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Geomorphology and soils of the Padang Terap District, Kedah, Peninsular Malaysia

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Abstract: Geomorphological and pedological field surveys were carried out in a joint program in the Padang Terap District of Kedah, Peninsular Malaysia.

A chronosequence of landforms was established and reveals (1) remnants of an older pediplain (2) a surface comprising younger pediments (P_2), shallow depressions (D_2) and river terraces (T_2) and (3) a most recent river terrace (T_1). The evolution of the landforms is explained by a concept of changing vegetation covers, from dense forest to an open cover (e.g. savanna) as a response to changing Quaternary climatic conditions.

Important layers of volcanic ashes were found in the upper part of the Padang Terap basin. Their geomorphic position,—on top of T_2 and eroded by T_1 —and their age (75,000 y B.P. or 30,000 y B.P.) permit the postulation of an important drier climatic phase for the area in the Late Pleistocene.

The field characteristics of the soils, developed on shale and clayey alluvium, are markedly different on the various landforms. Their physico-chemical and mineralogical characteristics, and their weathering indices fully support the proposed landscape model and chronology.

INTRODUCTION

Pedological and geomorphological field investigations were carried out in the Padang Terap area during the period 1980–1983 by Debaveye (Debaveye *et al.,* 1984 and De Dapper (1981b) respectively. They were part of a joint program between the Department of Agriculture of Malaysia, the Department of Development Co-operation of the Ministry of Foreign Affairs of Belgium and the Geological Institute of the Ghent State University in Belgium.

The geomorphology of the area was studied following the reconnaissance soil survey. In the course of the semi-detailed soil survey, the geomorphological survey was found to be an important tool in the understanding of the soil landscape, its distribution, evolution and correlation.

The present article presents the preliminary results of this interdisciplinary co-operation.

ENVIRONMENTAL SETTINGS

The Padang Terap District is located in the State of Kedah in the northwest of Peninsular Malaysia. Kuala Nerang, the administrative centre for the district is situated at 6°14′N and 100°38′E. The study area is partly bounded by Thailand and covers an area of about 1,360 km^2.

The bedrock of the area consists almost exclusively of sedimentary rocks of the Middle to Upper Triassic Semanggol Formation. They consist of interbedded sandstone and shales, with preponderance of lutites, that locally contain interbeds and lenses of conglomerate and chert. A large post-Semanggol granitic pluton occurs in the northwest corner of the district.

Climate in Kedah is "Am si" following the Köppen-classification system, Tropical Rainy Climate with a monsoonal type having a moderately dry season.

The mean monthly air temperature is fairly constant, averaging around 27°C throughout the year.

The average annual rainfall is high (2,128 mm for Kuala Nerang) but is still one of the lowest on the Peninsula. Its variation over the years amounts to 13 %. On a monthly basis however the rainfall is much more irregular. According to Nieuwolt (1982) the area can expect an "agricultural drought" (a period during which the rainfall is below 40 % of the potential evapotranspiration, corresponding to an equivalent of 40–60 mm of rainfall) once in five years, from December to March.

Following the Newhall (1975) system of computation, the soil temperature régime is isohyperthermic. The soil moisture regime is udic on average (Laboratorium Fysische Aardrijkskunde en Regionale Bodemkunde, 1981), although in three out of ten years the soil moisture regime is ustic (Debaveye *et al.*, 1984).

The natural vegetation consists of a lowland Dipterocarp forest (52 % of the area), while secondary forest and a succession of shrubs occurs on 12 % of the area.

The general pattern of land use in the district is one of extensive agricultural development and settlement on the large river valleys and the adjacent low hills. Rubber, sugarcane and rice are the major crops in the area.

GEOMORPHOLOGY

Macromorphography

The investigated area mainly coincides with the drainage basin of the Padang Terap river (Fig. 1).

The plain of the Padang Terap river and its main tributaries, the Pedu and the Tekai rivers, is surrounded by an upland at an average elevation of 400 m a.s.l. This upper surface is strongly dissected and a network of structural axes, trending N-S, NNW-SSE and NNE-SSW is clearly recognisable.

The plain itself, where elevations range between 15 m a.s.l. and 50 m a.s.l., is subdivided by a great number of parallel ridges whose crests range between 100 m a.s.l. and

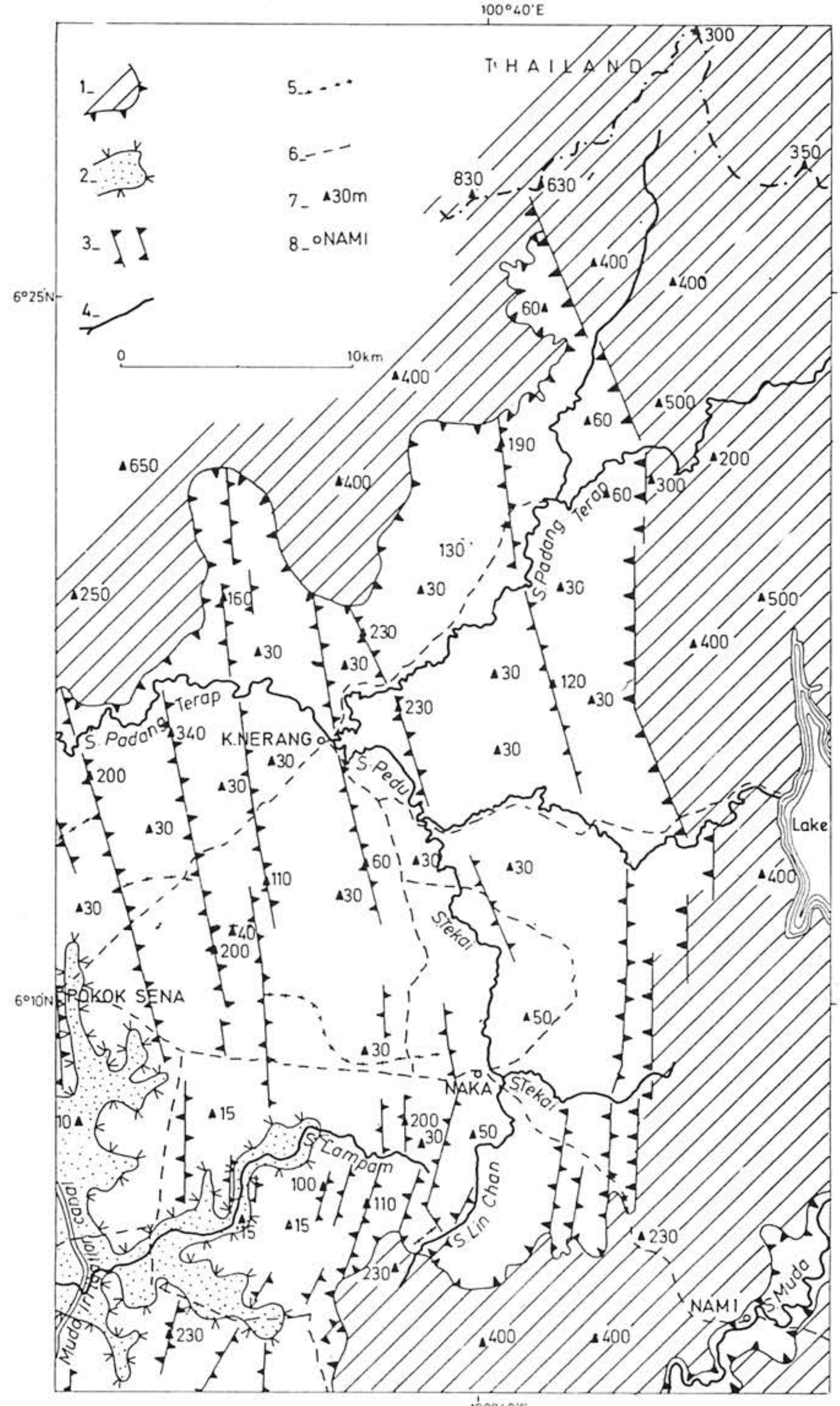

Fig. 1. Macromorphological outline of the Padang Terap District. Legend: 1 Strongly dissected upland 2 Coastal plain, 3 Ridges, 4 Main rivers, 5 Watershed S. Padang Terap—S. Lampun, 6 Principal roads, 7 Elevation in meters a.s.l., 8 Principal places.

300 m a.s.l.. The ridges emerge from the surrounding uplands and distinctly follow the structural lines of the upland.

As the ridges run almost perpendicular to the main drainage axes, the basin of the Padang Terap is compartmentalized into a number of subbasins. The outleting watergaps, in many places, form local temporary baselevels. Rapids on unweathered bedrock were observed even at the last watergap at Bukit Tinggi near the Alor Setar Airfield—just before the Padang Terap river enters the coastal plain. The coastal plain penetrates the area along the main drainage axes.

