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VARIATIONS IN THE COMPOSITION OF GRAVEL LAYERS ACROSS THE LANDSCAPE. EXAMPLES FROM SIERRA LEONE

BY

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SUMMARY. – Twelve morphofacies types occur in characteristic geomorphic positions across the Koidu landscape. Each contains a gravel accumulation layer that shows distinct variations in petrographic composition and texture. Three gravel layer types were identified : rock gravels, lateritic gravels and rounded quartz gravels. Variations in morphofacies types are attributed to the variable influences of three process domains : the Residual domain of weathering and pedogenesis ; the Colluvial domain of slopewash, lateral eluviation and the seasonal precipitation of iron sesquioxide compounds ; and the Fluvial domain of hydromorphic conditions, channelled flow, the dissolution of iron sesquioxide compounds and pronounced lateral eluviation. The morphologies of quartz clasts and iron sesquioxide accumulations were found to be indicators of both contemporary and past process domains. Gravel layer variations from the interfluve rim to the valley floor form a Pleistocene to Recent chronosequence. Allochthonous material on the hillside benches and near the centres of interfluves indicates a Tertiary alluvial source for some gravel components.

RÉSUMÉ. – *Variation dans la composition des nappes de gravier selon la position dans la topographie. Exemples pris au Sierra Leone.* – Douze faciès morphologiques ont été distingués dans les sites géomorphologiques caractéristiques de la région de Koidu (Sierra Leone). Chacun de ces faciès contient une nappe de gravier d'accumulation qui montre des variations nettes en composition et en texture. Trois types de nappe de gravier ont été distingués selon la nature lithologique : roche en place, concrétions latéritiques et quartz. Les variations dans les morphofaciès sont attribuées à l'influence complexe de trois domaines aux processus caractéristiques : le domaine résiduel de l'altération et de la pédogenèse, le domaine colluvial avec le ruissellement sur les versants, le lessivage latéral et les précipitations saisonnières de composés ferrugineux, enfin le domaine fluvial avec ses conditions hydromorphiques, son écoulement en chenal, la dissolution des sels de fer et une éluviation latérale prononcée. La morphologie des débris de quartz et des accumulations ferrugineuses semble un bon indicateur des deux ensembles de processus anciens et contemporains. Les variations dans les nappes

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de galets de l'interfluve jusqu'au fond de la vallée constituent une chronoséquence du Pléistocène au Récent. Le matériel allochtone trouvé sur les replats et dans les interfluves est l'indice d'une origine alluviale tertiaire pour certains composants.

SAMENVATTING. – *Variatie in de samenstelling van de stone-layers naargelang de topografische ligging. Voorbeelden uit Sierra Leone.* – Twaalf morfologische faciestypes werden onderscheiden in typische geomorfologische sites van de streek van Koidu (Sierra Leone). Elk van deze facies omvat een geaccumuleerde grintlaag die duidelijke variaties aantoont qua samenstelling en textuur. Volgens de lithologische aard werden drie soorten grintlagen onderscheiden : gesteentegrint, laterietgrint en afgerond kwartsgrint. De variaties in de morfofacies zijn te wijten aan de complexe invloed van drie procesgebieden : het residuele gebied met verwering en bodemvorming, het colluviale gebied met hellingsafvloei, laterale eluviatie en seizoenale precipitatie van ijzersesquioxiden, tenslotte het fluviatiele gebied met hydromorfische omstandigheden, geconcentreerde afvloei, oplossing van de ijzersesquioxiden en uitgesproken laterale eluviatie. De morfologie van de kwartsfragmenten en van de ijzersesquioxide-accumulaties blijkt een goede aanwijzer te zijn van zowel paleo- als hedendaagse processen. De variaties in de grintlagen van de interfluviumrand tot in de dalbodem vormen een chronosequentie van het Pleistoceen tot het Recente. Het allochthone materiaal dat werd aangetroffen op de hellingsschouders en in het centrale deel van de interfluvia duidt op een Tertiaire alluviale oorsprong voor sommige bestanddelen.

Introduction

This paper cites examples of gravel layers sampled in the Koidu basin of Sierra Leone, West Africa (8°38' N 11°03' W). The geomorphology and geology of this region have been described in detail by THOMAS and THORP (1980, 1985) and by TEEUW (1986). The basic setting is that of a granitic gneiss plateau with an average altitude of 390 m a.s.l., fringed by steep-sided ferricrete-capped hills of schist that rise to 810 m a.s.l. (Fig. 1). The climate is hot, humid and monsoonal, with 80% of the mean annual rainfall (2355 mm) falling within six months. Koidu lies in a transition zone between moist forest to the west and south, and derived savanna dominated by tall grass (*Agropogon* sp.) and fire-resistant palms (*Elaeis guineensis*) to the north and east.

Methodology

Samples were taken from two adjacent sub-basins, centred on the villages of Yengema and Kania (Fig. 1). Surveys of detailed slope morphometry were made at 1 : 1250 scale and geomorphological maps were compiled to show the distribution of landform types in each study area. The surficial geology was sampled by means of 10 interfluve crest-valley floor

