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Late Quaternary Geomorphological Evolution in the Uplands of Peninsular Malaysia

by

Morgan DE DAPPER
Dr. Sc.

ACADÉMIE ROYALE DES SCIENCES D'OUTRE-MER
Classe des Sciences naturelles et médicales
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ACADÉMIE ROYALE
DES
SCIENCES D'OUTRE-MER

Rue Defacqz 1 boîte 3
B-1050 Bruxelles
Tél. (02)538.02.11

KONINKLIJKE ACADEMIE
VOOR
OVERZEESE WETENSCHAPPEN

Defacqzstraat 1 bus 3
B-1050 Brussel
Tel. (02)538.02.11

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INTRODUCTION

This monograph presents the results of a geomorphological field survey in the uplands (see Ch. 1) of Peninsular Malaysia, located in the western part of the core region of South-east Asia between latitudes 6°30'N and 1°30'N (Fig. 1).

The investigations took several months and were carried out during five missions, effectuated between 1981 and 1984, in the framework of a Belgian Aid Program to map soils of West Malaysia. The program was a joint effort of the Soils and Analytical Services Branch of the Department of Agriculture of Malaysia and the Department of Development Co-operation of the Ministry of Foreign Affairs of Belgium (ABOS).

Current opinion among soil scientists is, that soil is a natural body occuring on the Earth's surface and that is dependent upon the soil forming factors : parent material, topography, time, climate and biological activity. One of these factors parent material, is partly geological and partly geomorphological in nature, whereas two others, topography and time, fully belong to the domain of geomorphology.

Thus the aim of the present geomorphological survey was not to provide a purely academic study but

(1) to establish workable models of landform chronosequences
(2) to pay special attention to the nature and genesis of superficial layers whereon the soil has developed.

The survey was focused on the uplands of the Peninsula, because the geomorphology of that part, excepting the highlands, which are less suitable for agricultural use, was but scarcely studied, most of the geomorphological investigations being done in the coastal lowlands and adjacent riverplains (De Dapper 1981a, 1983, 1985a,b, 1987, De Dapper *et al.* 1988).

In order to assess the whole of the Peninsula, three test areas were chosen, well spread from north to south (Fig. 3) :

(A) the Padang Terap area (6°15'N - 100°35'E ; Kedah)
(B) the Kuala Pilah area (2°45'N - 102°20'E ; Negeri Sembilan)
(C) the Johor Bahru area (1°30'N - 103°30'E ; Johor).

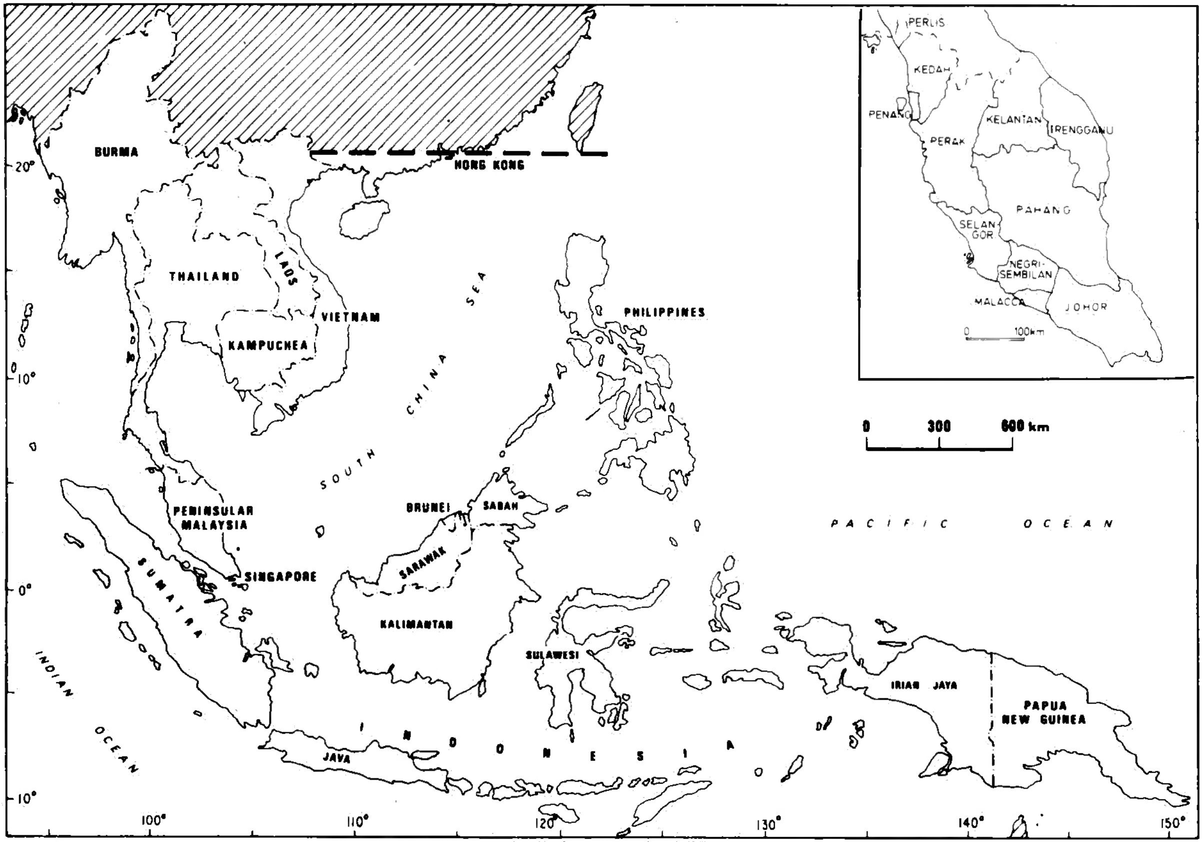

Fig. 1 — Situation of Peninsular Malaysia in Southeast Asia

Each survey was effectuated after a first soil reconnaissance survey was finished. In that way the geomorphological field work could efficiently profit of already existing observation pits and the survey could be focused on the specific problems put by the soil cartography. Additional observations on the superficial layers were done along fresh road cuts especially in recently opened forest areas. Riverine deposits were studied along river banks and in almost one hundred Eykelkamp hand drills reaching depths of up to 8 m.

The monograph is elaborated in five chapters. After an account of the physical environmental data relevant to the geomorphology (Ch. 1), the major landforms are studied in their form (Ch. 2), their genesis (Ch. 3) and their chronology (Ch. 4). In conclusion, a tentative table summarizes the chronosequence of landforms related to geomorphic events and environmental changes (Ch. 5).

* * *

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Laboratory for Physical Geography
Geological Institute
State University
Krijgslaan 281
B-9000 Gent (Belgium)

CHAPTER 1

ENVIRONMENTAL SETTINGS

1.1. Geology

Peninsular Malaysia records a Phanerozoic history without major gaps from the late Cambrian to the late Triassic. The record of the succeeding Jurassic and Cretaceous is less complete, and Tertiary rocks have a very limited distribution and are probably all late Tertiary. Quaternary deposits are extensive and have economic importance for the occurrence of tin placers (STAUFFER 1973a).

Peninsular Malaysia can be divided in three longitudinal belts, Western, Central and Eastern, each of which has its own distinctive characteristics and geological development (KHOO & TAN 1983) (Fig. 2). The Western Belt is underlain predominantly by Palaeozoic rocks. The northwest sector of this belt however, comprising Kedah, Perlis and north Perak States, on the whole has a rather different stratigraphic history, marked f.i. by the presence of important Triassic formations. The Central Belt is largely underlain by rocks of the Mesozoic and Permian. Rocks in the Eastern Belt range from a Carboniferous to Cretaceous age.

Slightly less than 40 % of the rocks are sedimentary, comprising clastics and limestones. Most sedimentary rocks have undergone some degree of metamorphism, largely the result of regional metamorphism. Volcanics are found in all three belts.

Another 40 % of the Peninsula is underlain by granitic rocks. Significant plutonic acid magmatism occurred during the early Permian, late Permian/early Triassic and the Late Triassic in the Western belt, late Triassic and late Cretaceous in the Central Belt and late Permian/early Triassic and late Triassic in the Eastern Belt. The main intrusive body is the Main Range Granite in the Western Belt.

The structure of all the three belts is generally complex. Most of the major faults trend in their longitudinal, direction. Many tectonic schemes can provide satisfactory explanations for one or more of the

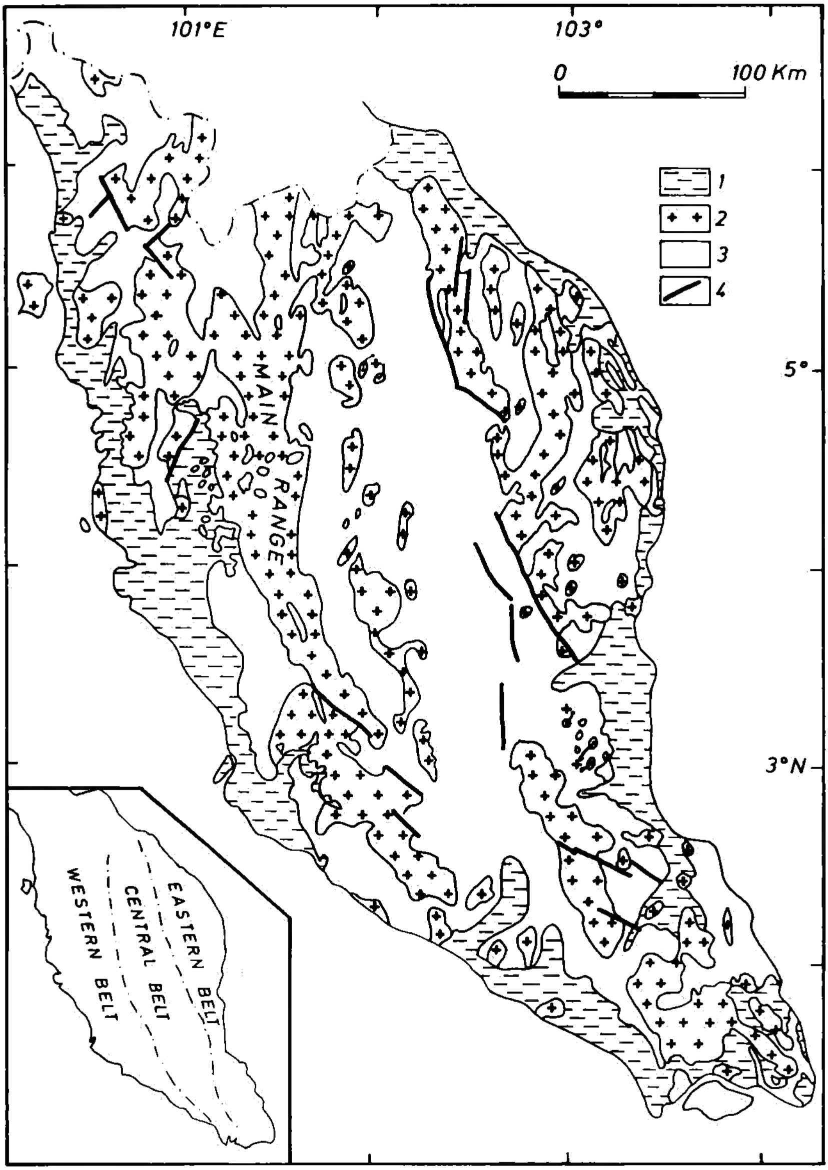


Fig. 2. — Generalized geology of Peninsular Malaysia.