The basic geomorphic unit of the area is the compartment between two ridges. The basic morphotype—a model constructed by synthesis of common characteristics—is illustrated by a planform (Fig. 2) and by a cross-section (Fig. 14). It

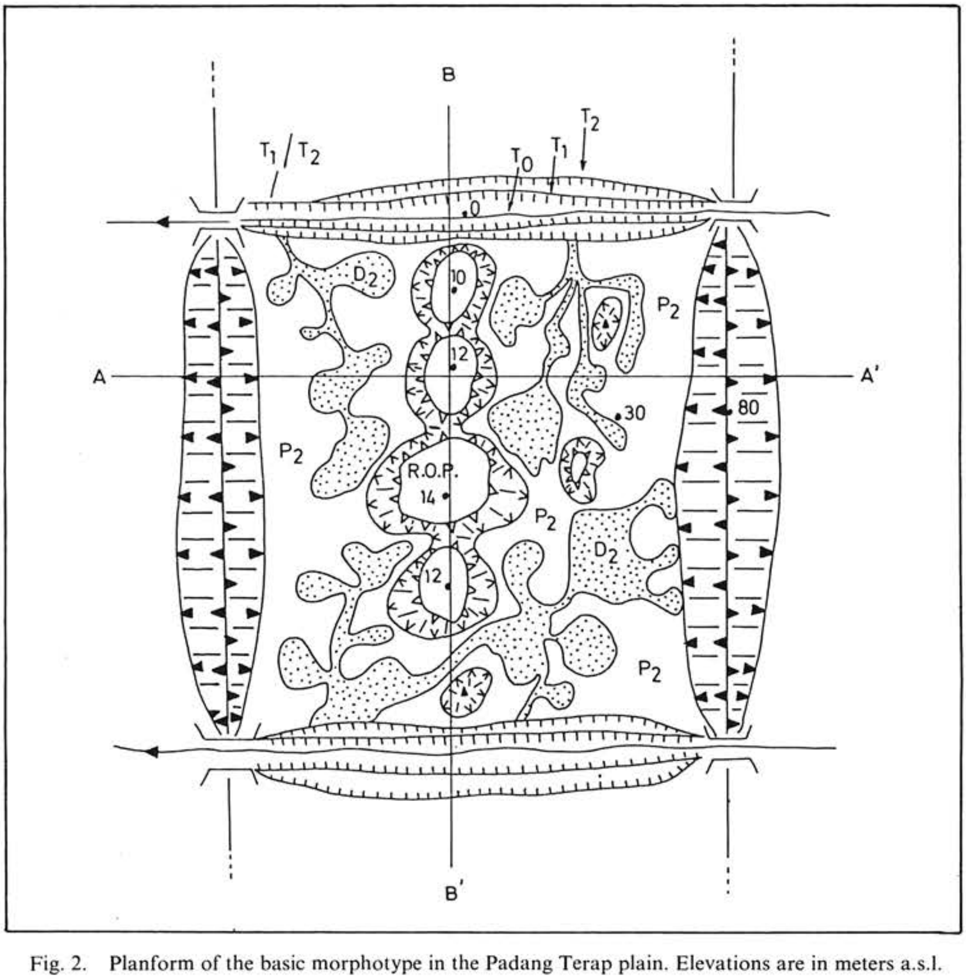

Fig. 2. Planform of the basic morphotype in the Padang Terap plain. Elevations are in meters a.s.l.

shows a regular recurrent pattern of landforms that can be subdivided into positive, negative and transition forms.

The positive forms consist of

(a) ridges that show a narrow crestline and sides sloping almost straight at values around 35°.

(b) low hills, mostly showing a flat top and commonly occurring in the central part or sometimes close to the ridges.

The negative landforms consist of a set of two river-terraces, T_2 and T_1, along the main river channels. The rivers break through the ridges by narrow watergaps. They cause a bunding effect so that at a short distance upstream of the watergap, the younger T_1-deposits can locally overlap the T_2-deposits.

Negative transition forms consist of shallow depressions which perform the extension of the T_2-terrace into the interridge area. Those depressions show a very irregular pattern of broad lobe-shaped parts linked by narrow stretches.

Positive transition forms consist of footslopes. The foot of the ridges is marked by an important concave slope break, that forms the onset of a long concave surface sloping at values from 10° to 2°. A less conspicious slope break also marks the feet of the low hills and confines shorter footslopes. The footslopes connect with the T_2-terraces either directly or indirectly through the shallow depressions.

More detailed attention will be focused on:

(1) the ridge footslopes

(2) the interridge low hills

(3) the river-terraces

Micromorphology

Ridge Footslopes

MORPHOGRAPHY AND SUPERFICIAL DEPOSITS

A typical cross-section of a ridge footslope developed on Bukit Ular Utara is shown in figure 3. A sudden break of slope—a piedmont angle—marks the transition from ridge to footslope. The footslope itself has a length of some 400 m and shows a concave profile sloping from 9.5° to 1° and grading into a shallow depression.

The superficial deposits on the footslope are shallow (less than 1 m) to somewhat deep (more than 2 m). Thus the footslope represents a degradational landform developed on the saprolitic bedrock.

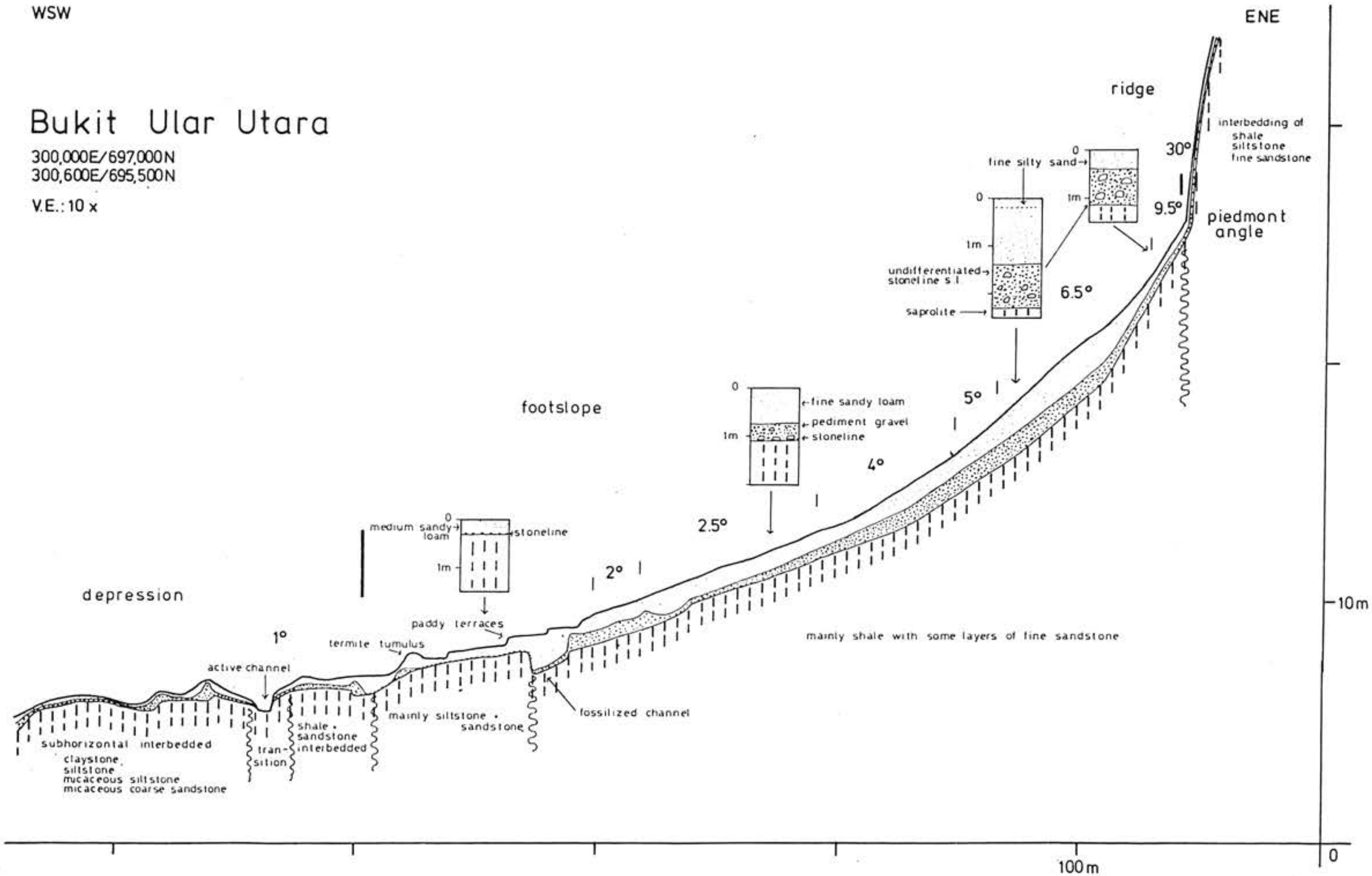

Fig. 3. Cross-section of a ridge footslope developed on Bukit Ular Utara. The Lambert co-ordinates refer to the RSO Grid (meters) of the topographical map on scale 1/63. 360 of the Directorate of National Mapping, Malaysia.