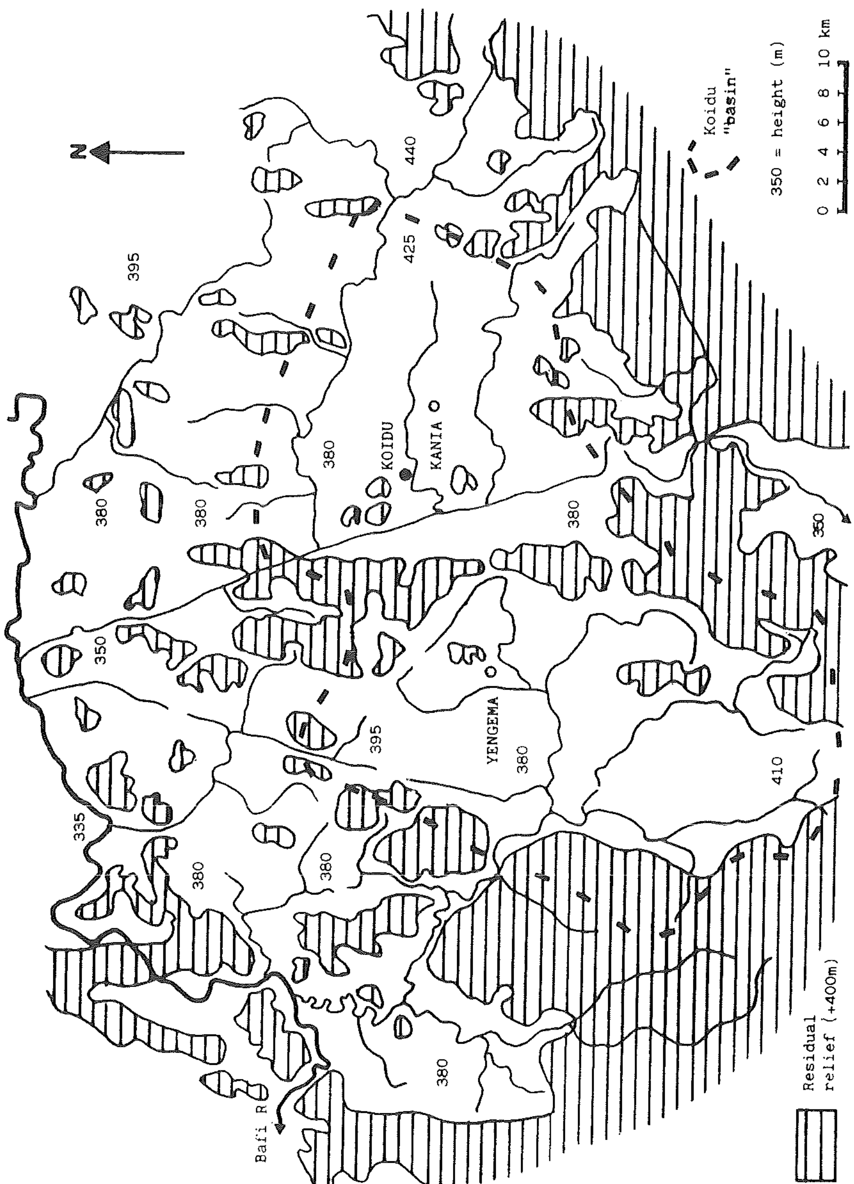

Fig. 1. – Relief of the Koidu "basin".

transects. Pits were dug near the centre of each slope facet along these transects and samples were collected at 30 cm intervals down to the bedrock or *in situ* saprolite (Fig. 2). Sample sizes were 200-300 g for particle size analyses and 0.14 m^3 for the petrographic analysis of clasts coarser than 8 mm. The visual assessment chart of KRUMBEIN (1941) was used to distinguish angular quartz (values up to 0.5) from rounded quartz (values over 0.5). The term "gravel layer" in any given sample pit is reserved for the sample layer with the highest percentage by weight of clasts over 2 mm diameter.

Variations in gravel composition

Twelve *morphofacies types* were identified, each having a characteristic slope angle, profile stratigraphy and gravel layer petrography (Tab. 1 and Fig. 3).

The results of this study indicate that a continuous gravel layer mantles the entire landscape of the Koidu granitoid basin, except where zones of bare rock occur. Thus the "gravel layer" is equivalent in its morphology to the "carpedolith" described by PARIZEK & WOODRUFF (1957) in the Piedmont region of the U.S.A. The term "stone-line" has not been used here because field observations showed the gravel to vary from an often discontinuous line one pebble thick, through to a clast-supported layer up to 1.5 m thick. The prefix "stone-" can also be ambiguous, some fieldworkers including lateritic clasts, others only accepting quartz and other fragments of bedrock.

The gravel layer can be grouped into three main types : rock gravel, lateritic gravel and rounded quartz gravel.

1. *Rock gravel* contains at least 40% rock fragments. It occurs most frequently in the hilltop, footslope and hillside bench morphofacies types, as well as in valleyhead swale zones where severe soil/saprolite stripping has occurred. Topsoil is thin or absent, with a mean value of less than 0.19 m.

2. *Lateritic gravel* can be divided into two subtypes.

(i) Gravel with over 30% *lateritic segregations* ("mottles") : soft, porous, yellow-brown to red, irregularly shaped iron sesquioxide accumulations (Fig. 4). These have micromorphological features similar to local parent material. This gravel type predominates in the distal glacis, interfluve rim and swale morphofacies types.

(ii) Gravel with over 40% *lateritic concretions* : smooth, hard, brown to black iron sesquioxide accumulations. These consist of amorphous or banded oxihydroxides, with grains of quartz or gibbsite occasionally preserving relict

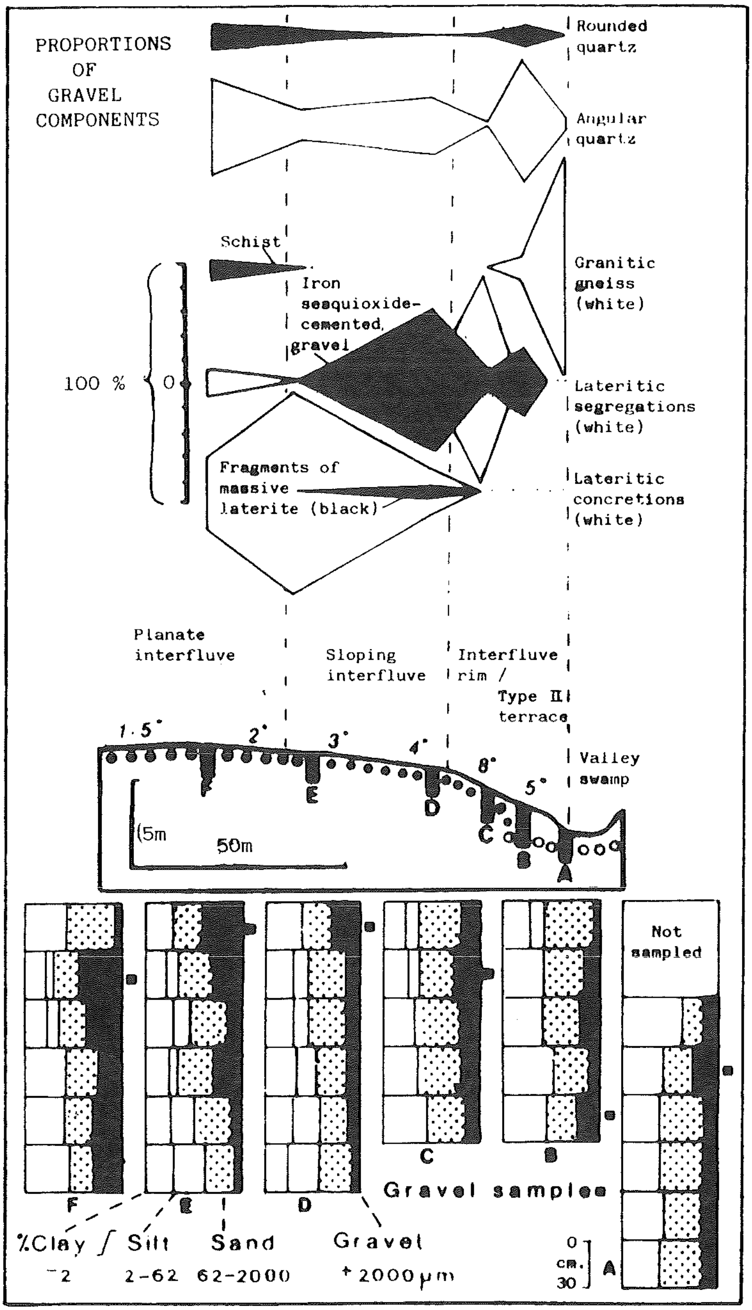

Fig. 2. – Representative sample transect. Top, variation in gravel layer petrography. Bottom, down-profile variations in texture.

soil/saprolite fabrics. This gravel type predominates in the planate interfluve and gently sloping interfluve morphofacies types, where it forms a relatively thick layer.