characteristics of the three belts in Peninsular Malaysia. The location of Peninsular Malaysia as a protrusion into the Indonesian archipelago which is bounded by impressive active subduction zones has encouraged attempts to reconstruct the Mesozoic and Palaeozoic evolution involving subduction and collisions. However, the development of large and deep offshore basins in the South China Sea region which are either fault bounded or where a horst-and-graben situation

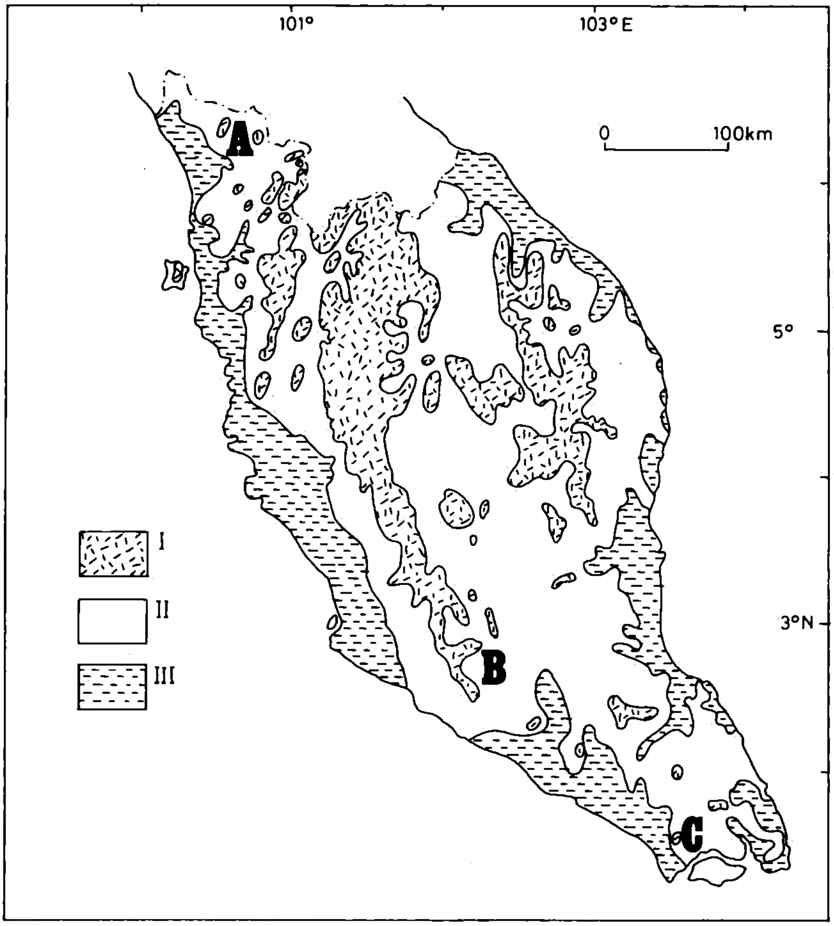


Fig. 3. — Megalandform-units in Peninsular Malaysia.
I : Highland
II : Upland
III : Coastal lowland
A,B,C : Test areas for the geomorphological fieldsurvey

has developed is equally impressive although there is little or no surface expression. KHOO & TAN (1983) are in favour of the aborted rift model for the tectonic development of Peninsular Malaysia. They believe that in the geological evolution of the continental part of the Southwest Asian region, graben tectonics may have more relevance and significance than previously accorded.

The Cenozoic underlies slightly more than 20 % of the land area of Peninsular Malaysia of which the majority of the sediments are of Quaternary age. The Cenozoic in Peninsular Malaysia has been relatively stable tectonically with activity confined to epeirogenic uplift and tilting, some fault movements and localised gentle downwarps (SUNTHARALINGAM 1983). The Quaternary sediments consist of fluviatile, lacustrine and marine deposits and mainly occur in the coastal area and along the main rivers.

The geology of each testarea will be discussed in more detail in the geomorphography-chapter.

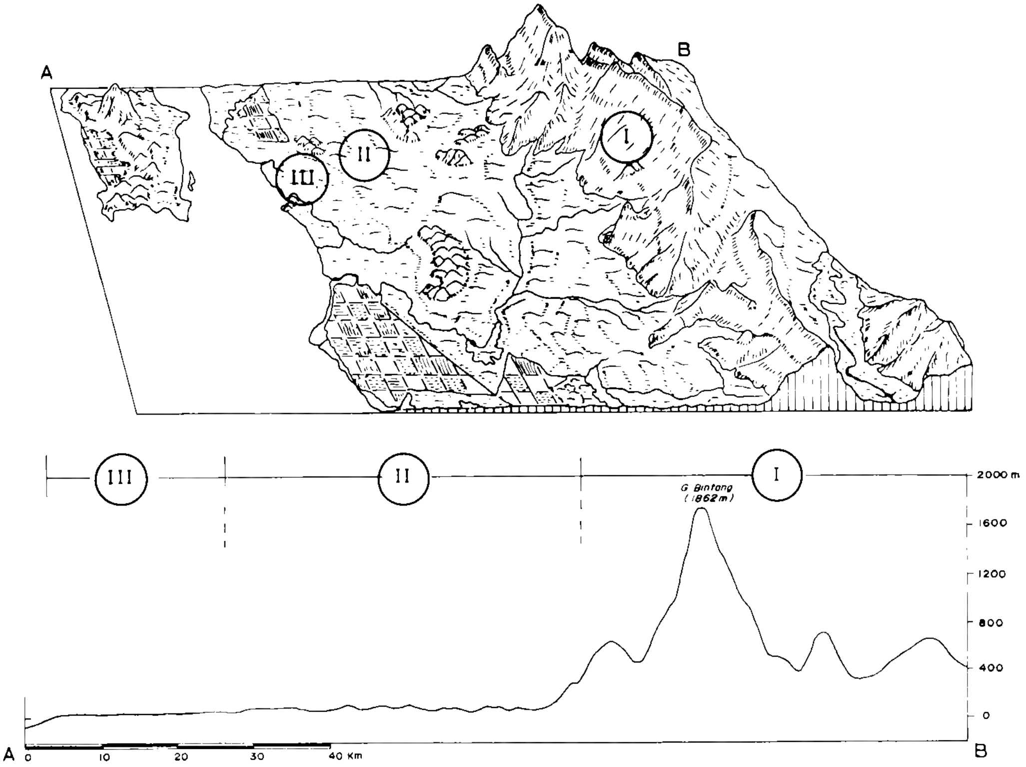


Fig. 4. — Blockdiagram and section representing the megalandform-units in Peninsular Malaysia (example from Kedah) (after MAHMOOD *et al.* 1983).

1.2. Mega-landforms of Peninsular Malaysia

On a megascale three landform units can be recognised in Peninsular Malaysia (Fig. 3). A central highland consists of eight prominent north-south to northwest-southwest trending mountain ranges (TJIA 1973). Most of the ranges are formed of granitic rocks and possess peaks up to 2,000 m. The highest summit of the Peninsula is formed by Gunong Tahan in the National Park, reaching 2,186 m and which consists of resistant sedimentary rocks. The highland is strongly dissected by narrow valleys with slope gradients generally exceeding 20 °. The highland is surrounded by an upland composed of isolated highland cores, hills and broad riverplains fingering out of the coastal lowland that finally seams the whole. The blockdiagram and profile section on figure 4 illustrate the above sketched threefold subdivision for an area in the south of Kedah (after MAHMOOD *et al.* 1983).

Figure 5 shows the drainage and main divides of the Peninsula. The trunk streams and major tributaries run parallel as well as transverse to the structural grain. The peninsular divide, separating the waters flowing to the Malacca Strait and the South China Sea respectively, runs by large over the granitic Main Range. Three of the large rivers, the Sungei Pahang (420 km) and the Sungei Kelantan (280 km) debouch into the South China Sea ; the third large river, the Sungei Perak (350 km) drains into the Malacca Strait.

As was already mentioned in the introduction, the present study is mainly involved with the geomorphological evolution of the upland area.

1.3. Climate

Peninsular Malaysia lies completely within the tropical rainbelt and the Indo-Australian monsoon regime (Fig. 6). Its climate is characterised by high uniform temperatures (monthly means around 27 °C, somewhat lower in the highland, with only slight seasonal variations), high relative humidity (mean annual value of 84 %), abundant rains and generally feeble winds.

According to Köppen's classification (KÖPPEN 1936) most of the peninsula has an Af (continuously moist, having in the least rainy month more than 60 mm of precipitation) or Am (monsoon rain climate, with moderate dry periods) tropical climate.