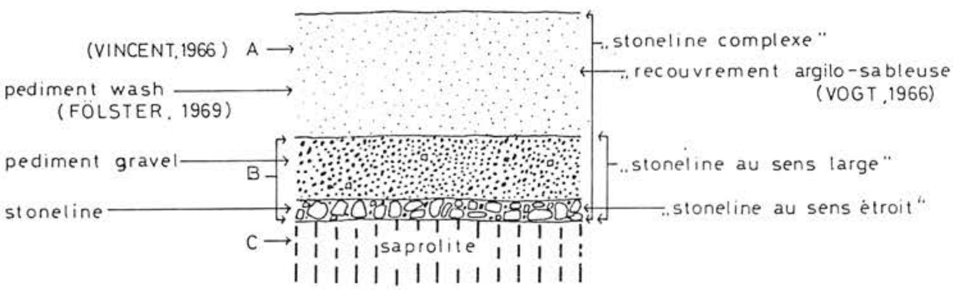

Fig. 4. Layering and nomenclature of the superficial deposits.

The superficial deposits show a typical layering as illustrated in figure 4. On top of the saprolite-C (following the Vincent (1966) nomenclature)—rests a complex stonelayer-B, composed of gravels and blocks of elements resistant to weathering.

On the lower footslopes, the stone-layer is clearly sorted, a pavement or stone-line (sensu Fölster 1969) composed of quartz, metamorphic sandstone and ferruginous rocks, ranging in size from 5 cm to 20 cm and sometimes including even larger blocks. On top of the stone-line comes a gravel layer (pediment gravel, sensu Fölster, 1969) composed of some quartz and very large quantities of ferricrete gravel (De Jong *et al.*, 1984). The gravels are subangular to rounded and range in size from 2 mm to 30 mm. They are imbedded in a fine earth matrix of varying proportions. The top layer or cover-A, is almost exclusively composed of fine grained material.

The cover and the gravel matrix always show a very close relationship with the underlying saprolite. This is illustrated by the grain size frequency distribution diagrams of the 50–250 μm fraction of layers A, B and C (fig. 5). In most cases however, the cover and the top few centimeters of the gravel matrix tend to possess a lower clay content than the rest of the debris' matrix and the saprolite. The build-up of the superficial deposits on hillslopes is very typical for tropical regions where wet seasons alternate with important dry seasons (Vogt, 1966, De Dapper, 1978 and 1981a).

MORPHOGENESIS

The superficial deposits just described have been considered both autochtonous, as the result of pedogenetic alterations of the bedrock *in situ*, and allochtonous. The "allochtonist" approach, which attributes the layering of the superficial deposits to processes of erosion and deposition, is steadily gaining ground as the "autochtonists" fail to proof any plausible mechanism for the formation of the complex (Fölster, 1969). Only one process, i.e. the transport of fine materials from the subsoil to the surface by burrowing animals, especially termites, is accepted by many authors as contributing to the formation of the cover (Tricart, 1957; De Ploey, 1964; Stoops, 1964; Alexandre, 1966, Lee and Wood, 1971, Aloni, 1975; De Dapper, 1978). The nest building termites do play an important role in Padang Terap but they cannot be held as being solely responsible for the genesis of the cover (De Dapper and Debaveye, 1984).

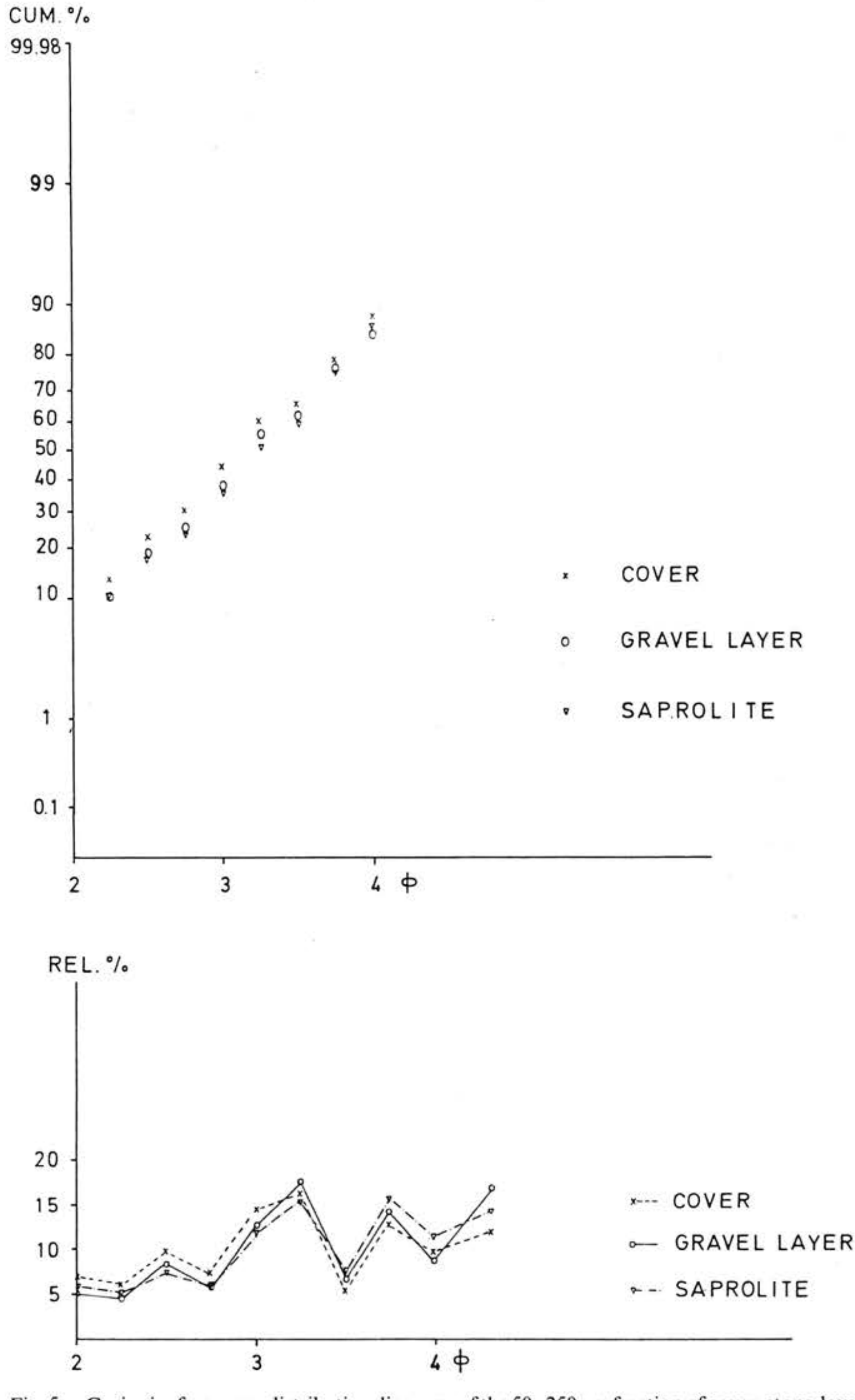

Fig. 5. Grain size frequency distribution diagrams of the 50–250 μm fraction of cover, stone-layer an saprolite.

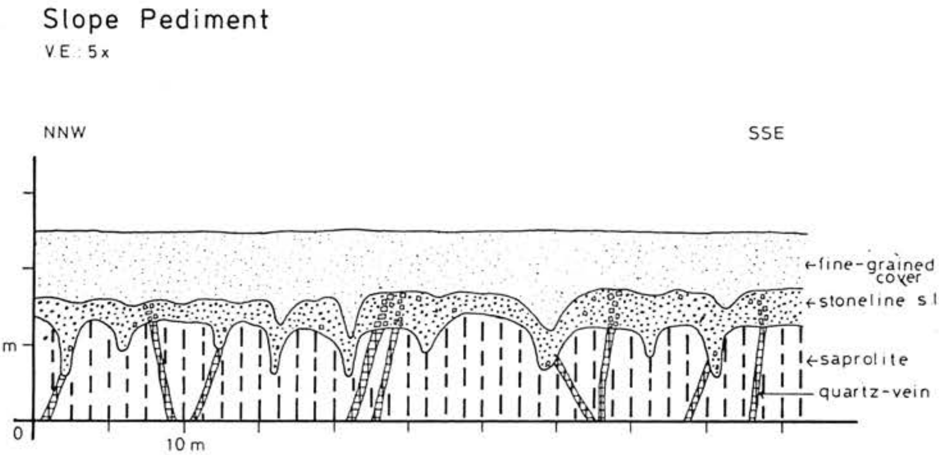

Fig. 6. Detail of the superficial deposits of a footslope on a cross-section perpendicular to the slope.

Cross-sections perpendicular to the footslope figure 6 reveal the true nature of the superficial deposits' complex. The cover and the stone-layer generally run parallel to the surface, though with many minor irregularities. Undulations and runnel-like depressions of one to several meters width characterize both the A/B and the B/C plane. It is very remarkable that on the "interfluves" between runnel-like depressions quartz veins or thin beds of sandstone continue, though somewhat broken-up, into the B-set. This observation is important because it excludes true river action or colluviation as directly responsible for the deposition of the gravel. From this pattern one has to conclude that (1) the stone-layer and cover are separate deposits differing in type of material as well as in their mode of formation but (2) that they are linked to the same phase of erosion and deposition. The only process that may lead to such a differentiation is that of slope-pedimentation or micropedimentation.

