made in the vicinity of a core stone point to the sedimentological origin of the pedisediment. The presence of blocks of secondary nodular petroplinthite is an indication of the cyclic character of pedimentation in the area. The pedimentation process acting upon an already existing incised pediplain is illustrated by Fig. 7.

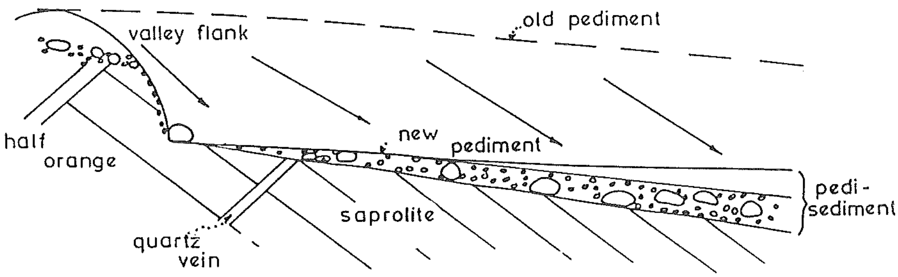

Fig. 7. – Pedimentation on an already existing incised pediplain.

The formation of a layer of pediment gravel with a thickness of 4 to 5 m, composed primarily of garnet pseudomorphs, requires the erosion of a saprolite of considerable thickness.

The gradual lowering of the retreating pedimentation scarp with increasing slope gradient is at the origin of the diminishing thickness of the pedisediment towards the watershed.

The presence in high landscape positions of rock outcrops and of core stones near the upper limit of the saprolite gives rise to the formation of the stone line. At lower elevations, rock outcrops are scarce and core stones are less frequent in the upper parts of the saprolite. The pediment gravel present in these positions is mainly composed of reworked material from older pedimentations. The process described in the Fébé area was called hillslope pedimentation (EMBRECHTS & DE DAPPER 1987). The classification of the sand fraction according to roundness and shape indicates that the sand grains (85 to 95% of quartz) are relatively little affected by pedogenetical processes acting upon the pedisediment. The fine traction population is the coarser part of the sand fraction and is as such only weakly influenced by soil forming processes.

The very low value of the similarity index determined on the gravel fraction of a horizon belonging to the stone layer and a horizon of the hill wash cover indicates a very clear lithological discontinuity (defined by grain size and relative importance of components but not defined by mineralogical differences) between both horizons.

The evolution of the similarity index of the sand fraction calculated between the top horizon and horizons of increasing depths within the pedisediment proves the existence of a gradual shift in the grain size distribution of the sand fractions of the parent material of the soils. This can be due to the slow retreat of a pedimentation scarp and hence to the gradually changing sedimentological conditions.

At the basis of the pediment gravel no distinct stone-line is observed. However large fragments of petrolinthite are frequently observed in the pediment gravel. This poor sorting may have several causes (FÖLSTER 1969) :

1. close to the watershed only small amounts of water are available, the transportation distance is short and the sorting is poor ;
2. zones with petroplinthite collapse after the retreat of the scarp and petroplinthite blocks are deposited at the same time as the pediment gravel ;
3. on a slope, very coarse and heavy elements can move by pure gravity.

The gradual change of the mean diameters calculated on horizons belonging to the stone layer shows that the coarsest elements are present at the basis of the pediment gravel. This is an analytical confirmation of FÖLSTER's (1969) observation.

The moderately high to high clay contents of the pedisediment on the steep slopes can be explained when it is assumed that during pedimentation clay particles are transported as micropeds. Micropeds are the water stable silt and sand-sized aggregates that are at the origin of the fine granular microstructure of Oxisols and related soils (EMBRECHTS & STOOPS 1987 ; EMBRECHTS 1986). Micropeds may be transported by water over short distances. This is illustrated by the small aggregates of clay and Fe-oxyhydroxides often found at the foot of recent artificial or natural scarps or erosion gullies in humid tropical areas with highly weathered soils.

Conclusions

The field observations in the area point to a sedimentological origin of the pedisediment including the stone layer. The process involved is hillslope pedimentation. These observations are confirmed by the study of the grain size distribution of the sand fraction and by the study of the sedimentological parameters of the fine traction population of the pedisediment. The clay particles present in the hill wash cover and in the interstices of the stone layer were transported as pseudo-silts and pseudo-sands.

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