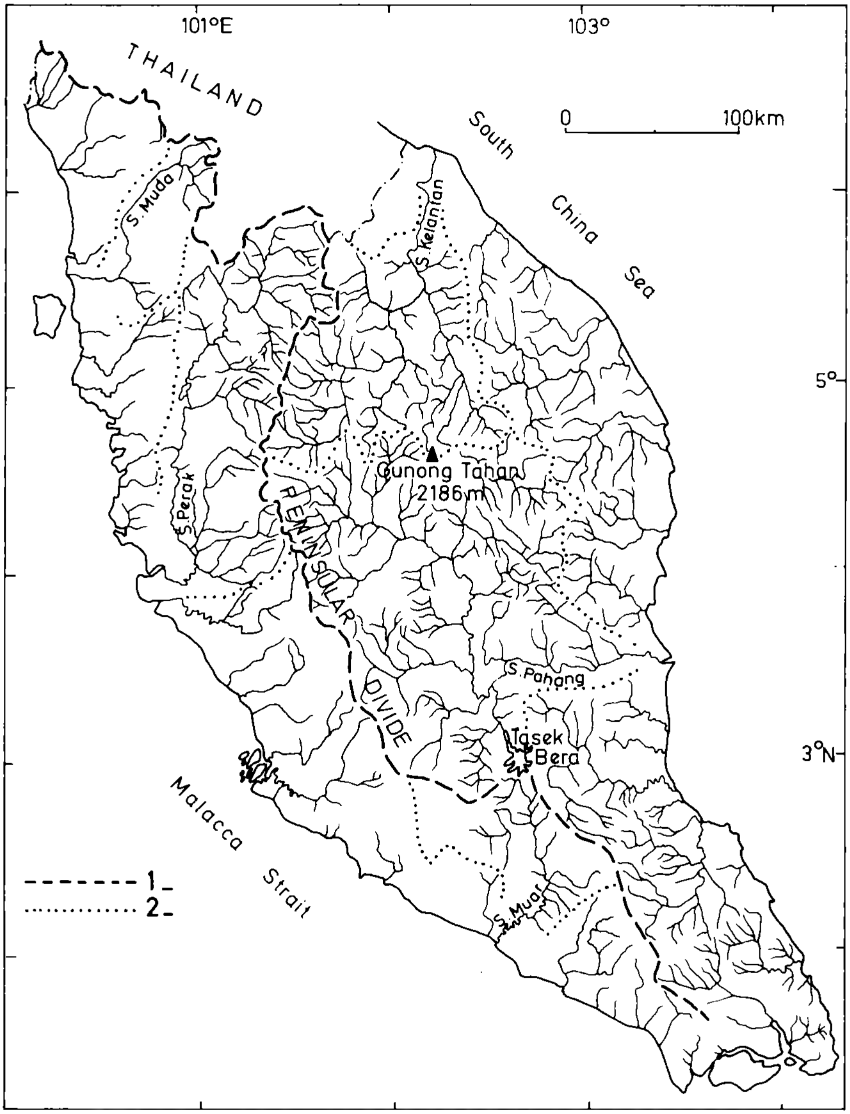


Fig. 5. – Drainage and major divides of Peninsular Malaysia (after TJIA 1973).

Following the NEWHALL (1975) system of computation, soil temperature regime is isohyperthermic, except for the highland. VAN WAMBEKE (1985) suggests that only two types, udic and perudic soil moisture regimes occur in Peninsular Malaysia. The perudic moisture regime is confined mainly to areas above 300 metres elevation. He also indicates an area in the northwest which is udic but marginal to ustic. This indication has been corroborated by DEBAVEYE & ABDUL RAHMAN (1983). In addition an aquic moisture regime is present in the low-lying areas which have a high water table.

Rainfall is the most variable element of climate in West Malaysia.

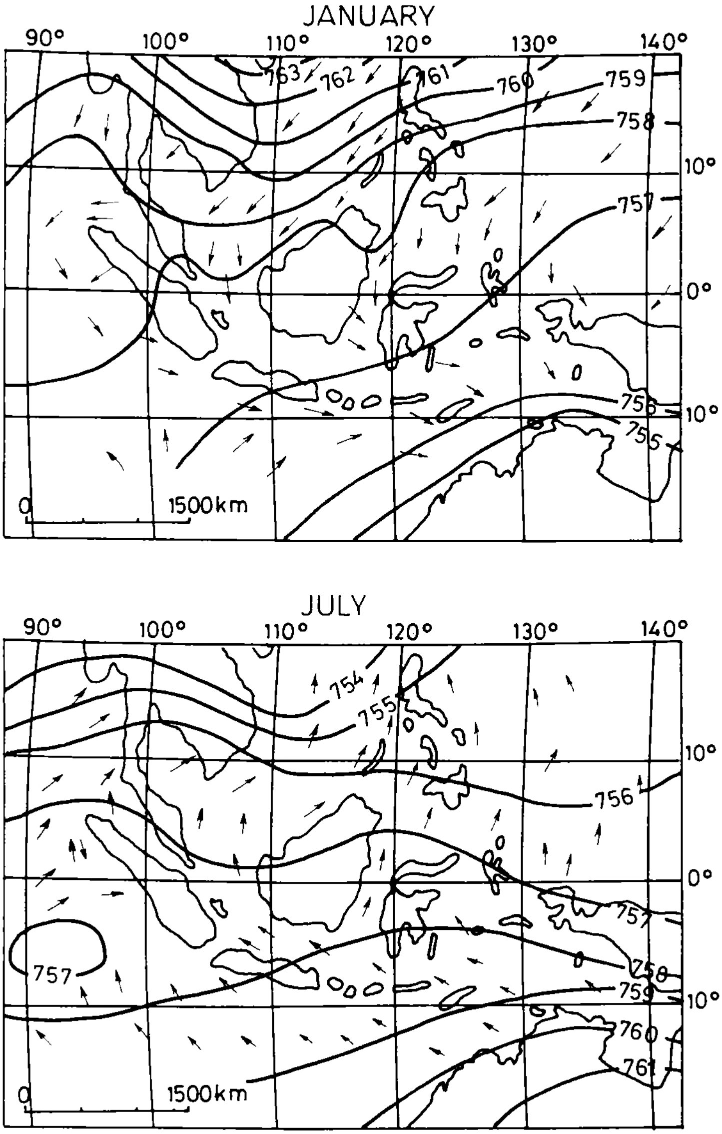


Fig. 6. — Air pressure and wind direction in Southeast Asia, in January and in July.

It is influenced by latitude, by monsoonal effects, by the nearby seas, by mega-landforms and by the rain-forest cover.

The mean annual rainfall is about 2,540 mm. Annual rainfall varies however between less than 2,000 m in the coastal area of Selangor and the Central part of Negeri Sembilan to over 4,000 m in some highland parts and the coast of north Trengganu (Fig. 7).

These averages however do not show the strong seasonal, diurnal and year to year variability of rainfall. NIEUWOLT (1982) states that periods with little or no rainfall occur much more frequently in Peninsular Malaysia than is commonly realized. To assess those dry periods

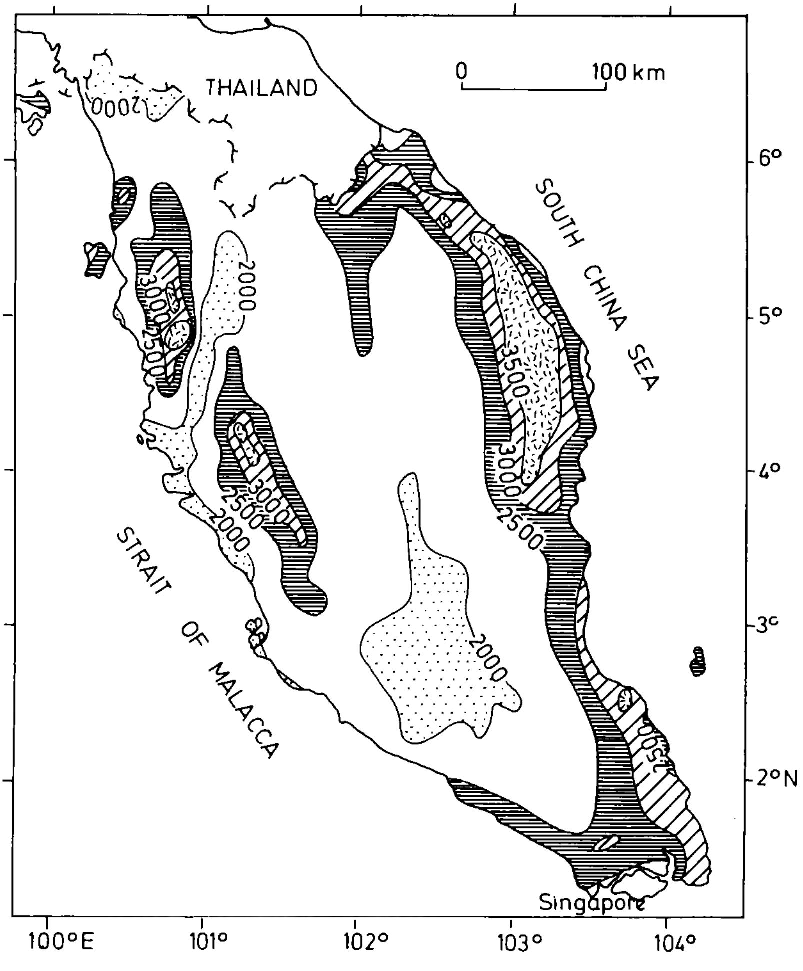


Fig. 7. — Annual rainfall (in mm) in Peninsular Malaysia (after DALE 1959).

and their importance to agricultural production he introduced the concept of an Agricultural Rainfall Index, ARI, that expresses rainfall as a percentage of potential evapotranspiration. In the computation of ARI, the amount of rainfall that may be expected with a probability of 80 % is used. A "dry period" is defined as the number of consecutive months with ARI less than 40. This means that less than half of the necessary moisture for most crops is supplied by rainfall. Monthly values of potential evapotranspiration in the lowland and upland of Peninsular Malaysia generally vary between about 100 and 150 mm (SCARE 1976) so that the equivalent of a dry month is between 40 and 60 mm of rainfall.

Although the agricultural potential is not the aim of this study, Nieuwolts concept throws a light on the possibility and the variability of dryness in "everwet" West Malaysia, that may influence natural vegetation or might have influenced it in the past. The map of the areas where a dry period occurs at least once in five years (Fig. 8) shows that this is the case in Padang Terap from December into March and in Kuala Pilah around January-February and in June-July. In Johor Bahru there is no indication for a dry period.