The slope-pedimentation concept was introduced by Rohdenburg (1969) following a study in SE-Nigeria and was since then described for North- and West-Africa (Rohdenburg, 1977) and Brazil (Rohdenburg, 1982). Similar processes were observed in Zäire by De Dapper (1979). The processes are characterized by a rapid parallel retreat of very low scarps (less than 1 meter to a few meters), connected with an extremely dissected area in regolith or originally non-consolidated rocks.

The critical point in a pedimentation process—a case of backwearing—is the removal of debris derived from the parallel retreat of scarps (Young, 1972). If insufficient, the accumulated debris will protect the pediment and down-wearing will dominate over backwearing. A dense network of gullies developed on the footslope can play the role of such a debris remover and form the link between scarps and rivers, the ultimate sewers.

Figure 7 shows how pedimentation acts along a gully. The gully-head, which is less than 1 m to a few meters high—will be undermined even by a small amount of

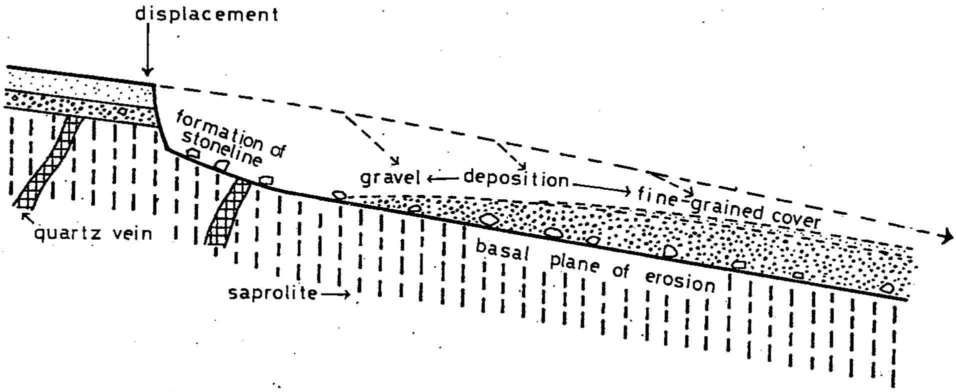

Fig. 7. Model indicating the differentiation of stoneline, pediment gravel and pediment wash below a retreating gully scarp (adapted after Fölster, 1969).

flowing water. This action will initiate collapse and hence the gully-head will retreat parallel to itself. This is a case of true backwearing but on a micro-scale. Hence the process is also referred to as micro-pedimentation. Coarse debris, too heavy to be transported by water, is deposited at the foot of the scarp or close to it, so that a stone-line is formed. The rest of the former soil mantle and saprolite is transported over the newly cut basal surface of erosion. During transport some degree of sorting takes place. Gravel mixed with fine earth is dumped onto the stone pavement and forms a pediment gravel. Fine earth is transported further downslope. Part of it covers the gravel and fills the voids at the top of the gravel layer; while another part is finally evacuated by the rivers. Silt and clay are more easily removed, resulting in a relative accumulation of sand in the cover and in the top of the gravel matrix. The final result is the differentiation of a cover on top of a stone-layer overlying the saprolite. Layers A, B and C are closely related to each other but the cover is somewhat sandier.

The block diagram presented in figure 8 shows the slope pedimentation process, the correlated sediments and the evolution with time, in more detail.

In the eo-stage or an unstable morphogenic phase, a dense consequent network of gullies develops, in this case, on an older slope pediment. The gully-heads and -sides are steep and can play the role of pedimentation scarps, whereon the superficial deposits A and B on plinthitic C, are exposed. By local lowering of the groundwater table, due to the incision, processes of irreversible hardening can already start on the plinthite. The side scarps of the gullies remain relatively stable but the head scarps move rapidly backwards. The eroded materials are transported and sorted. Most of the fine earth is removed. During the pleni-stage, as runoff increases, the side scarps of the gullies become unstable. As more fine textured sediments are supplied, part of it will be temporarily deposited mostly in the form of microfans. The gullies widen and grow close to each other until only a narrow interfluve remains. Due to the lack of erosive runoff on these reduced catchment areas, neither blocks nor gravel-size material can be transported. Only the fine material is removed by splash and sheet wash. Local

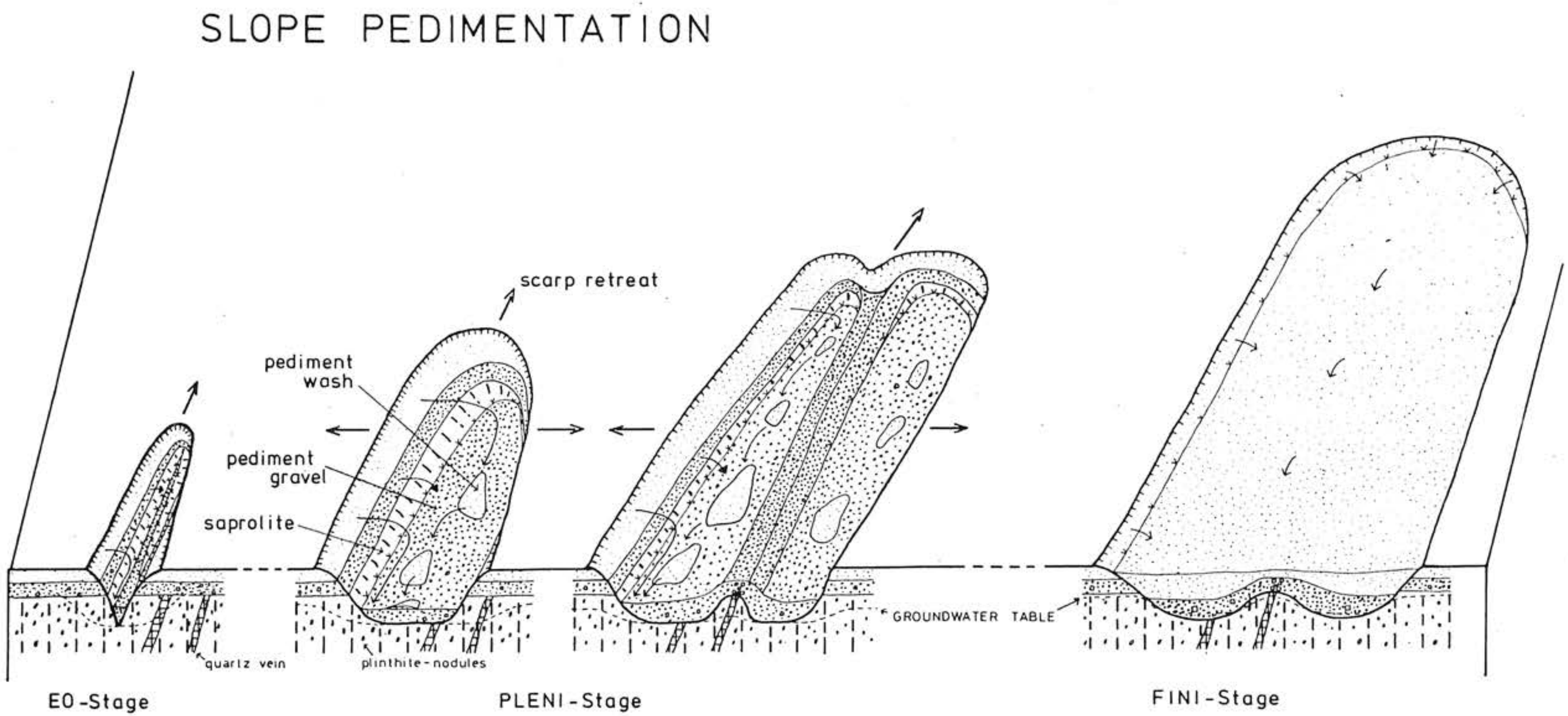

Fig. 8. Model indicating the evolution of gullies and the differentiation of the superficial deposits during a slope pedimentation cycle.

lithosomes in the bedrock, such as quartz veins and small sandstone beds, will not be removed but will continue into the gravel layer, a pattern frequently observed in the field. The head scarps will coalesce and form a complete slope pedimentation scarp retreating parallely to the backing upland.

During the fini-stage runoff weakens again. Only fine-grained material can be transported and the pediment gravel becomes fixed. Redistribution of the fine sediments results in a complete covering by pediment wash (Fölster, 1969) and a levelling of the microrelief resulting in a very gently undulating slope pediplain.

The final result of the slope pedimentation process described is (1) the development of ridges as well as footslopes through backwearing with conservation of the piedmont angle; (2) the differentiation of a pediment wash on top of pediment gravel and eventually a stone-line, overlying the saprolite; (3) the close relationship between A, B and C.

It is obvious that the slope pedimentation process described cannot operate under the natural dense forest cover that prevails in the Padang Terap area at present day. On the contrary, it frames in an environment marked by a significantly less dense vegetation, for instance a savanna.

Interridge low hills

SUPERFICIAL DEPOSITS

The low hills show striking analogies with ridge footslopes as to the superficial deposits resting on their tops. Here again, a cover and a stone-layer is present on top of the saprolite. The stone-layer however is somewhat thicker and can reach more than 1 m. It also contains less rounded elements: 35 to 60 % of the laterite gravel is subangular, whereas on the ridge footslopes 50 to 60 % of the laterite gravel is subrounded to rounded. In many cases the rims of the low hills are protected by a ferricrete cap, in which the gravel layer and the top of the saprolite have been cemented with iron (Fig. 9).