3. *Rounded quartz gravel* contains at least 10% rounded quartz (Fig. 5) and occurs as a basal lag gravel, directly overlying bedrock or *in situ* saprolite (Fig. 3). Four subtypes occur : (i) those of the foodplain, 1 m-high Type II terraces and channelless valley swamps ; (ii) those of the 2-3 m high Type I terraces ; (iii) those of the infilled valleyheads and palaeo-rills that feed into

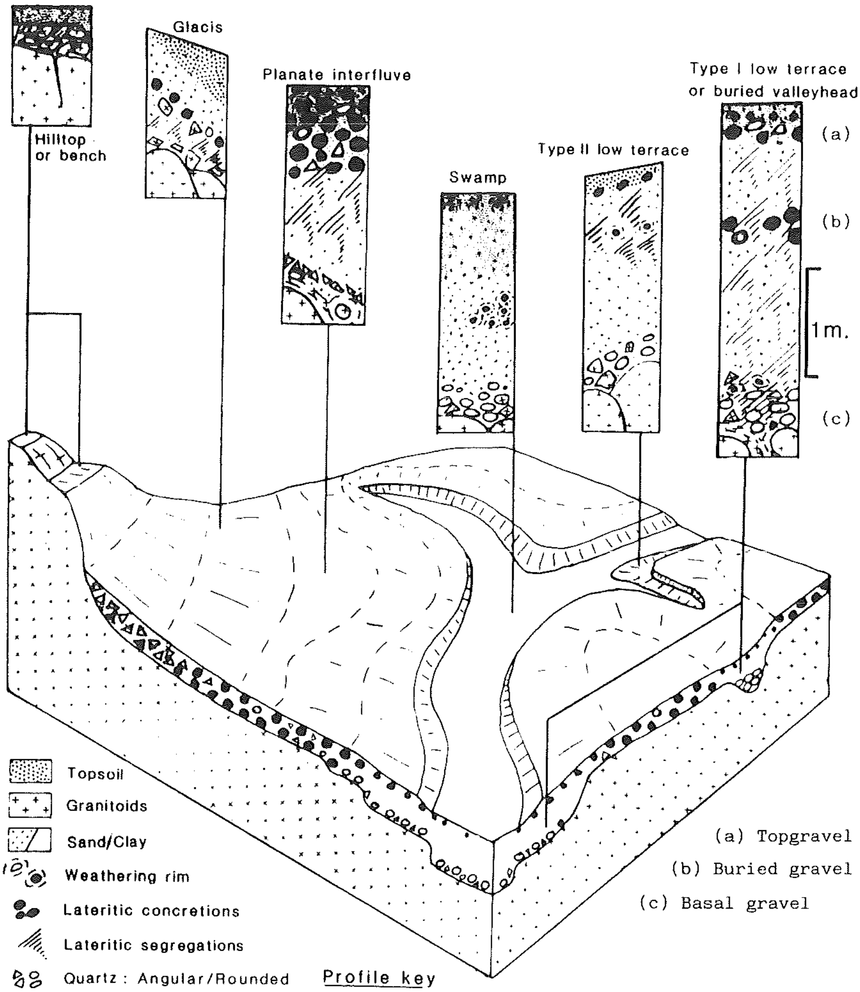

Fig. 3. – Typical morphofacies types.

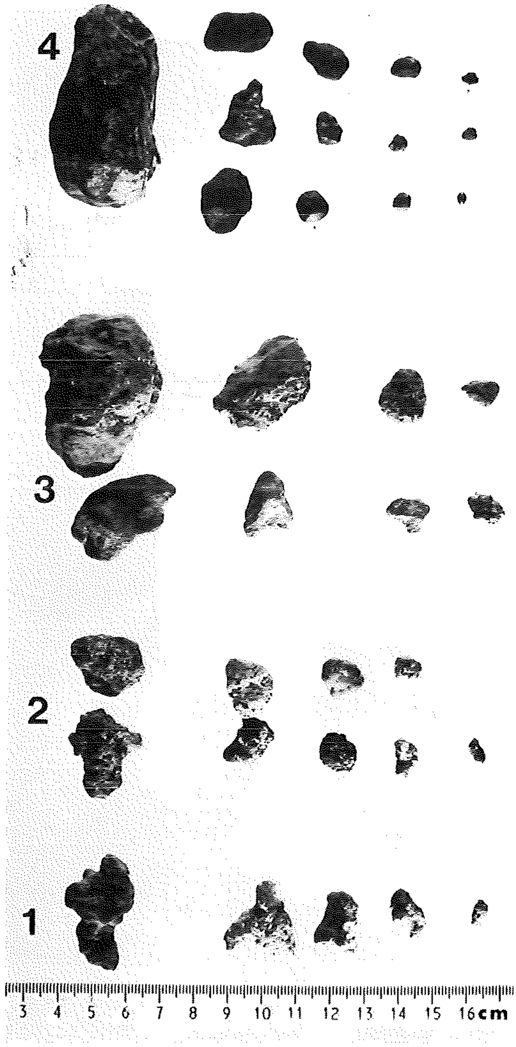

Fig. 4. – Iron sesquioxide accumulation. 4 to 1 : down-profile sequence. 1 & 2, lateritic segregations, yellow-brown to red (Munsell colours : 7.5YR 6/2 to 5YR 7/8). 3 & 4, Lateritic concretions, brown (Munsell 7.5YR 5/2 to 10YR 6/2) to black.