While it is generally assumed that the northeast monsoon brings much rainfall to the eastern parts of Peninsular Malaysia, this is actually only true during the beginning of its season, in November and December. Once the monsoon firmly established, onwards from about January, it is frequently a rather dry wind, as it carries the rests of a trade wind inversion, which produces stable conditions in its upper air layers (NIEUWOLT 1977). It has even been demonstrated that a strong and steady monsoon brings less rainfall to these areas than a weak and often interrupted one (NIEUWOLT 1966). South of latitude 5°N however the effects of the northeast monsoon become weaker. This is because the monsoon tends to change direction to a more northerly one as it approaches the equator, and this results in lower wind velocities allowing convectional disturbances to develop.

From about June to September the general circulation is dominated by the southwest monsoon slowly pushing back the northeast monsoon. Though it arrives in Peninsular Malaysia after crossing the high mountain ranges of Sumatra, it nevertheless brings much rain so that the probablity of dry periods is lower than during the northeast monsoon period. The main reason is that the monsoon converges with another air stream from the southeast, which recurves into a southerly air stream over Peninsular Malaysia. The convergence of two major air currents creates unstable conditions in deep layers of the atmosphere,

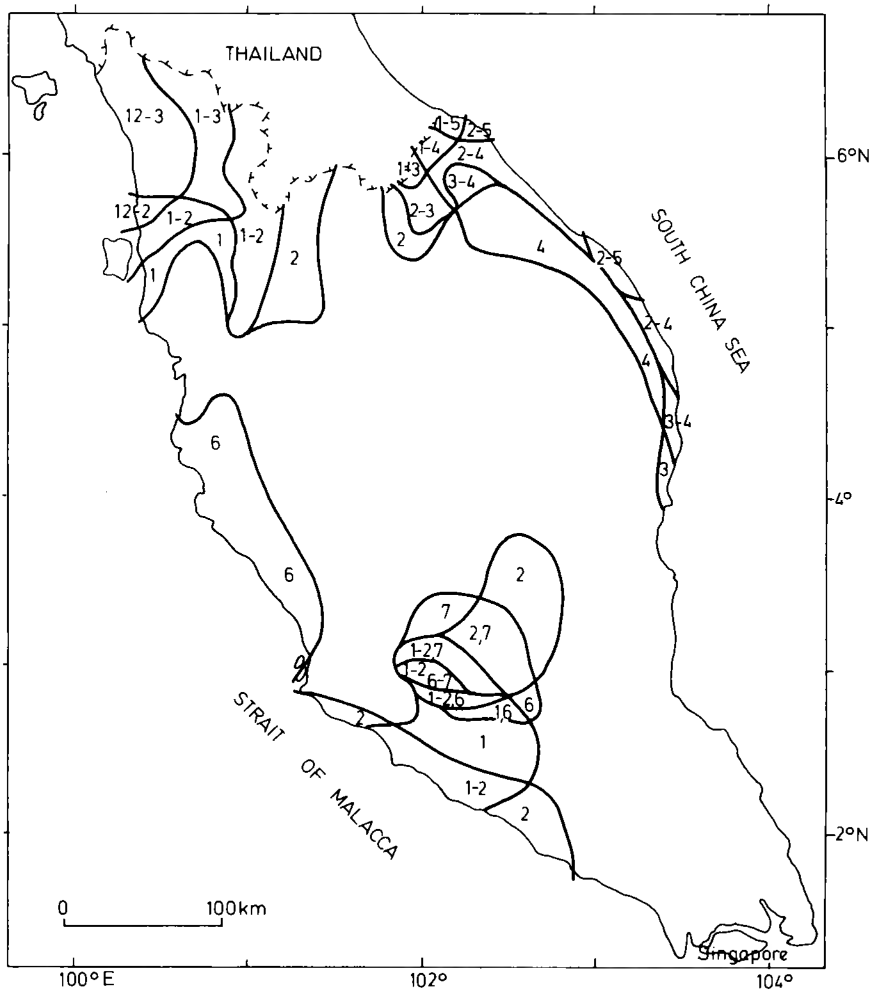


Fig. 8. – Dry months in Peninsular Malaysia. Areas where the Agricultural Rainfall Index (A.R.I.) remained below 40 at least once in five years during the indicated months (1 = January, 2 = February, etc.). Based on rainfall records over 1951-1980 at 42 stations (after Nieuwolt 1982).

so that convectional disturbances can develop freely. Both the position and the intensity of the zone of convergence however are very variable so that large local differences in rainfall may occur. As e.g. the Kuala Pilah area is in the rain shadow of the Main Range, also the southwest monsoon season is rather dry. Here, the combined effect of both monsoon seasons is the occurrence of two regular dry seasons, with probabilities of ARI values below 40 being over 40 % (NIEUWOLT 1982).

In Peninsular Malaysia, as in many parts of the tropics, there is also a strong irregularity of rainfall from day to day so that monthly figures are not always truly representative of actual conditions. The main reason for this high short-term variability of rainfall is the large contribution by rainstorms, usually of convectional origin. They cause intensive rainfall with high erosivity, over periods no longer than about two hours, and the areas they cover are rarely more than about 100 km^2.

1.4. Vegetation

Before interference of man, a century or so ago, nearly 98 % of the Peninsula's total area must have supported a rainforest cover (Fig. 9). About 84 % of this must have been lowland forest, including freshwater swamp forest, about 8 % submontane forest and about 8 % montane-forest. In the welldrained areas rainforest is of the Dipterocarp type. Other small areas were covered by mangrove tidal swamp forest, primarily along the west coast from Perlis State to Singapore, and by "beach forest" — a thin growth of Casuarina trees, screwpines and low herbaceous plants — along more than two thirds of the east coast (WYATT-SMITH 1964). Only a small proportion of the whole must have been unforested and opened for agricultural purposes at any point in historical time prior to the middle of the 19th century (DUNN 1975).

Nowadays 65 % of Peninsular Malaysia is still covered by forest but that area is rapidly decreasing by deforestation for timber logging and agriculture. Huge areas are opened for new rubber and oil palm estates. Malaysia is the first world producer and exporter of natural rubber (1.5 million tons in 1983) and palm oil (3 million tons in 1983).

1.5. Deep weathering

As in other humid tropical regions, chemical weathering processes are very important in West Malaysia because of the constant high temperature, the availability of water, and the resulting dense vegetation. As a result, most primary minerals, except for quartz, are deeply weathered and most originally hard rocks are transformed at the surface into a soft saprolite.

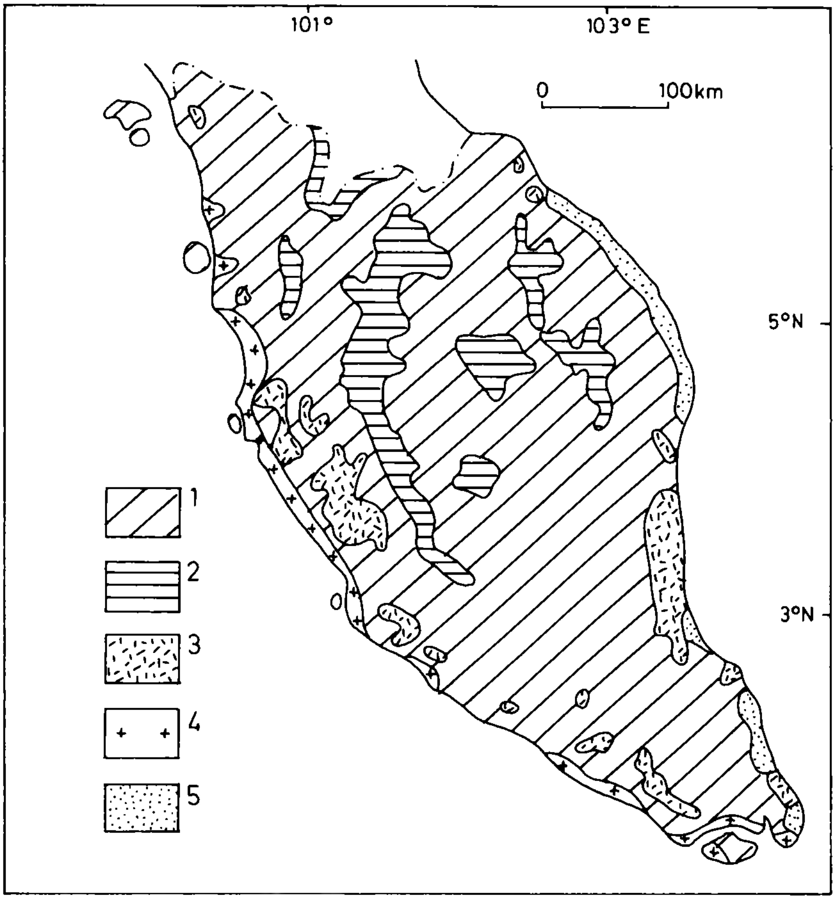


Fig. 9. — Holocene forest cover in Peninsular Malaysia prior to the 19th century (after DUNN 1975).
1. Lowland rainforest
2. Montane and Sub-montane rainforest
3. Swampforest
4. Mangrove forest
5. Beach forest (width exaggerated).

Due to the prolonged Cenozoic landsurface stability, long-term chemical weathering penetration rates overruled denudation rates so that deep regoliths (*in situ* saprolite and upper transported layers) could develop (THOMAS 1974, RAJ 1982, FANIRAN & JEJE 1983). STAUFFER (1973a) states that thicknesses for the regolith in excess of 30 m are very common for the Peninsula. In the Padang Terap-area, deep drillings for the Kedah-Perlis Water Resources Management Study revealed regolith thickness from 6 m up to 36 m (MacDonald & Partners Ltd., 1982).

In dense, well-jointed rocks such as granites, the junction between saprolite and fresh rock is remarkably abrupt and forms a basal front of weathering (Ollier 1974). In porous rocks or very fissile rocks, like shales, that boundary is not so sharp and forms merely a zone than a front.

It stands for reason that the texture of the saprolite is dependent on the composition of the original fresh rock. The weathering allowed the coarse size fractions to reduce to silt and clay size particles. The presence of coarser fractions in the saprolite will highly depend on the presence and size of quartz in the parent rock. Rotten granite e.g. shows a typical bimodal texture, with a peak in the clay size and one in the coarse sand to fine gravel size, the so-called grus.