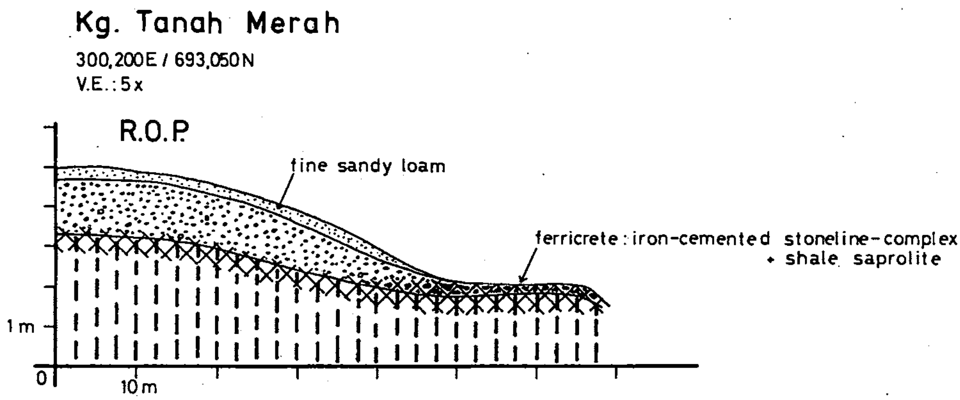

Fig. 9. Cross-section of the superficial deposits on top of an interridge low hill.

MORPHOGENESIS

The low hills are considered to be Remnants of an Older Pediplain—R.O.P.—and have resulted from a process of relief inversion.

The R.O.P. originally occupied the middle and lower sections of the ridge footslopes where maximum fluctuation of the groundwater table and hence maximum development of the plinthite took place (Fig. 10.A). During a morphogenised phase marked by dominant dissection, probably under a dense forest cover, incision occurred downslope but on places where plinthite development was minimal (Fig. 10.B). Slope pedimentation started from those drainage lines, where shallow depressions developed, consuming the remaining parts of the older pediplain and affecting the ridges (Fig. 10.C). By steepening of the hydraulic gradient at the rims of the hills, due to

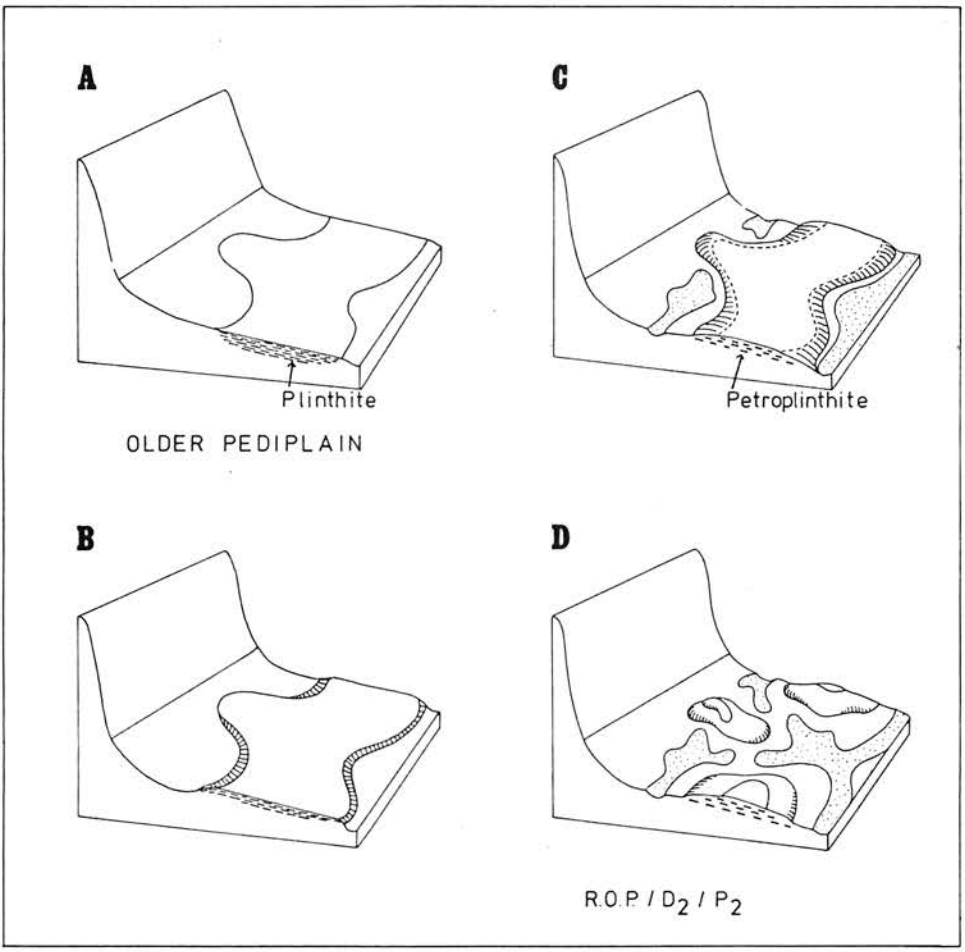

Fig. 10. Geomorphological evolution of an Older Pediplain

the inversion, ferricrete could develop and slow down the breakdown of the Older Pediplain. This type of landform development results in (1) low hills with flattops still showing the characteristics of the original Older Pediplain; (2) shallow depressions with irregular planform; (3) younger slope pediments develop out of the ridges (discussed earlier) and out of the low hills, grading into the shallow depressions (Fig. 10.D).

River terraces

MORPHOGRAPHY

Figure 11 shows a typical cross-section in a river terrace sequence. The T_2-terrace forms a narrow (50 to 100 m wide) but continuous strip along the main river channel, whereas the T_1-terrace is often eroded in convex meander bends.

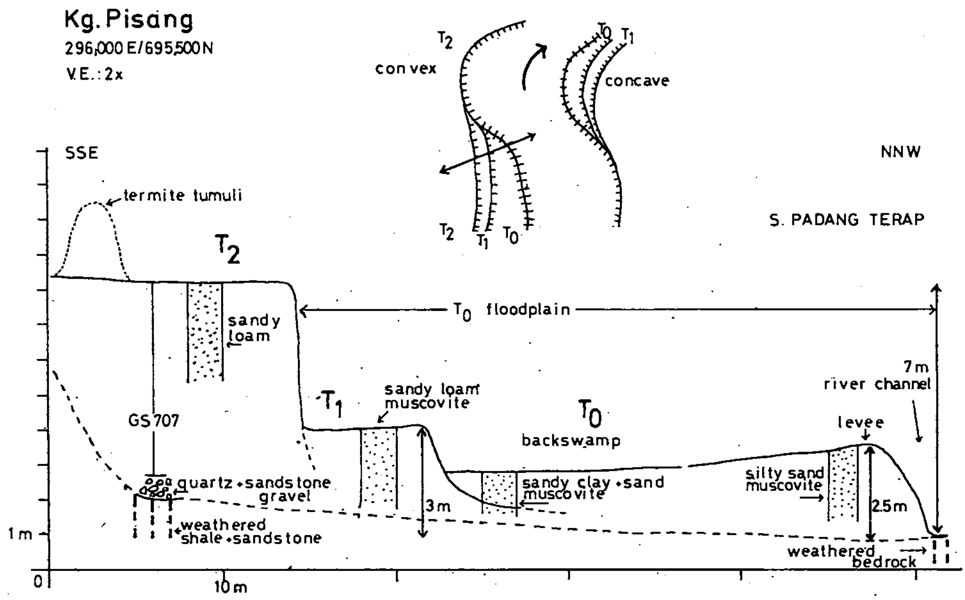

Fig. 11. Typical cross-section in a river terrace sequence along the Padang Terap river.

T_2 is located between 5 m and 9 m above the river channel and the level difference between T_2 and T_1 is some 4 to 5 m. Close and upstream of the ridges a thin veneer of T_1-deposits can be found on top of the T_2-terrace. These were probably deposited during short floods due to the bunding at the narrow watergaps.

The bed of the T_2-deposits is always cut in the bedrock. The T_1 are mostly cut and fill in the T_2-deposits. The T_1-bed is cut in the bedrock in the upper sections of the rivers.

RIVER DEPOSITS AND MORPHOGENESIS

All the field observations show that the T_2-terraces connect with the shallow depressions and the younger slope pediments (Fig. 12).

At the base of the T_2-deposits occurs a gravel layer, with a thickness of 0.50 m to 1.50 m and almost entirely composed of subangular to subrounded quartz and rare sandstone fragments. This basal gravel shows traces of current bedding and interfingers with the pediment gravel and is almost exclusively composed of laterite gravel. On the top of the basal gravel rests a 0.5 m to 6 m thick layer of fine sand clay loam to sand loam. No stratification was observed in the fine grained fill that shows close relationship with the hillwash cover on the slopes. In many cases the shallow depressions are the transition between T_2 and younger pediments. Here the basal gravel becomes very thin, in some cases only a few centimeters, and is almost entirely composed of laterite gravel. The fine textured fill is more clayey than the hillwash cover and the T_2-fill and can be considered as a local alluvium washed down from the surrounding slopes.