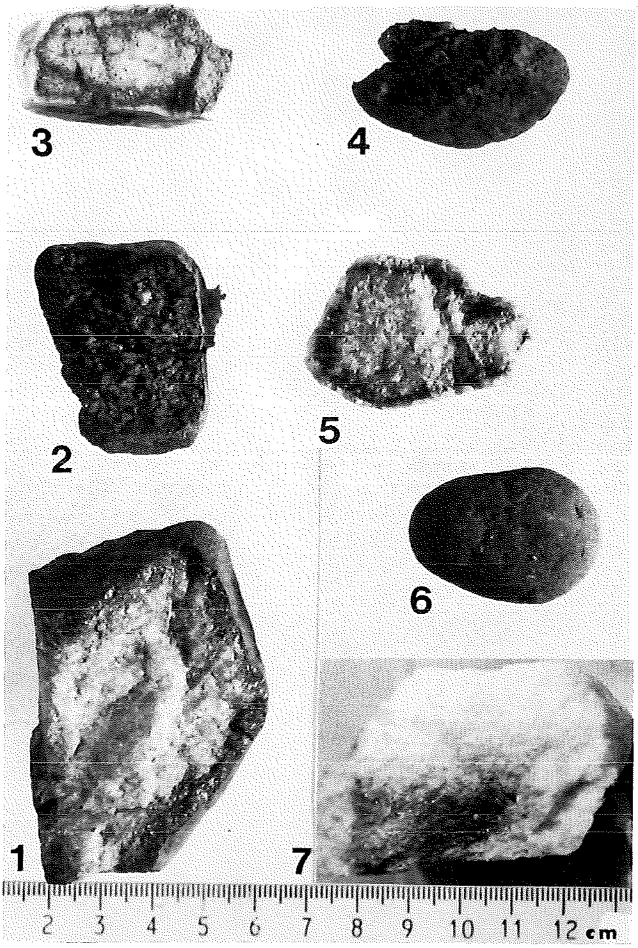

Fig. 5. — Iron-sesquioxide-stained quartz clasts. 1, 2 & 4 from planate interfluve lateritic gravels (red-brown staining) ; 7 from sloping interfluve palaeo-rill (red-brown to yellow-brown staining) ; 6, Type I terrace pebble (red-brown to pink surface staining) ; 3 & 5 valley floor and Type II pebbles (red to yellow-red staining).

Table 1

Morphometric data and variations in gravel layer texture (mean percentages)

(Number of samples in brackets)	Hillside benches (4)	Footslopes (4)	Proximal glacis slopes (7)	Distal glacis slopes (8)	Planate inter-fluves (10)	Sloping inter-fluves (9)	Swales (7)	Inter-fluve rims (8)	Low Terrace I (8)	Low Terrace II (14)	Valley swamps (7)	River floodplain (4)
Slope angle	2.0	10.00**	4.7**	2.9*	0.8**	3.2*	5.2**	5.9**	2.8**	4.5	1.0	0.7
Profile depth (m)	0.83*	0.68	1.15*	1.42**	1.50**	1.61**	1.84	1.57*	2.55**	1.62**	1.50**	2.90
Topsoil thickness	0.14	0.23	0.24*	0.43*	0.22	0.21	0.16	0.14	0.30	0.30	0.43	0.52
Top gravel thickness	0.61*	0.33	0.35	0.26	0.39	0.55	0.24**	0.46	0.17	0.01	0.03	0.00
Basal gravel thickness	0.00	0.00	0.00	0.01	0.04	0.02	0.14	0.02	0.25**	0.23**	0.40*	0.30*
Gravel Layer composition (% by weight)												
Clay + silt	26.8*	27.8	28.0	31.7**	34.4**	29.2**	30.9**	35.6**	37.1**	34.5*	17.3*	19.3*
Sand	32.1	41.2*	40.1*	37.8**	30.2**	27.9**	36,2**	31.9*	38.9**	42.1**	55.6**	59.7*
Gravel	41.0**	31.0**	32.0*	30.5*	35.4*	42.9*	24.5**	32.4**	24.0	23.3*	27.0*	21.2

Coefficients of variation : ** 10-30%   * 30-50%   Blank, + 50%

the interfluve margins ; and (iv) rare pockets of rounded gravel in the hillside bench, glacis and planate interfluve morphofacies types. The variations in the nature of rounded quartz gravel across the landscape have important morphogenetic implications and will be discussed in detail later.

Variations across the landscape

From Table 1 and Table 2 it is clear that the stratigraphic setting, texture and petrographic composition of the gravel layer varies according to its position in the landscape.

From the hilltops, hillsides and footslopes, to the distal glacis slopes the gravel layer becomes thinner and is buried under a progressively thicker layer of colluvium. From the hilltop to the proximal glacis there is a shift in petrographic composition from a gneissic rock gravel to an angular quartz rock gravel, with the distal glacis having a lateritic gravel dominated by segregations. The calibre of the gravel decreases with distance downslope ; whilst the proportion of fine material (clay + silt) in the gravel layer shows a progressive downslope increase, culminating in the planate interfluve.

The gravel layer of the planate and gently sloping interfluves contains the highest mean percentages of both lateritic concretions and fragments of massive laterite (47-66%). The mean thickness of the gravel increases more than 100% from the distal glacis slopes to the gently sloping interfluves. Towards the interfluve rim and in the swale zones the topsoil becomes thinner and there is a marked increase in the proportion of lateritic segregations.

In the foodplain and terrace zone the dominant gravel is the rounded quartz type, buried under at least 1.0 m of alluvial/colluvial fill. The proportions of lateritic clasts show a progressive decrease from the interfluve rim to the valleyfloor : the mean percentage of lateritic segregations falling from 40% in the Type I terraces, to less than 8% in the floodplain gravels. The proportion of fine material in the gravel layer shows a similar decrease towards the valleyfloor.

Morphogenetic implications

The variations in gravel layer composition outlined above, plus micromorphological examinations, indicate that inputs, storages and exports of weathered material occur from the interfluve crest to the valleyfloor. This echoes TRICART's (1965) concept of sections of the landscape where the exportation, transportation and accumulation of weathered material occur.

Table 2

Variations in gravel layer petrography by morphofacies types (mean percentages)
Note : Rounded quartz ratio obtained by excluding Lateritic segregations from the gravel petrography calculations

(Number of samples in brackets)	Hillside benches (4)	Footslopes (4)	Proximal glacis slopes (7)	Distal glacis slopes (8)	Planate inter-fluves (10)	Sloping inter-fluves (9)	Swales (7)	Inter-fluve rims (8)	Low Terrace I (8)	Low Terrace II (14)	Valley swamps (7)	River floodplain (4)
Angular quartz	5.1	27.4	33.8	22.5	25.2	13.0	18.4	10.8	22.7	35.3	24.5	49.1
Granitic fragments	49.0	43.0	11.4	3.7	1.5	1.1	0.6	2.6	10.0	26.3	22.6	15.2
Rounded quartz	0.5	0.0	13.0	8.4	5.2	1.9	3.2	0.7	20.2	11.6	20.7	13.1
Laterite segregations	23.4	12.7	21.4	51.7	8.0	17.8	41.0	30.0	41.3	18.0	18.8	7.8
Vermiform laterite	4.1	1.6	0.0	0.0	2.8	5.3	0.1	2.3	0.0	0.0	0.0	0.0
Laterite concretions	25.2	16.9	18.5	11.8	44.3	60.2	18.5	28.9	4.9	2.8	7.5	14.7
Rounded quartz ratio	0.6	0.0	17.7	15.4	6.2	2.5	8.8	7.6	31.1	14.8	22.3	14.2
% of pits with heavy minerals	50.0	0.0	28.6	37.5	40.0	44.4	100	25.0	78.0	64.3	100	100