Associated with the intense weathering under humid tropical conditions is the accumulation of iron and aluminium oxyhydrates, often referred to as laterite. The accumulation can be relative or absolute (D'Hoore 1954). Relative accumulation results from the elimination of silica and bases from the weathering zone and the residual formation of the sesquioxides. Absolute accumulation results from the oxidation and precipitation of reduced iron compounds transported by subsurface water movements into the landscape. The sesquioxides may initially occur as soft material and may subsequently harden upon exposure to form separate ironstone nodules or larger ferricretes (Alexander & Cady 1962, McFarlane 1983).

CHAPTER 2

GEOMORPHOGRAPHY

2.1. Padang Terap-area

2.1.1. Geology

The Padang Terap area is almost exclusively underlain by Mesozoic sedimentary rocks of the Middle to Upper Triassic Semanggol Formation. Palaeozoic sedimentary rocks of the Kubang Pasu Formation occur in the western corner. The northern fringes of the area are build up of a large post-Semanggol granitic intrusive (Fig. 10 ; Table 1).

The Semanggol Formation is tentatively divided by BURTON (1970) into three members : a lower chert, a middle rhythmite and an upper conglomerate member. The chert component at the base is mostly found in the west of Padang Terap, towards the Kubang Pasu Formation. The conglomerate top member occurs mainly in the eastern and southeastern part of the area. The central and most important part of Padang Terap is underlain by the rhythmite member. It shows a rapidly changing sequence of shales, siltstones, and coarse, ill-sorted, sandstones.

After deposition, the rocks of the Semanggol Formation were intensively folded along a roughly north-south axis. They were then further deformed into a series of larger amplitude anticlynes and synclines. As a result the rocks have nearby vertical dips with a strike varying from NNW-SSE to NNE-SSW. Associated with the tight folding are a number of faults.

2.1.2. Macro-landforms

The investigated area mainly coincides with the upper and middle parts of the drainage basin of the Padang Terap river that debouches into the Malacca Strait at Kuala Kedah. Only a minor part in the southwest is drained by the Sungei Lampan, a short coastal river (Fig. 11).

The plain of the Padang Terap and his main tributaries, the Pedu and the Tekai rivers, is surrounded by a highland at an average elevation of 400 m a.s.l. This upper surface is strongly dissected in a geostructural grain that clearly trends following the major strike directions.

TABLE 1. — Geology of the Padang Terap-testarea (cf. Fig. 10) (after BURTON 1970; Geological Survey of Malaysia 1973; MACDONALD & PARTNERS Ltd. 1982; HATTA 1983; DEBAVEYE & ABDUL RAHMAN 1983).

	AGE	FORMATION	DESCRIPTION
1	Quaternary	Superficial deposits	Unconsolidated deposits including alluvium, slope deposits and soil
2	Upper Triassic or younger	Granite Intrusive	Coarse grained porphyritic granite
3	Middle to Upper Triassic	Semanggol Formation	Interbedded shales, siltstones and sandstones, containing (1) abundant conglomerate at the top (2) abundant chert at the base
4	Upper Devonian to (?) Triassic (?)	Kubang Pasu Formation	Mainly light to dark gray sandstone and dark grey to red shale. Minor amounts of light to dark grey chert, siltstone and mudstone
5	Probable faults		

The plain itself, where elevations range between 15 m a.s.l. and 50 m a.s.l., is split up by a great number of parallel ridges which crests range between 100 m a.s.l. and 300 m a.s.l. The ridges emerge from the surrounding highland and distinctly trend following the highland structural lines.

As the ridges run almost perpendicular to the main drainage axes, the basin of the Padang Terap is compartmentalized into a number of

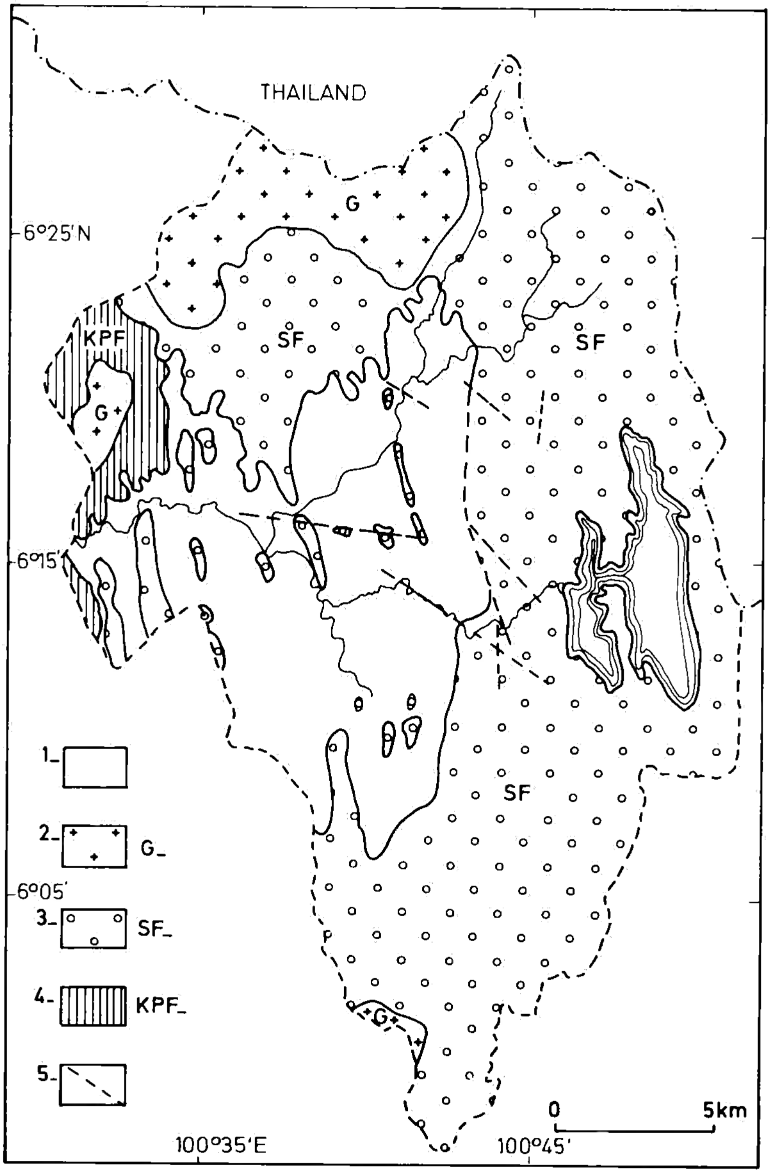


Fig. 10. — Geology of the Padang Terap-test area. The legend is explained in Table 1.

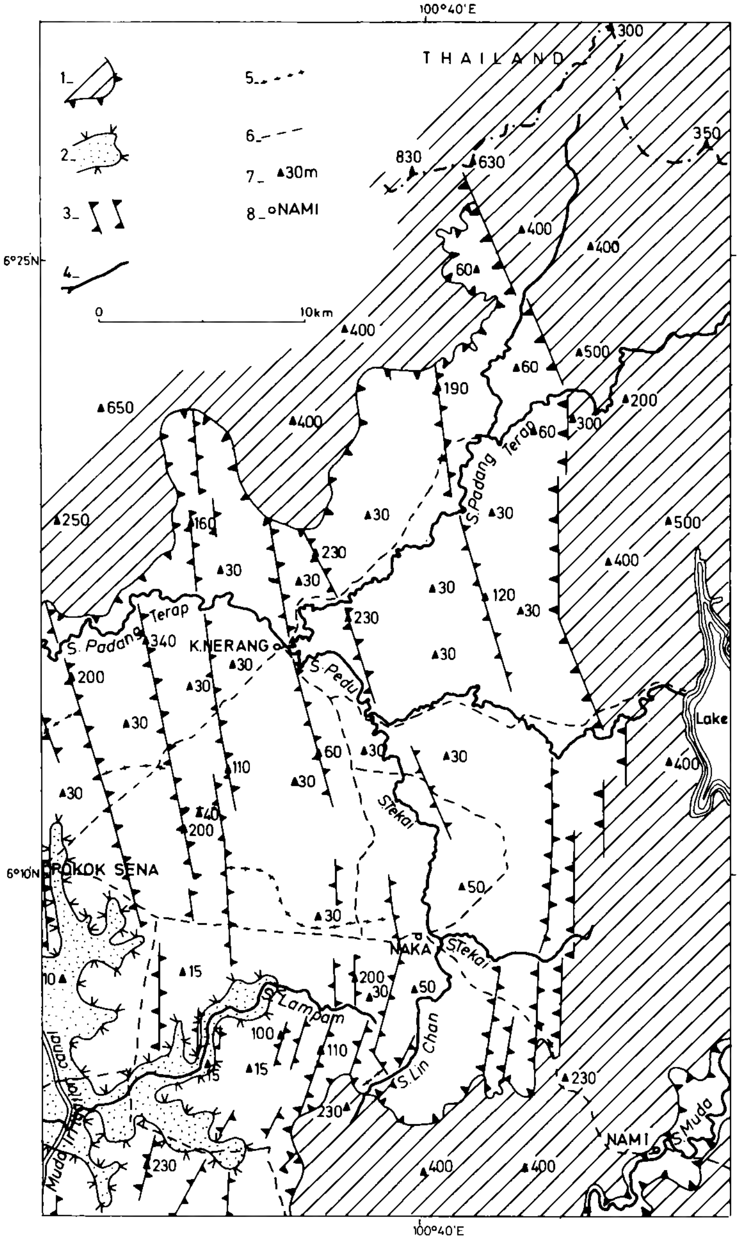


Fig. 11. — Macromorphological outline of the Padang Terap-test area

1. Highland
2. Coastal plain
3. Ridges
4. Main rivers
5. Padang Terap-Lampam divide
6. Principal roads
7. Elevation a.s.l. in metres
8. Principal places

subbasins. The outleting watergaps, in many places, form local temporary baselevels. We observed rapids on unweathered bedrock even at the last watergap — Bukit Tinggi near the Alor Setar Airfield — just before the Padang Terap enters the coastal plain that penetrates the area along the main drainage axes.

The basic geomorphic unit of the area is the compartment in between two ridges. The basic morphotype — a model constructed by synthesis of common characteristics — is illustrated by a planform (Fig. 12) and by a cross-section (Fig. 13). It shows a regular recurrent pattern of landforms that can be subdivided in ridges, low hills, footslopes, shallow depressions and river terraces.