The younger T_1-alluvia always show rapid lateral lithostratigraphical changes from fine sandy clay to loamy fine sand. Peaty intercalations and muscovite are frequently observed. Downstream the T_1-sediments grade into the coastal plain deposits.

Morphochronology

Evolution

The landforms of the tropics, like the glacial and periglacial landforms of higher latitudes, are relict landscapes altered by the impact of younger land formation processes and reflecting the effects of changing climatic conditions. Unstable morphogenic phases, during which the landforms are shaped and erosion and deposition are the predominant processes, alternate with stable phases during which deep weathering and soil formation are predominant.

In our concept of the geomorphological evolution of the Padang Terap area, the vegetation cover, and its changes in response to the wetter or drier Quaternary climatic conditions, are the major factors controlling the formation of landforms. Other factors, such as changes in sea-level, do play a role but are complementary or are only of indirect importance. The landform evolution in Padang Terap is framed in a sequence of dense vegetation environments, such as a tropical forest where linear erosion, alternating with less dense vegetation environments, such as a tree or grass savanna, where denudation dominates over dissection. The transition from one environment to another will cause morphogenic instability, a phase of rhexistasy *sensu* Erhart (1956). Those unstable phases will be shorter than the stable phases—Erhart's phases of biostasy—as they only represent an adapting response to a disturbance of the latter balanced ones. According to the degree of adaptation, the transition from a dense forest environment to a savanna environment will cause a more pronounced instability than a change in the opposite direction. We are aware of the fact that our concept is merely based on geomorphic evidences and that it has to be corroborated by other evidences, such as palynological data.

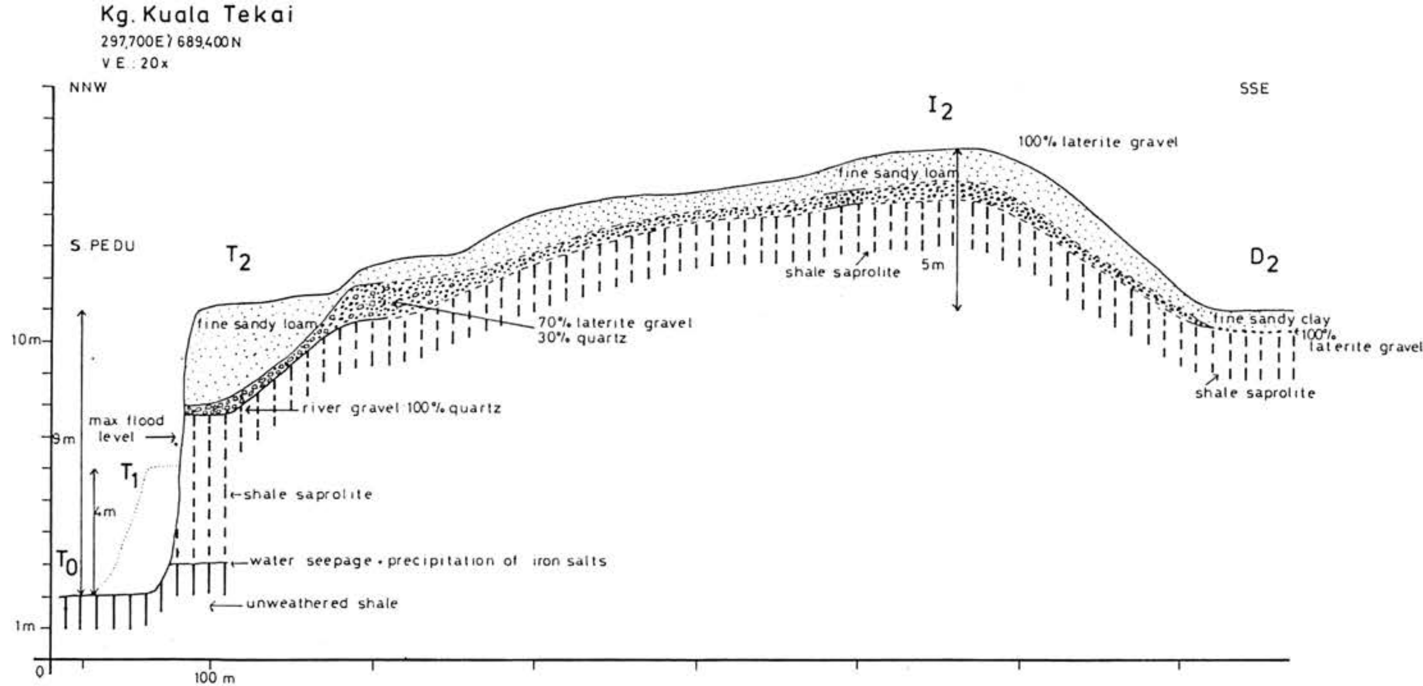

Fig. 12. Geomorphological connection between T_2-terraces, shallow depressions and younger pediments as observed near Kg. Kuala Tekai.

From the morphogenetical interpretation of the landforms and superficial deposits in the Padang Terap area, the following chronosequence can be deduced (Table 1).

An Older Pediplain was formed between the ridges during a phase of major instability, following the transition from a dense forest to a savanna environment. During the next phase of stability, soils developed and the environment gradually changed from savanna to dense forest. During the savanna stage, plinthite developed preferentially on the middle and lower sections of the pediments. During the dense forest stage, dissection prevailed over denudation. Incision took place along the main drainage axes and this also penetrated the Older Pediplain surface.

A new change to drier climatic conditions ushered in a new phase of major instability due to the transition from a dense forest to a savanna environment. Slope pedimentation started from the incision lines on the Older Pediplain and operated towards the ridges and towards the central parts of the interridge space. Remnants of the Older Pediplain (R.O.P.), younger pediments and shallow depressions were the resulting landforms. During the eo-stage of the slope pedimentation process, pediment gravels were deposited on the slopes and river gravels along the main river channels. During the pleni- and fini-stages of the unstable phase, the supply of fine material was strongly increased. Hillwash was deposited on the slopes and aggradation along the rivers built up the T_2-surface. During the new stable phase under savanna, soil formation took place. Younger pediments, shallow depressions and T_2-terraces belong to the same phase of land formation and are therefore labeled: P_2, D_2 and T_2.

The transition from the last savanna environment to a dense forest environment, which still prevails at the present-day, gave rise to a phase of minor morphogenic unstability whereby restricted valley deepening took place. The T_2-surface was cut and transformed in a T_2-terrace.

The aggradation of the T_1-deposits can be connected with the development of the coastal plain. Young soils developed on the T_1-surface.

Minor inclusion shaped the present-day river morphology and turned the T_1-surface into a T_1-terrace.

Correlation and chronology

On top of the T_2-terrace, extensive layers of volcanic ashes were observed. They were never found on the T_1-terrace and, close to watergaps they are even locally covered by T_1-deposits. These ashes were deposited all over the Padang Terap area after an eruption of the Toba in Northern Sumatra. They were next washed down and redeposited on top of the T_2-surface (Debaveye *et al.*, 1984). The presence of a fairly open vegetation could favour that process.

Similar ashes were dated 75,000 y. B.P. by Ninkovich *et al.* (1978a and 1978b) and Ninkovich (1979). Stauffer *et al.* (1980) disagreed with the hypothesis that the eruption of Toba about 75,000 years ago was a solitary event and provided radiometric dating

TABLE 1

MORPHOCHRONOLOGY

CLIMATIC ENVIRONMENT	MORPHOGENIC PHASE	GEOMORPHIC RESPONSE: HILLSLOPES	GEOMORPHIC RESPONSE: RIVER VALLEYS	CONSERVED LANDFORMS: HILLSLOPES	CONSERVED LANDFORMS: RIVERVALLEYS	RESULTING SOILS	CORRELATION & CHRONOLOGY	
DENSE FOREST SAVANNA	UNSTABLE*	Slope pedimentation	accelerated alluviation	Older Pediplain				
	STABLE	Denudation > Incision Reduced chemical weathering Soil development Plinthite development on middle & lower sections of pedimentslopes				Oxisols		
DENSE FOREST	unstable*	Incision	Deep incision	Outline of D_2	Bedrock-cut valley floors			
	STABLE	Incision > Denudation Increased chemical weathering Soil development				Oxisols		
SAVANNA	UNSTABLE eo-stage	Slope pedimentation starting from incision lines	Bed-load alluviation	Remnants of Older Pediplain : R.O.P.	Basal gravel of T_2-fill			
	pleni-stage	Slope pedimentation in fully developed gully-pattern		Younger Pediments : P_2				
	fini-stage	Redistribution of hillwash		Microdepressions : D_2				
	STABLE	Denudation > Incision Reduced chemical weathering Soil development Deposition & concentration of Toba volcanic ashes	Alluviation of suspended sediments		Bulk of fine T_2-fill	Ultisols Alfisols	75,000 y B.P. (NINKOVICH et al., 1978 & 1978) (NINKOVICH, 1979) 30,000 y B.P. (STAUFFER et al., 1980) (ALDISS et al., 1984)	LATE PLEISTOCENE
DENSE FOREST	unstable	Restricted incision of D_2	Incision		T_2-terrace		Sea level drop -40 to -60 m between 36,000 - 10,000 y B.P. (GEYH et al., 1979)	
	STABLE	Incision > Denudation Increased chemical weathering Soil development	Alluviation of suspended sediments	Channels in D_2	T_1-fill	Inceptisols	Sea level rise from -13 m to +5 m from 8,000 - 4,000 y B.P. (GEYH et al., 1979)	HOLOCENE
			Incision		T_1-terrace		Sea level drop to present level (GEYH et al., 1979)	
		* UNSTABLE : major unstable phase unstable : minor unstable phase	Incision & Alluviation		Present day river morphology : T_0			

evidence for four or five great eruptions in the last 1.9 million years. They suggested an age of about 30,000 years for the most recent catastrophic eruption and show that the Malayan ash deposits may have formed at that time. This hypothesis was supported by Aldiss and Ghazali (1984) who added that the Toba Tuffs also include a 30,000-year-old airfall tuff, which was erupted from a centre just N of the Toba depression. They also reported that on Sumatra the ashes do not extend onto Recent alluvium. K-Ar datings on samples collected in the Padang Terap area are in progress and will be reported in a forthcoming paper.