More recent studies (ARNETT & CONACHER 1973, HUGGETT 1977) have emphasized that the drainage basin is the fundamental unit of landscape morphogenesis, with down-slope transfers and temporary storages of material between the interfluve crest and the valleyfloor, and down-valley losses of material from the drainage basin along the valley floor. The work of BÜDEL (1957) and THOMAS (1975, 1983) indicates that the supply of material for export from tropical drainage basins is maintained by the differential weathering of bedrock across the landscape. These studies support the view that the form of the weathering front, and the differing degrees to which surface and near-surface processes can remove (or store) weathered material, dictate the relief of the drainage basin.

Process domains

Both GLAZOVSKAYA (1968) and SIMONSON (1978) have ascribed variations in soil types to the differing durations and intensities with which geochemical and biochemical processes interact across the landscape. It appears that most of the variations between morphofacies types within the Koidu basin can be attributed to the variable influences of three major *process domains.* It has to be emphasized that the operation of these process domains can only be deduced from the presence of materials that are assumed to have resulted from a given set of processes. The allocation of each morphofacies type to a given process domain is partly based on the study of profile stratigraphies, percentage clay depth functions, silt : clay ratios and micromorphological studies of topsoil, gravel, colluvial/alluvial fill and saprolite layers. However, the composition of the gravel layer was found to be the most effective indicator of contemporary process domains, which are summarised in Fig. 6.

1. *The Residual domain* is dominated by pedogenesis and associated weathering.
2. *The Colluvial domain* is dominated by slopewash, soil/saprolite stripping, lateral eluviation and the seasonal precipitation of iron sesquioxides at seepage zones.
3. *The Fluvial domain* is a hydromorphic environment where the main processes are channelled flow, the rolling and rounding of clasts, the dissolution of iron sesquioxide compounds and the maximum lateral eluviation of weathered material.

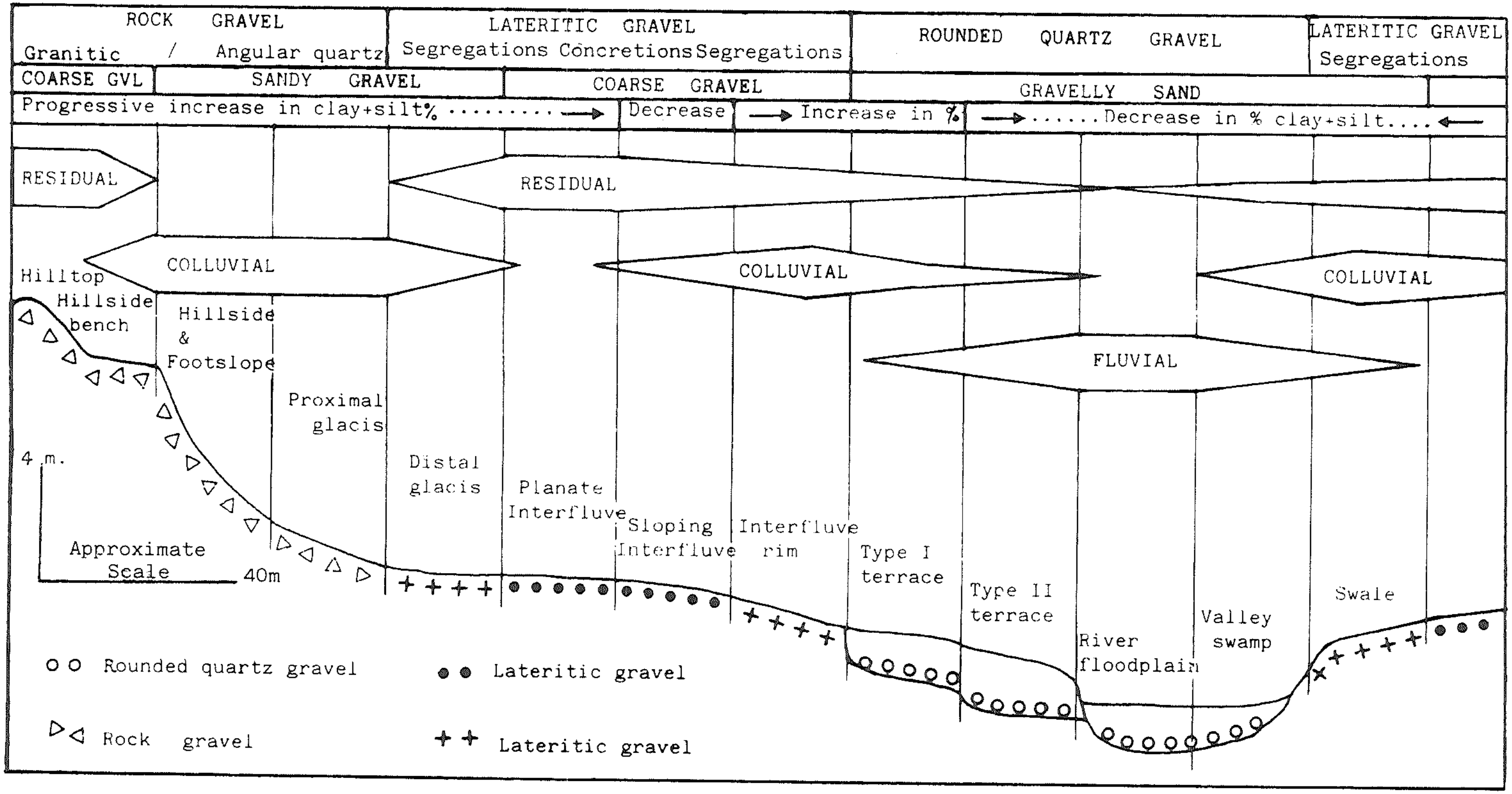

Fig. 6. – Process Domain interaction and variation in gravel layer composition.

"Fluvial domain" is a term of convenience, because three distinct process suites interact within it : (i) sediment movement in concentrated channel flow ; (ii) the chemical processes associated with hydromorphic conditions, notably carbonation, hydrolysis and reduction ; and (iii) the throughflow of vadose or valley floor water with the lateral eluviation of clays and sesquioxides. Given that river channels in the Koidu basin are rarely in contact with valleyfloor bedrock and that 80% of the drainage network consists of channelless valley swamps (HALL, 1974), the contemporary Fluvial domain appears to be dominated by process suites (ii) and (iii). A similar morphodynamic environment has been reported from the humid tropical zone of Sri Lanka by BREMER (1981a) and SPÄTH (1981).