The ridges are local cores of highland marked by a narrow crestline and sides sloping almost straight at values around 35°. The

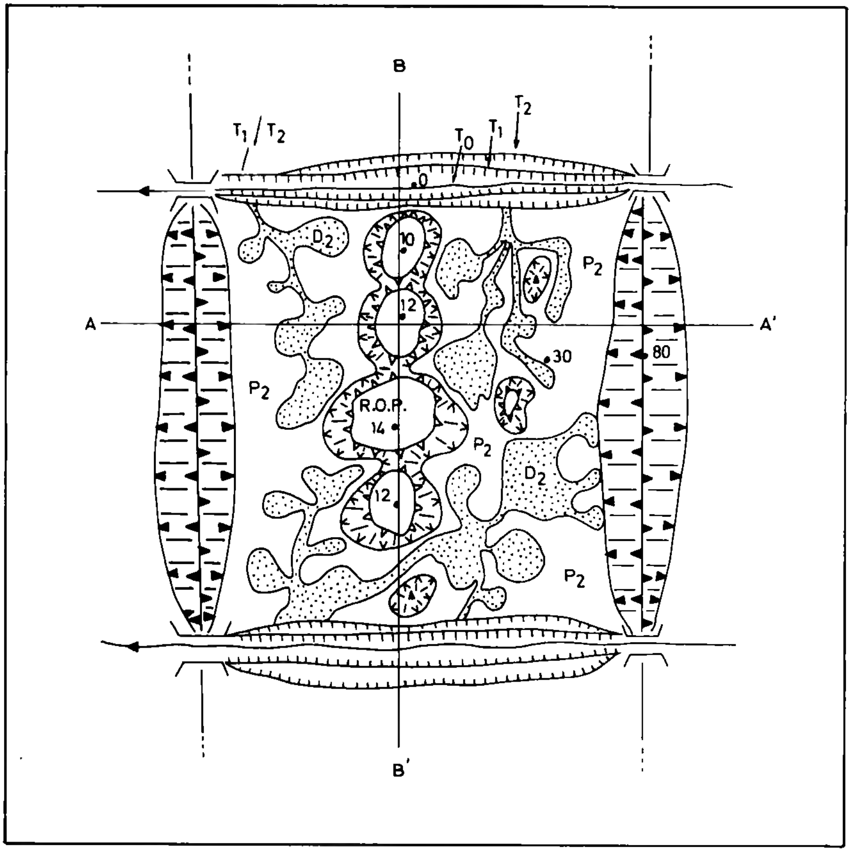


Fig. 12. — Basic morphotype in the Padang Terap-test area : planform.

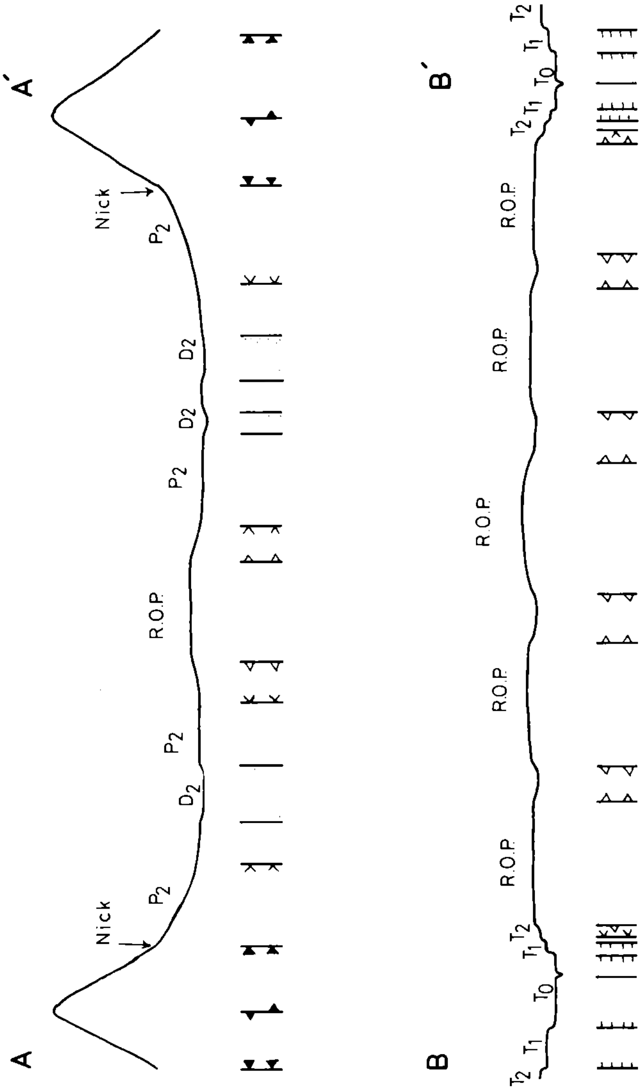


Fig. 13. — Basic morphotype in the Padang Terap-test area : cross-sections.

low hills commonly occur isolated in the central part of the interridge-compartment. A set of two riverterraces, T_2 and T_1, occurs along the main river channels (To), that break through the ridges by narrow watergaps. The transition between the positive landforms — ridges and low hills — and the negative landforms — river terraces — is formed by long footslopes interfingered by shallow depressions. The shallow depressions form the extension of the T_2-terrace into the interridge area. Those depressions show a very irregular pattern of broad lobeshaped parts linked by narrow stretches.

2.2. Kuala Pilah-area

2.2.1. Geology

The area is made up of a diverse assemblage of rocks, consisting of sedimentary, metasedimentary, metamorphic and igneous rock types (Fig. 14 ; Table 2). The ages of the bedrock east of the Main Range granite batholith range, going from west to east, from Devonian to Upper-Triassic.

The Devonian Pilah Schists border the Main Range and form a metamorphic basement of the greenschist facies, including quartz-mica schists, mica schists and graphitic schists. Quartz-mica schist is the most abundant, forming about two-thirds of the formation. Occurrences of metaquartzite and chert are characteristic. A large body of serpentinite outcrops 5 km SE of Kuala Pilah, along the Tampin road. These ultrabasic rocks are postulated to be formed contemporaneously with the metamorphisation of the schists. A few faults stretch in NW-SE and NNW-SSE direction.

The Kepis Formation is of Lower Permian age and consists of metasedimentary and sedimentary rocks, unconformably overlaying the metamorphic basement. Interbedded rudaceous, arenaceous and lutaceous facies can be distinguished, but cannot be arranged in a strict stratigraphical succession. Shale is the dominant lithology of the sequence followed by conglomerate. A localised facies of Carbonaceous limestone is mapable and is referred to as the Jelai Marble Member. It occurs near the confluence of the Jelai and Muar rivers. The Kepis Formation is tightly folded. The strike trends are more or less in a NNW-SSE direction.

The youngest unit, overlaying unconformably the Kepis Formation, is the Gemas Formation of Middle to Upper Triassic age. This sedimentary rocks are characteristically unmetamorphosed and comprise mainly shales with minor sandstone beds. Tuffs and limestone are present but in minority. Near the base of the Gemas Formation is a sequence of hard quartz sandstone and chert conglomerates occuring as lenses in the same stratigraphic horizon. Maximum thickness of these lenses exceeds 150 m. As a result of facies change, the sandstone-conglomerate unit is discontinuous. The rocks of the Gemas Formation are almost homoclinal and steeply dipping to the east.

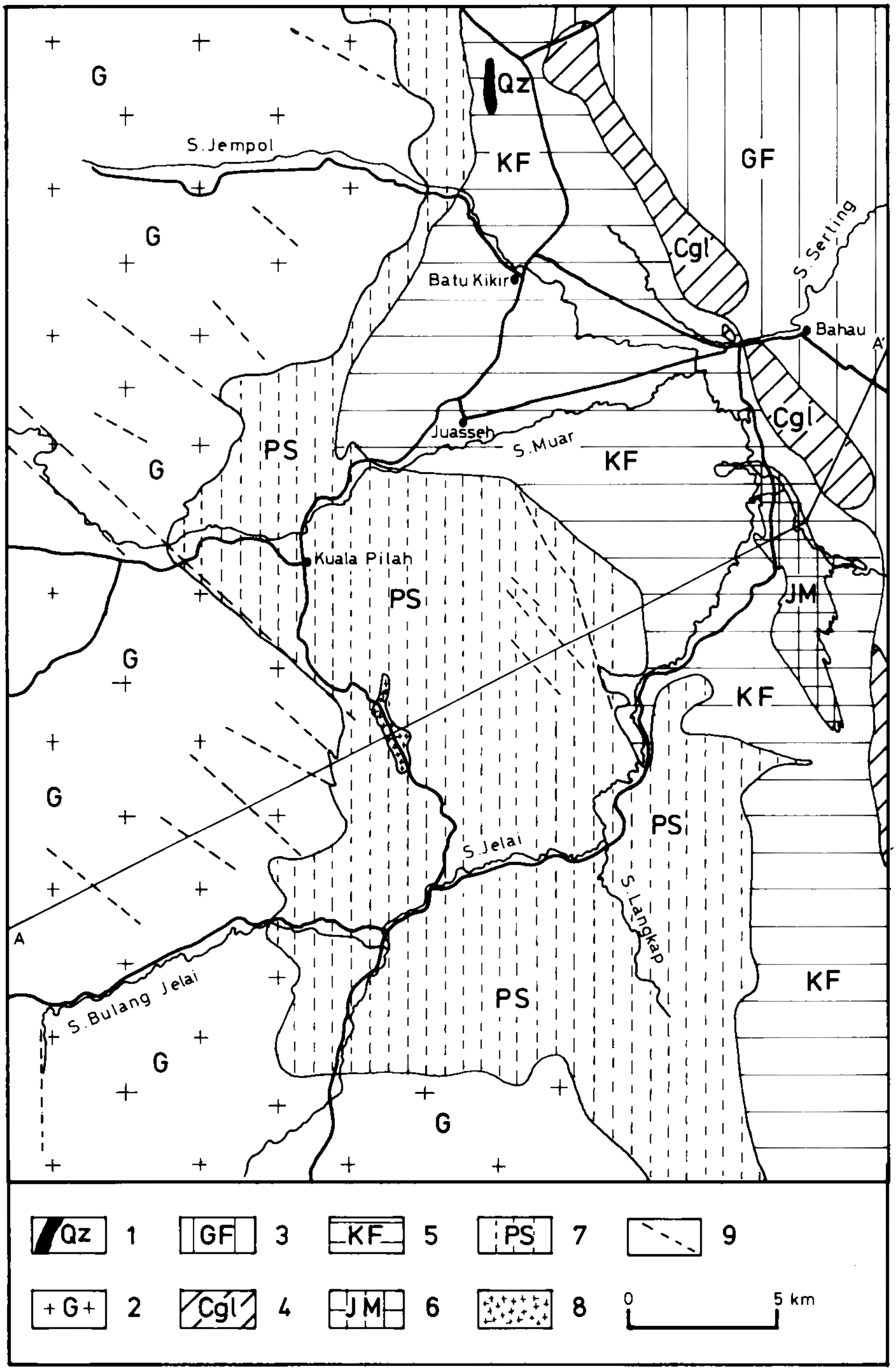


Fig. 14. — Geology of the Kuala Pilah-test area. The legend is explained in Table 2.