The geomorphic position of the volcanic ashes permits us to attribute the development of the T_2-surface, the related young pediments and shallow depressions to the Late Pleistocene. These findings support the conclusions of Verstappen (1974) that drier conditions with lower precipitation values and a longer dry season have occurred in Malesia during the Pleistocene glacials, the Würm-glacial in the present case. Additionally, it lends support to the evidence of severe aridity throughout most of the tropical savanna and forest zones during the Late Pleistocene (Thomas, 1978; Street, 1981).

Important sea-level changes during the Late Pleistocene and Holocene were reported for the southern South China sea area and for the Straits of Malacca by Tjia *et al.* (1977) and Geyh *et al.*(1979) respectively. Geyh *et al.* have obtained C^{14} dates from *in situ* roots and peat which indicate that the sea-level was lowered eustaticaly to at least 40–60 m below the present level between 36,000 and 10,000 B.P.; the sea-level rose from -13 m to about $+5$ m from 8,000 to 4,000 B.P. and subsequently approached its present level. According to Verstappen (1974) the main effect of the sea-level lowering on these extensive shallow shelf areas was the growing continentality leading to dryness of the lowlands. Verstappen further postulated that the lowering in sea-level did not result in incision of the river courses in that area. The main objection against an incision he suggests is the fact that the glacial extensions of the lower river courses in shelf areas had an extremely gentle gradient. Verstappen was rather inclined to generally link the incision, in areas that remained emerged, to the interglacial conditions marked by a dense forest cover. We agree with Verstappen in his reasoning that open vegetation promotes denudation and that dense vegetation favours incision but, we do not agree with his objection on the effect of sea-level change on the stream profile. In the lower valleys, sea-level changes will have a direct effect on dissection and aggradation of alluvia as they are graded to the ultimate base level. The effect on bedrock incision will depend on the distance from the shelf margin and the thickness of unconsolidated deposits on the shelf. Some retardation of the rock incision can be expected and can eventually be countered by a new sea-level rise.

The incision of the T_2-surface in the Padang Terap area can be linked with the retarded effect of the low sea-level between 36,000 and 10,000 B.P. The effect of a restored dense forest cover can eventually add to the incision. The accumulation of the T_1-surface can be linked with the sea-level rise up to $+15$ m from 8,000 to 4,000 B.P., whereas the elaboration of the T_1-surface corresponds with the lowering of the sea-level to its present position.

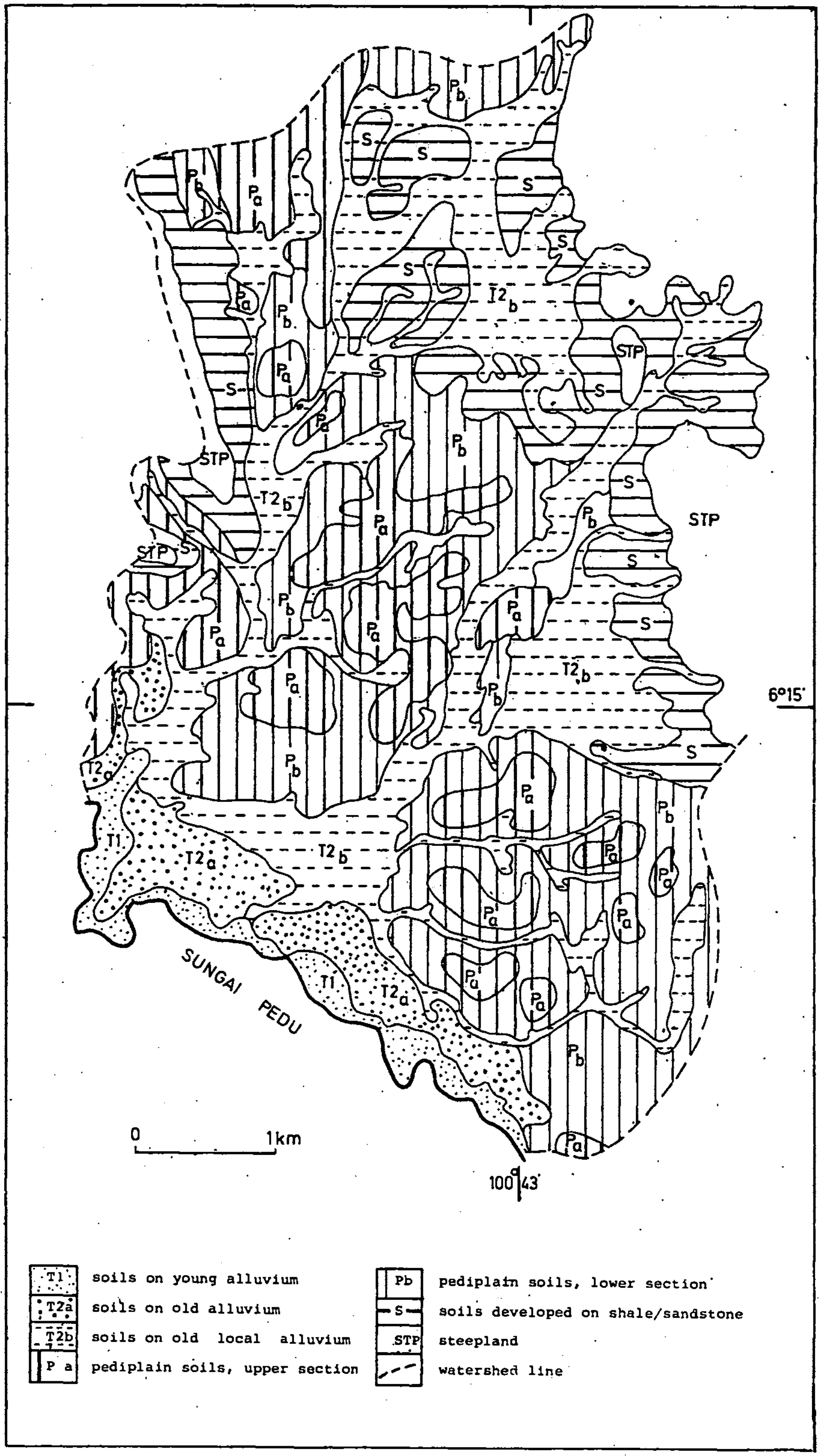

Fig. 13. Distribution of the soil units in a sample area in the Padang Terap District.

SOILS

On the different landforms, different soils have developed. A sequence of soils which developed on shale and clayey alluvium as parent materials is considered here. Attention is paid to the field characteristics, i.e. the profile morphology, the physico-chemical characteristics and the mineralogy of the soils. The distribution of the soil units in a sample area is illustrated on figure 13. The correlation between the soil units and the geomorphic units is given in figure 14.

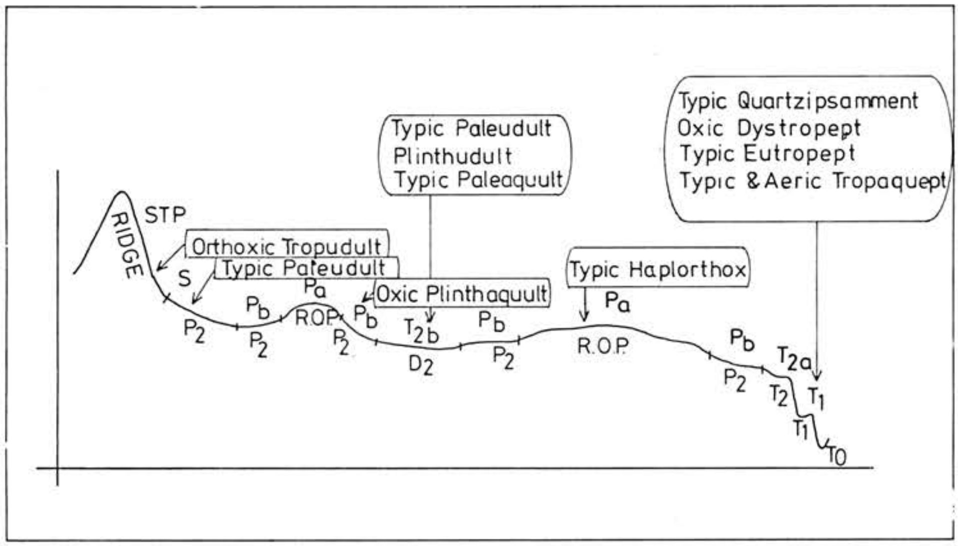

Fig. 14. Correlation between soil units and geomorphic surfaces illustrated on a cross-section of the basic morphotype in the Padang Terap basin.