This process domain concept is related to the genetic classification of gravel layers proposed by MARCHESSEAU (1966) : (i) "type eluvial", residual accumulation of gravel with the removal of fine material by surface wash ; (ii) "type colluvial", the gravel layer thickens downslope as a result of mass movements and surface wash ; (iii) "type alluvial", formed by fluvial deposition. The fundamental difference between the two concepts lies in the realisation over recent years that sub-surface processes, such as piping and lateral eluviation, rather than the more obvious surface processes of slope wash and rilling, play a crucial role in the accumulation of a gravel layer.

Support for the importance of lateral eluviation as a key process in the denudation of Tropical landscapes comes from the work of NYE (1954), who noted that the gravel layer was a zone of water seepage ; and ALEVA (1983), who stated that the gravel layer is the main conduit for the lateral transfer of water and weathered material. RUXTON (1957) and recently O'BRIAN and BOUL (1984) noted that the relative impermeability of the saprolite led to a zone of preferred water flow over the saprolite surface. In the Koidu area, the juxtaposition of interfluve zone gravel layers directly over saprolite, points to the gravel layer acting as a "conveyor belt" for the removal of material from the weathering front, partly by the removal of gravel clasts by mass movement, but primarily by the loss of fine material due to lateral eluviation. This is supported by the excavation of a colluvially infilled valleyhead in the Kania study area (Fig. 1) by THOMAS and THORP (1985) : this revealed a "washed" layer depleted in clay + silt at the basal gravel/saprolite interface.

Micromorphological examinations of valleyfloor and terrace morphofacies types revealed the basal gravel layer to be the main site of lateral eluviation. The throughput of fine material is far less effective in the Type I and Type II terraces, where mean clay + silt values were between 34% and 38%, than in the valley swamps and floodplains, where mean clay + silt values were between 17% and 20%.

Process domain indicators

The variations in gravel layer composition across the landscape are indicative of the varying intensities at which the process domains outlined above interact across the landscape (Fig. 6). Two gravel layer components in particular, lateritic clasts and quartz clasts, show morphological variations that are clearly related to the interaction of different process domains.

Lateritic clasts show morphological variations both down-profile and down-slope. The down-profile sequence appears to be a type that occurs commonly in the Tropics (McFarlane, 1976, 1983 ; Coventry *et al.* 1984, Debaveye & De Dapper 1986). There is a general progression from soft, irregularly-shaped iron sesquioxide segregations in the saprolite and at the base of the lateritic gravel layer, with hard irregularly-shaped concretions dominating the lower section of the gravel layer, and very hard round concretions dominating the top of the gravel layer (Fig. 4).

Across the landscape, the highest proportions of lateritic segregations in the gravel layer occur at the sites where both surface wash and groundwater seepage are most likely to occur. These sites are the distal glacis slope, the interfluve rim, the swales and the junction of the interfluve and the terraces (Fig. 3 & 6). Even though lateritic segregations occur in saprolite throughout the landscape, these sites are where (a) there is a relatively large supply of weathered material ; (b) where soil/saprolite stripping is most likely to occur ; and (c) where seasonal differences in soil microclimate allow the induration of iron sesquioxide segregations.

Mineralogical analyses of lateritic gravels in south-east Sierra Leone by Westerveld (1969) indicate that the factors that differentiate lateritic concretions from segregations are twofold : first, the degree of exposure to indurating, aerobic conditions ; and second, the degree of wear by surface transport. However, the results from the Koidu study areas indicate that a third factor, pedogenesis, is particularly important in the transformation of segregations to concretions. If transport and wear was the most important factor then the highest proportions of concretions should be at the Colluvial domain sites where surface wash occurs most frequently. Reference to Table 2 shows that this is not the case, the highest proportions of concretions occur in the gravels of the planate and gently sloping interfluves.

The planate interfluves are the "core" of the Residual domain : uniform percentage clay depth functions (Northcote 1971) and micromorphological analyses indicate that pedogenetic processes and weathering predominate, with minimal lateral eluviation or slopewash. As the highest proportion of concretions occurs in the sloping interfluve, the optimum conditions for concretion formation appear to be intermediate between the dominantly pedogenetic processes of the Residual domain and the pronounced lateral eluviation and slope wash of the Colluvial domain (Fig. 6).

Quartz clasts occur in the gravel layer throughout the landscape, the main source of quartz gravel being quartz veins, thus the majority of quartz pebbles are rectangular in cross-section, and blade-like or rod-like after weathering and wear.

One assumption that is central to this discussion is that rounded quartz clasts are the result of wear by fluvial or colluvial processes, rather than the result of *in situ* chemical weathering. Reports of rounded quartz gravel been formed by chemical weathering are few. BOYÉ (1960, p. 16) described apparently autochthonous well-rounded gravels in French Guiana. More certain is the recent observation by MCFARLANE (1987, pers. comm.), of a quartz vein in Malawi that had been weathered to produce rounded cobbles. However, no comparable weathering was seen during the examination of numerous quartz veins exposed by surface mining in the Koidu region. Furthermore, if the proportion of rounded quartz was solely related to the amount of angular quartz fragments available for weathering, then the proportions of both angular quartz and rounded quartz should both show increases or decreases "in tandem" across the landscape. Reference to Table 2 shows that this is not the case.

The large inputs of iron sesquioxide accumulations into the gravels layer at seepage zones have obscurred the true proportions of the relatively resistant gravel components, notably angular and rounded quartz. By excluding the most transient type of iron sesquioxide accumulation, the lateritic segregations, from the calculations of gravel composition, the "Rounded Quartz Ratio" is obtained (Table 2). The Type I terrace gravel is the seen to have a higher proportion of rounded quartz than any other morphofacies type, indicating that if formed under longer-term, more stable conditions than the floodplain deposits and Type II terraces, a view supported by the C14 dating of THOMAS & THORP (1980).