TABLE 2. — Geology of the Kuala Pilah-testarea (cf. Fig. 14) (after GEOLOGICAL SURVEY OF MALAYSIA 1973, 1982, NG 1970, MOHD YUSOP 1973).

	AGE	FORMATION	DESCRIPTION
1	Post Granite	Intrusive Q dyke	Late-phase q intrusive
2	Possibly Jurassic to Upper Triassic	Main Range Granite	Mainly coarse grained porphyritic biotite granite
3	Middle to Upper Triassic	Gemas Formation	Unmetamorphosed sedimentary rocks Mainly shales with minor sandstone and a lower
4			conglomeratic unit
5	Lower	Kepis	Mainly rudaceous, arenaceous, lutaceous and calcareous metasediments
6	Permian	Formation	Jelai Marble member is mappable
7	Palaeozoic	Pilah Schists	Mainly quartz-micaschist and graphitic schists
8			Occurrences of serpentinite are characteristic
9	Major faults		

Basic igneous rocks intrude the Gemas and Kepis Formations and presumable the metamorphic basement as well. These hypobyssal rocks intruded the area possibly in the Cretaceous and Tertiary.

The granite country that occupies the western part of the area is part of the eastern flank of the Main Range granite batholith that was emplaced during the Upper Triassic to Middle Lower Jurassic. The granite rocks are generally holocrystalline, coarse to medium grained, mostly porphyritic and composed essentially of quartz, potash feldspar and plagioclase with subordinate amounts of biotite and muscovite. Jointing is the most common structural feature shown in the granite body. The trends of the major sets of joints are parallel to the NE-SW and the NW-SE directions. A few faults trend in NW-SE direction.

A large N-S striking post-granite intrusive quartz dyke occurs 5 km N of of Batu Kikir.

2.2.2. Macro-landforms

Most of the rivers that drain the Kuala Pilah test-area i.e. the Jempol, Muar and Jelai rivers, belong to the basin of the Muar emptying in the Malacca Strait. The Serting river however belongs to the basin of the Pahang, flowing in the South China Sea. Consequently part of the important peninsular divide runs through the area (Figs. 5, 15 and 16).

Three macrolandform-complexes can be distinguished : a riverplain, a hill-complex and a massive highland.

The core of the area is occupied by an extensive riverplain of some 100 km^2, referred to as the Juasseh-plain (DE DAPPER 1983) and stretching along an ENE to NE-running axis formed by the Upper-Muar and the Middle-Serting. The plain is roughly bounded by the 60 m contour level in the eastern part and by the 75 m contour level in the western part. The Middle-Serting leaves the area at an elevation of 50 m a.s.l., and the Middle-Muar at an elevation of 30 m a.s.l. The bulk of the Juasseh-plain is occupied by a higher T_2 river terrace. A lower river terrace, T_1, forms a narrow discontinuous strip along the main river channels (T_0).

The open basin wherein the riverplain is shaped, is surrounded by a massive highland, with elevations up to 786 m a.s.l. and whose boundary roughly conforms to the 250 m contourline. The highland is part of the granitic Main Range and shows a very rugged relief, strongly incised by deep and narrow valleys with rectilinear, steep to very steep sloping sides. Two broad valleys however, the heads of the Jempol and the Muar, disrupt the continuity of the highland.

The transition between the riverplain and the highland is formed by a dense complex of hills. Most of the hills are small and low and arranged around restricted highland cores with elevations around 200 m a.s.l. The hills are lined up in distinct directions. The NNE-SSW direction is the most important one, followed by NNW-SSE and N-S. These directions clearly reflect the structural trends of the country rock : NNW-SSE strikes of the folded Kepis-Formation, NNW-SSE and NW-SE faults of the Pilah-schists and the Main Range granite, NE-SW and NW-SE jointing of the granite, N-S-post-Granite intrusions. The lining is extremely striking in the case of the narrow and long Bahau-ridge. It forms an exceptional highland core, 1.5 km wide, 20 km long, and with crest elevations between 388 m and 240 m a.s.l., running in NNW-SSE direction. Small parts however strike in a N-S-

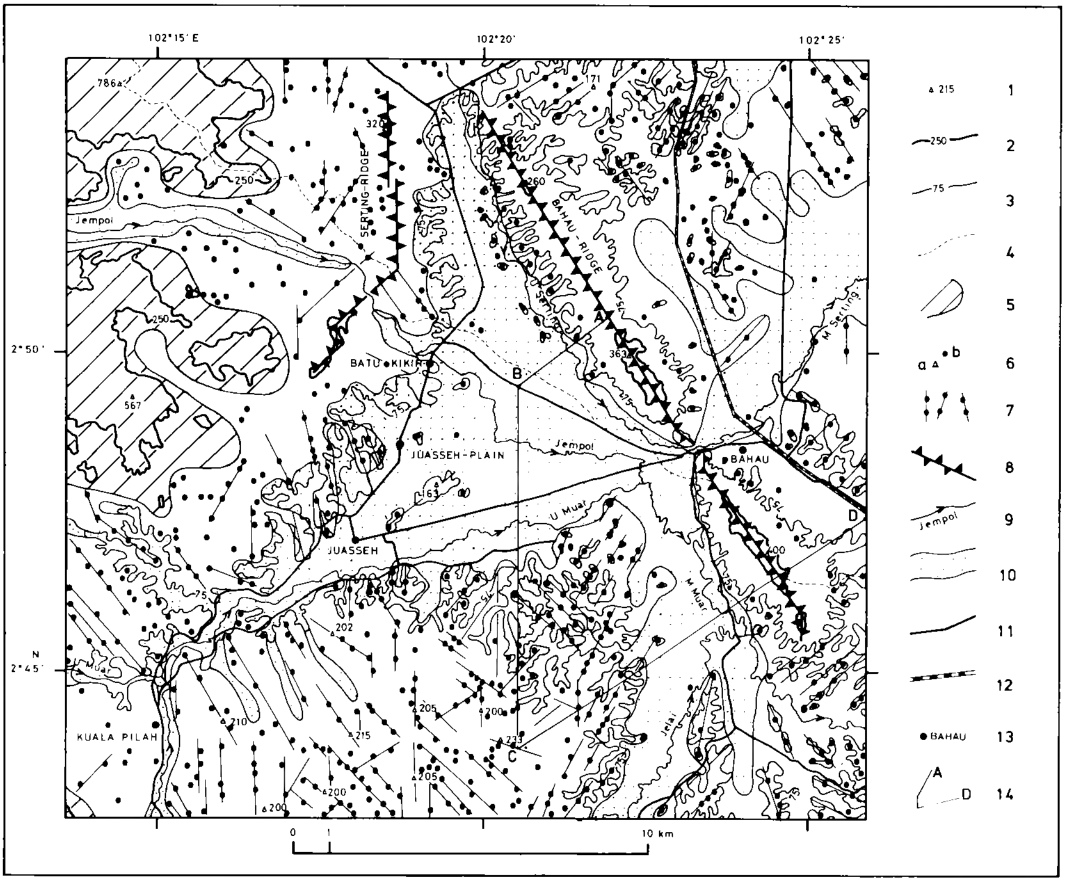


Fig. 15. — Macromorphological outline of the Kuala Pilah-test area.

1. Elevation a.s.l. in metres
2,3. 250 m- and 75 m- contour-line
4. Muar-Pahang divide
5. Granitic highland
6a. Highland core
6b. Low hill
7. Trend lines of interfluve grain
8. Important ridge
9. Main rivers
10. Riverplain
11. Principal roads
12. Railroad
13. Principal places
14. Topographic profile (cf. Fig. 16).

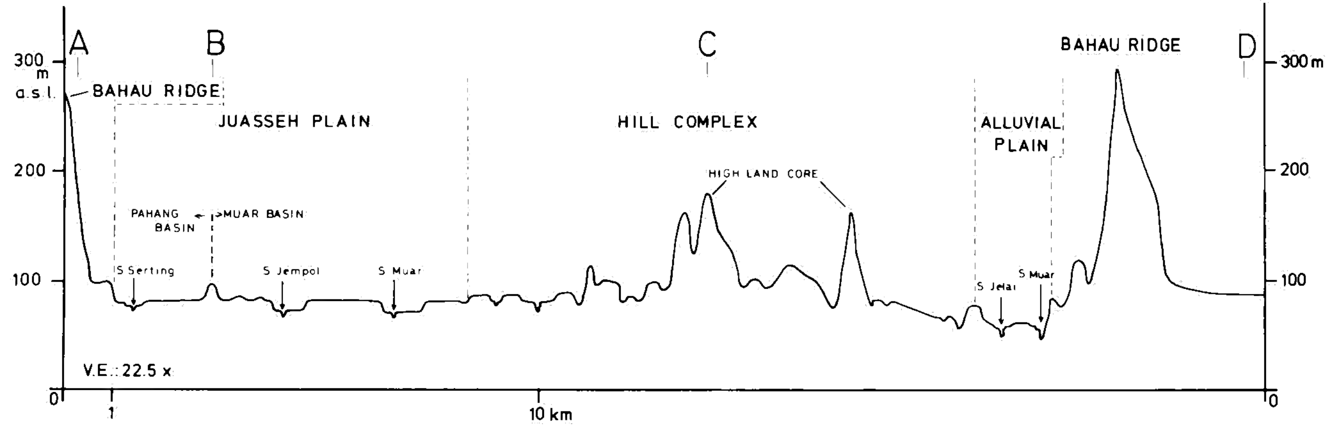


Fig. 16. — Topographic profile (following ABCD, marked on Fig. 15) showing the major landform elements in the Kuala Pilah-test area.