Field characteristics

In the upland area and on the ridges, on strongly sloping terrain (< 20°), moderately well to well drained soils occur which have the shale saprolite or rock at shallow (< 50 cm) or moderate (50–100 cm) depth (S). The soil colour is light yellowish brown (10 YR 6/4) to pale brown (10 YR 6/3). The texture of the fine earth in the subsoil (25–50 cm) is clay loam to sandy clay. Often a layer of gravel or stones is observed overlying the rock or saprolite. The fragments which consist of shale or sandstone are angular and are not or only slightly impregnated or coated with iron. The thickness of this gravel or stone layer does not exceed 25 cm. The subsurface diagnostic horizon in these soils is an argillic horizon. In the silt and fine sand fractions, some weatherable minerals are present. The clay fraction is however strongly weathered and the CEC is low. The base saturation is less that 35 %. The soils in this rejuvenated landscape are classified, according to Soil Taxonomy (Soil Survey Staff, 1975), as an Orthoxic Tropudult.

At the foot of the ridges, on gently sloping terrain, soils have the rock or saprolite below 100 cm from the surface (S). These soils are more or less freely drained, have a reddish brown (7.5 YR 6/6) to brownish yellow (10 YR 6/6) colour, and a clay loam to sandy clay subsoil texture. The diagnostic horizon is argillic. In the silt and fine and fraction, no weatherable minerals are observed. These soils are classified as Typic Paleudult.

At the level of the interridge low hills, distinction is made between an upper section (Pa) and a lower section (Pb). The former consists of the hill topflats and the upper slopes which are considered remnants of an older pediplain. The latter consists of the younger slope pediments developed from the former.

In the upper section of the pediplain landscape, on gently undulating terrain, soils have developed which have the shale saprolite at a depth of more than 100 cm from the surface. A gravel layer covers the saprolite and starts within 50 cm depth on the flat tops in the landscape and between 50 and 100 cm depth on the convex slopes. The gravel layer has a thickness of 30 to more than 100 cm. The gravels consist of 35 to 60 % (by volume) subangular ironstone nodules. The subsoil texture is fine sandy clay to clay. The soil colour is yellowish brown (10 YR 5/6) to strong brown (7.5 YR 5/6) or yellowish red (5 YR 5/6) to red (2.5 YR 5/6). The diagnostic horizon is oxic. The soils are well drained. According to Soil Taxonomy these soils are classified as Typic Haplorthox. A further distinction can be made between residual soils, i.e. remnants of the older pediplain *s.s.*, and reworked soils.

In the soils, developed on the remnants of the old pediplain *s.s.*, the ironstone gravels consist of a mixture of brown oblong slightly platy (1 to 4 cm diameter) and black spherical (0.2 to 1 cm diameter) particles. The coarser gravels are mostly ironcoated parent materials (shale); the finer gravel is petroplinthite. The average size of the gravels increases with depth.

In the lower section of the pediplain the shale saprolite occurs within 100 cm from the soil surface. The soil colour is light gray (10 YR 4/2) to pale brown (10 YR 6/3) with yellowish red (5 YR 5/8) to red (2.5 YR 5/8) mottles. The texture of the fine earth fraction in the subsoil is fine sandy clay to clay. A gravel layer, 25 to 40 cm thick, with 50–60 % by volume of black spherical ironstone nodules occurs within 100 cm from the surface. The diagnostic horizon is argillic. The soils are imperfectly to poorly drained. They are classified as Oxic Plinthaquult. In places, iron may cement the ironstones together. Upon hardening the gravel layer then forms an impenetrable pan.

The soils on old alluvial deposits occur in a slightly undulating to level landscape. The old alluvium includes both strictly riverine sediments (T_{2a}) and local sediments in shallow depressions, deposited by run-off water, heavily loaded in the course of micro-pedimentation and over land flow (T_{2b}).

In the shallow depressions, well drained clayey soils occur in the highest positions (Typic Paleudult). On the concave lower slopes imperfectly drained soils are found. They are classified as Plinthudults. In the amphitheaters and depression centers, clayey soils which are saturated with water during most of the year were encountered. These poorly drained soils are classified as Typic Paleaquults.

The old riverine deposits are limited to only narrow tracts of land along the main rivers. The sequence observed consists of an old leave with well drained clayey soils, (Typic Paleudult), and imperfectly drained soils (Plinthudult), in the depressions behind the levee.

Apart from their position in the landscape, no distinct differences were observed between soils on these two types of old alluvial deposits.

Young alluvia (T_1) are found along the main river channels. They form a slightly undulating to flat landscape and can be subdivided into a levee and a backswamp area. The levee forms a narrow band along the channel and is often disrupted. The soils on the levee are sandy textured, have a yellowish brown color (10 YR 5/5) and are well drained. They are classified as Typic Quartzipsamment. Somewhat more inland, clayey, well drained soils with a yellowish brown (10 YR 5/5) soil colour occur. They have a cambic horizon and a relatively low base saturation. These soils are Oxic Dystropepts. On the slopes towards the backswamp the soils become imperfectly drained. In places where a break of slope is observed, manganese nodules are found in the soil profile. The base saturation is high, and the soils are classified as Typic Eutropept. Poorly drained, light gray (10 YR 7/2) coloured with strong brown (7.5 YR 5/8) mottles clayey textured soils are found in the back swamp areas. These are Typic and Aeric Tropaquepts.

Physico-chemical characteristics and mineralogical composition

The physico-chemical properties and mineralogical composition of the subsoils of soils on the rejuvenated landscape, the pediplain and the old alluvium are rather similar. They can be summarized as follows: the soil reaction is generally acid to very acid (pH 4–5). The amount of exchangeable Al present is high. The amounts of exchangeable Ca, Mg and K are low and Ca is the most depleted element. The apparent C.E.C. exceeds 16 meq./100 g clay on the rejuvenated landscape. On the pediplain and the old alluvium the apparent C.E.C. is always lower than 16 meq./100 g clay. The mineralogical composition of the clay (0–2 μm) fraction of the B horizons shows a clear dominance of kaolinite. Mica and its transformation product, a mixed layer mica-vermiculite, geothite, boehmite and quartz also occur but in very small amounts. The silt (2–50 μm) fraction of the B horizons consists of quartz only but on the rejuvenated landscape, mica is also present. In the surface horizons the organic C content was found to linearly proportional to the clay content. P, Zn and Cu contents are very low.

The physico-chemical properties and the mineralogical composition of the soils developed on the young alluvium show marked differences. The soil reaction is acid with pH values varying between 5 and 6. The amount of exchangeable Al is very low. The amounts of exchangeable bases (Ca, Mg and K) are relatively high and the base saturation exceeds 35 %. The clay fraction (0–2 μm) consists of predominantly mica and kaolinite. Only very small quantities of a mixed layer mica-vermiculite are present. Quartz is the only component in the silt (2–50 μm) fraction. In the surface horizons no good correlation could be established between the organic C content and the clay content. The amount of P present is very low. Zn and Cu are found in sufficient quantities.

The fine silt/total clay ratio (Van Wambeke, 1962) of the B horizon of well drained clayey soils, as an expression of the degree of weathering of the soil, shows clear differences between the various geomorphic surfaces in the landscape. The weathering index increases in value as weathering proceeds (Table 2).

TABLE 2

THE WEATHERING INDEX (FINE SILT/CLAY RATIO) FOR THE B HORIZON OF THE SOILS ON THE YOUNG AND OLD ALLUVIAL SURFACE, THE REJUVENATED AND PEDIPLAIN SURFACE

Geomorphic surface	B horizon	Weathering index
Young alluvium (T_1)	(B)	1.3
Rejuvenated landscape (S)	Bt	1.1
Old alluvium ($T_{2a\ \&\ 2b}$)	Bt	0.7
Pediplain, lower section (P_b)	Bt	0.5
Pediplain, upper section (P_a)	Box	0.1

The data in table 2 indicate that the soils on young alluvium are in an initial stage of weathering. The soils occurring on the rejuvenated surface, old alluvium and in the lower section of the pediplain landscape are in an intermediate stage of weathering. The soils in the upper section of the pediplain have reached an ultimate state of weathering.

CONCLUSION

The study of the landforms, their distribution and the processes involved in their formation permits the construction of a landscape model which is found to match very well with the soils distribution. The field morphology, the physico-chemical and mineralogical characteristics and the weathering indices of the soils developed on the different landforms support the proposed chronology and further contribute to the validity of the model.

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