The iron sesquioxide staining of quartz clasts is a useful indicator of process domains, both contemporary and past. In the planate interfluve zone, where even the quartz veins show slight iron staining, a whole range of staining can be found (Fig. 5), culminating in totally iron-stained pebbles that are so structurally weakened that they have a granular surface texture weak enough to crumble by hand. Micromorphological analyses indicate that this iron sesquioxide impregnation process is the same as the "pedoplas-

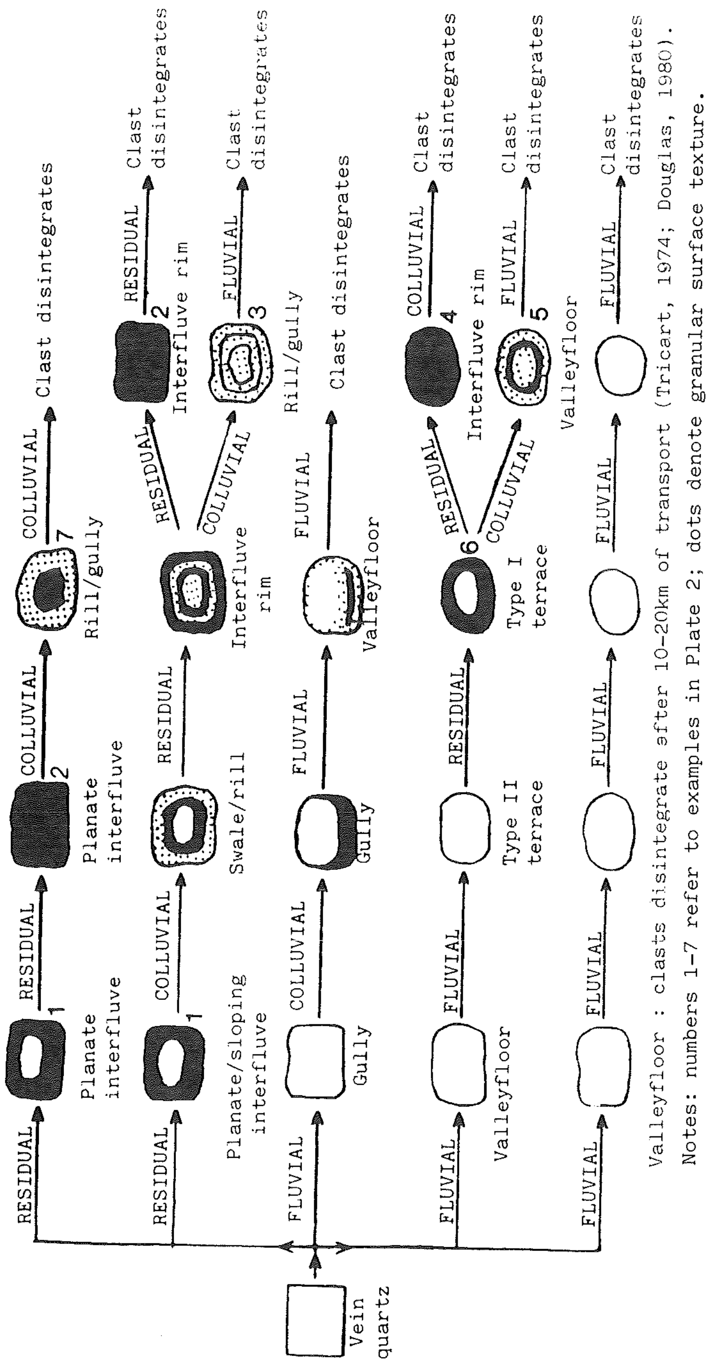

Fig. 7. – Internal morphologies of quartz pebbles and hypothesized Process Domain pathways (in capital typeset).

mation" described by ESWARAN *et al.* (1975). These iron-impregnated clasts disintegrate relatively rapidly on being transported to hydromorphic sites: they appear to be a major contributor of sand and silt to the valleyfloors. Figure 7 is an attempt to relate the various degrees of iron staining observed in quartz clasts during this study and the sites where these clast types occur, to the likely process domain pathways each clast has followed.

The rounded quartz gravels of the Koidu basin are part of both a toposequence and a chronosequence. C14 dating of valley floor and terrace deposits by THOMAS & THORP (1980) provides a time-base from which the morphological variations of the quartz clasts can be assessed. The permanently waterlogged basal gravel layer of the Recent valley floor and Early Holocene Type II terrace deposits is dominated by white, unstained, rounded quartz pebbles; whilst those of the higher-level Late Pleistocene Type I terraces have iron-stained rims. If the 'ergodic principle' is followed, the highly iron-stained rounded quartz pebbles found in the interfluve, glacis and hillside bench gravel layers must be considerably older than the valleyfloor and terrace deposits, the hillside bench gravel perhaps containing clasts of Tertiary age.

It thus appears that the variations in the amounts of rounded quartz in the gravel layer of the Koidu basin are primarily due to the occurrence of varying amounts of transport-worn quartz. Beyond the valley floor and terraces such material must be relict and indicative of ancient alluvial deposits. Supportive evidence comes from the occurrences in the interfluve and hillside bench gravel layer of autochthonous material such as Schist Belt cobbles (viz: Fig. 2) and resistant minerals such as tourmaline, corundum, staurolite, and – in the absence of local kimberlite – diamonds. Similar pockets of "ancient" rounded quartz of probable alluvial origin have been reported from interfluves in central Togo (LEVÊQUE 1979) and in Southern Australia (MILNES *et al.* 1985).

Conclusions

There has been a long-standing controversy over whether "stone-lines"/"stone-layers"/"gravel layers" result from the *in situ* weathering and pedogenesis of bedrock (e.g. STOOPS 1968, ALEVA 1983), or from erosional and depositional processes (PARIZEK & WOODRUFF 1956, FAIRBRIDGE & FINKL 1984).

The results of this study indicate that the entire landscape of the Koidu basin, apart from areas of bare rock, is blanketed by a layer of gravel clast accumulation. The composition and stratigraphic position of this gravel layer show considerable variation across the landscape, indicating that more than one set of processes is reponsible for its formation. Twelve major morpho-facies types have been defined on the basis of surface slope, stratigraphy, micromorphology and the petrography of the gravel layer.

Three process domains were recognised : (i) Residual, dominated by weathering and pedogenesis ; (ii) Colluvial, with slopewash, lateral eluviation and the seasonal precipitation of iron sesquioxide compounds ; (iii) Fluvial, where clasts are transported and eroded by channelled flow, and where hydromorphic conditions produce the dissolution of iron sesquioxide compounds, with their removal by lateral eluviation. The variations in the nature of the gravel layer apparently result from the differing intensities at which these process domains interact across the landscape.

These process domains appear to have shifted in their areal extents over time in response to environmental changes. The occurrences of autochthonous clasts in the gravel layers of the planate interfluves and hillside benches indicate pronounced drainage modification and widespread relief inversion in the Koidu basin since the late Tertiary. This "ancient alluvial" material has been reworked during the relatively short-term environmental instability events (soil/saprolite stripping and cut-and-fill episodes) that have occurred since the late Pleistocene. During the last event the Fluvial domain expanded at the expense of the Colluvial domain to produce extended valleyheads and palaeo-rills. The Colluvial domain has since expanded, infilling the valley heads with colluvium. Throughout these events the "core" of the Residual domain, the planate interfluve zone, has remained virtually undisturbed.

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REFERENCES

ALEVA, G. J. J. 1983. On weathering and denudation of high terrace interfluves and their triple planation surfaces. – *Geol. en Mijnb.*, **44** : 45-58.

ARNETT, R. R. & CONACHER, A. J. 1973. Drainage basin expansion and the nine unit landsurface model. – *Austral. Geographer*, **12** : 237-249.

BOYÉ, M. 1960. Morphométrie des galets en Guyane Française. – *Rev. Géomorphol. dyn.*, **11** (1-3) : 13-22.

BREMER, H. 1981. Reliefformen und reliefbildende Prozesse in Sri Lanka. – *Relief, Boden, Paläoklima,* **1** : 7-184.

BÜDEL, J. 1957. Die Doppelten Einebnungsflachen in den feuchten Tropen. – *Z. Geomorph.* N.F., **1** : 201-288.

COVENTRY, R. J., TAYLOR, R. M. & FITZPATRICK, R. W. 1983. Pedological significance of the gravels in some red and grey earths of central north Queensland. – *Austral. J. Soil Res.*, **21** : 219-240.

DEBAVEYE, J. & DE DAPPER, M. 1986. Laterite, soil and landform development in Kedah, Peninsular Malaysia. – *Z. Geomorph.* N. F.

DOUGLAS, I. 1980. Pebbles of the Sungai Gombak. – *Malays. J. Trop. Geog.*, **2** : 1-7.

ESWARAN, H., SYS, C. & SOUSA, E. C. 1975. Plasma infusion – a pedological process of significance in the humid tropics. – *An. Edofologia y Agrobiol.*, **34** (9-10) : 655-673.

FAIRBRIDGE, R. W. & FINKL, C. W. Jr. 1984. Tropical stone-lines and podzolized sand plains as palaeoclimatic indicators for weathered cratons. – *Quaternary Sci. Rev.*, **3** : 41-72.

GLAZOVSKAYA, M. A. 1968. Geochemical landscapes and types of geochemical soil sequences. – *In* : Trans. 9th Internat. Congr. Soil Sci. (Adelaide), Vol. **4**, I.S.S.S., London, pp. 303-312.

HALL, P. K. 1974. The diamond fields of Sierra Leone. – *Sierra Leone Geol. Survey, Bull.*, Freetown, 5, 133 pp.

HUGGETT, R. J. 1975. Soil landscape systems, a model for soil genesis. – *Geoderma,* **13** : 1-22.

KRUMBEIN, W. C. 1941a. Measurement and geological significance of shape and roundness of sedimentary particles. – *J. Sed. Pet.*, **11** :64-72.

LEVÊQUE, A. 1979. Pedogénèse sur le socle granito-gneissique du Togo – différentiation des sols et remaniements superficiels. – *Trav. et Doc. de l'O.R.S.T.O.M.*, Paris, 108, 224 pp.

MCFARLANE, M. J. 1976. Laterite and landscapes. – Academic Press, London, 151 pp.

MCFARLANE, M. J. 1983. Laterites. – *In* : GOUDIE, A. & PYE, K. (eds.), Chemical sedimentation and geomorphology. Academic Press, London, pp. 7-58.

MARCHESSEAU, J. 1966. Étude minéralogique et morphologique de la stone-line au Gabon. – *Asequa, Bull.*, **10** : 15-19.

MILNES, A. R., BOURMAN, R. P. & NORTHCOTE, K. H. 1985. Field relations of ferricretes and weathered zones in southern South Australia : a contribution to "laterite" studies in Australia. – *Austral. J. Soil Res.*, **23** : 441-465.

NORTHCOTE, K. H. 1971. A factual key for the recognition of Australian soils. – Rellin, Adelaide.

NYE, P. H. 1954. Some soil forming processes in the humid Tropics. Part 1 : A field study of a catena in the West African forest. – *J. Soil Sci.*, **5** : 7-27.

O'BRIEN, E. L. & BOUL, S. W. 1984. Physical transformation in a vertical soil/ saprolite sequence. – *Soil Sci. Soc. Am. J.*, **48** : 354-357.

PARIZEK, E. J. & WOODRUFF, J. F. 1956. Description and origin of stone-lines in soils of the southwestern States. – *Am. J. Sci.*, **65** : 23-34.

RUXTON, B. P. 1958. Weathering and sub-surface erosion in granite at the Piedmont Angle, Balos, Sudan. – *Geol. Mag.*, **95** : 353-377.

SIMONSON, R. W. 1978. A multiple-process model of soil genesis. – *In* : MAHANEY, W. C. (ed.), *Quaternary Soils.* Geobooks, Norwich, pp. 1-25.

SIVARAJASINGHAM, S. 1968. Soil and land use survey in the Eastern Province. – Rept. to Govt. of Sierra Leone, UNDP/FAO, TA 2584, Rome.

SPÄTH, H. 1981. Bodenbildung und Reliefentwicklung in Sri Lanka. – *Relief, Boden, Paläoklima,* **1** : 185-238.

STOOPS, G. 1968. Micromorphology of some characteristic soils of the lower Congo (Kinshasa). – *Pedologie* (Gand), **18** (1) : 110-149.

TEEUW, R. M. 1986. The geomorphology and surficial geology of the Koidu area, Sierra Leone. – Ph. D. Thesis, University of Stirling, Scotland, 254 pp. (unpublished).

THOMAS, M. F. 1974. *Tropical geomorphology.* – Macmillan, London, 332 pp.

THOMAS, M. F. 1983. Contemporary denudation systems and the effects of climatic change in the humid tropics – Some examples from Sierra Leone. – *In* : BRIGGS, D. J. & WATERS, R. S. (eds.), *Studies in Quaternary geomorphology.* Geobooks, Norwich, pp. 195-214.

THOMAS, M. F. & THORP, M. 1980. Some aspects of the geomorphological interpretation of Quaternary alluvial sediments in Sierra Leone. – *Z. Geomorph.* N.F. Supp. – Bd. **36** : 140-161.

THOMAS, M. F. & THORP, M. 1985. Environmental change and episodic etchplanation in the humid tropics of Sierra Leone. – *In* : DOUGLAS, I. & SPENCER, T. (eds.), Environmental change in the Tropics. George Allen & Unwin, London, pp. 239-267.

TRICART, J. 1965. Principes et méthodes de la géomorphologie. – Masson, Paris, 496 pp.

WESTERVELD, D. H. 1969. Morphological and mineralogical differences between two types of iron concretions in a soil of Sierra Leone, West Africa. – Ir.(M.Sc.) Thesis, Wageningen Agric. University, Netherlands, 250 pp.