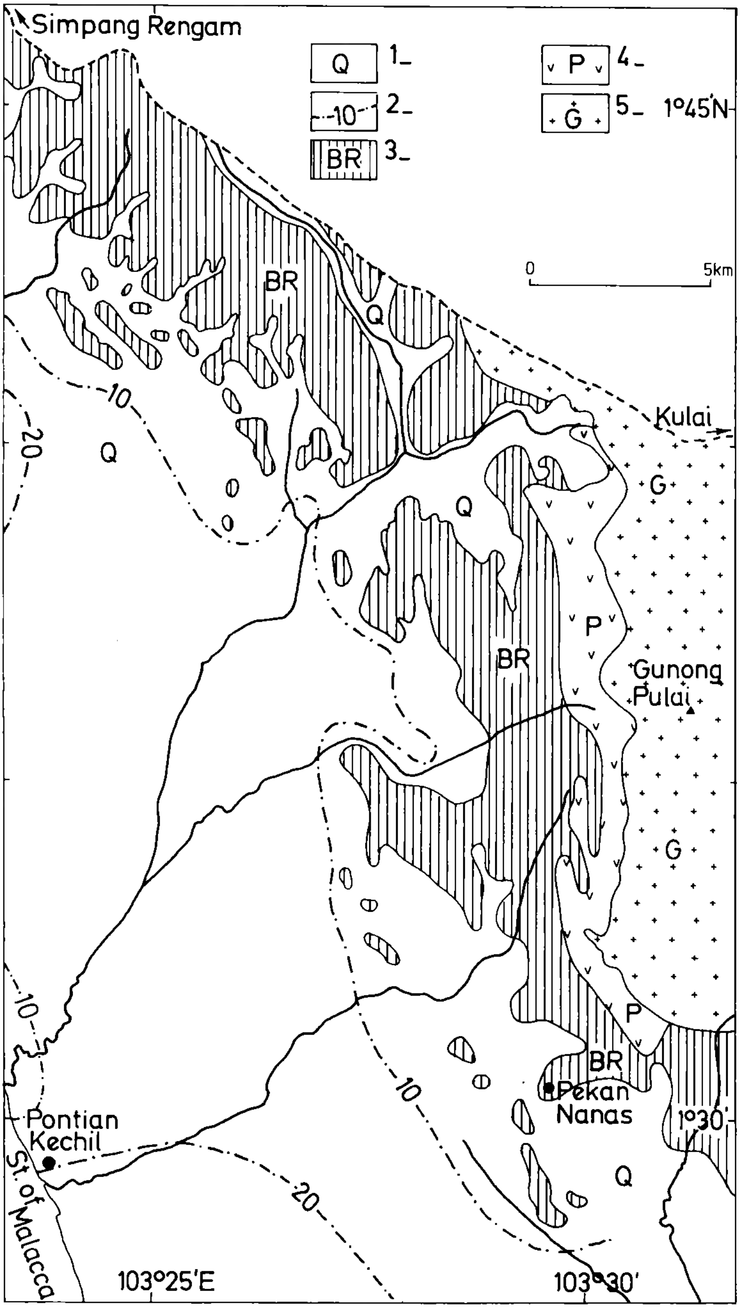


Fig. 17. — Geology of the Johor Bahru-test area. The legend is explained in Table 3.

direction breaking up the continuity of the ridge ; they form zones of weakness, giving way to the development of watergaps and windgaps. A very important watergap is developed near Bahau where the Serting breaks through, to join the Pahang basin. The Bahau-ridge forms an important structural element in the drainage pattern, as the southern part serves as Muar-Pahang divide. Following Ng (1970) the ridge is a hogback controlled by the presence of steeply dipping homoclinal sedimentary strata. Another exceptional core of highland is the less important Serting-ridge (0.75 km wide, 6.5 km long, crest elevations between 320 m and 230 m a.s.l.) running close to the northern edge of the Bahau-ridge in N-S direction. This ridge forms an igneous hogback controlled by a near vertical resistant quartz-dike. The junction between hills and riverplain or valleys is always marked by a distinct footslope.

2.3. Johor Bahru-area

2.3.1. Geology

The area is made up of a diverse assemblage of rocks comprising sedimentary, volcanic and igneous rock types (Fig. 17 ; Table 3).

The eastern margin of the testarea is underlain by granitic rocks that are part of a NNW-SSE trending granite range outcroping extensively in Johore and Singapore. The main component of that batholith is a coarse-grained hornblende-bearing adamellite. Following Hutchison (1973) the age of the intrusion, based on radiometric determinations, is Upper Cretaceous to Lower Triassic for that area.

To the west of the batholith lie consolidated stratified rocks, tentatively named the Jurong Formation by Burton (1973). The lower part of this formation consists of volcanic rocks, mainly tuffs, which are referred to as the Gunong Pulai Volcanic Member. They are of Lower Triassic age or older and form a narrow belt in contact with the granite.

The upper portion of the Jurong Formation is a sequence of detrital strata, made up mainly of shale and sandstone, with some siltstone, conglomerate, and volcanic layers. This portion is referred to as the Bukit Resam Clastic Member and is thought to represent a late-orogenic molasse facies. The Bukit Resam Clastic Member is extensively exposed in the eastern part of the area. The sedimentary rocks are striking in NNW-SSE direction and have uniform steep to very steep dips away from the granite contact.

TABLE 3. Geology of the Johor Bahru-test area (cf. Fig. 17) (after GEOLOGICAL SURVEY OF MALAYSIA 1973, BURTON 1973, HAGEN & STREIF 1976).

	AGE	FORMATION	DESCRIPTION
1	Quaternary Recent to sub-recent	Superficial deposits	Unconsolidated sands and clay of both fluviatile and shallow-marine origin
2	Isopachs of recent to sub-recent coastal plain deposits	Jurong Formation	
3	Upper Triassic to (?) Middle Jurassic (?)	Bukit Resam Clastic Member	Shale, silstone, sandstone and conglomerate
4	(?) Lower Triassic or older (?)	Gunong Pulai Volcanic Member	Mainly rhyodacite tuff with minor interbeds of other acid to intermediate tuffs and lavas
5	Upper Cretaceous to Lower Triassic	Granite Intrusive	Mainly coarse-grained hornblende bearing adamellite

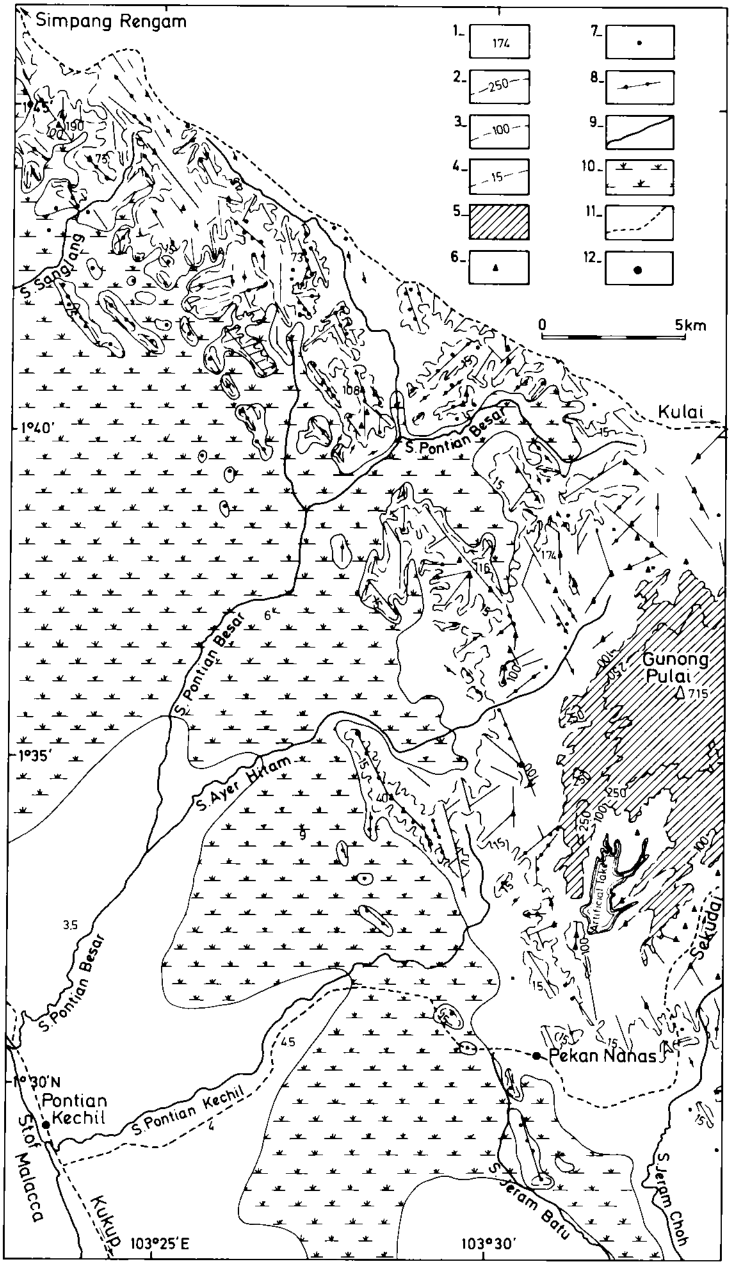
Nearly half of the area is occupied by Quaternary unconsolidated sand and clay deposits of both fluviatile and shallow-marine origin. Their thickness gradually increases towards the coast where it reaches values of more than 20 m (HAGEN & STREIF 1976).

2.3.2. Macro-landforms

The bulk of the area is formed by a lowland bordering the coast and roughly bounded by the 15 m contourline (Figs. 18 and 19). Extensive parts of the lowland are occupied by a swampy peat area.

The eastern part of the area is dominated by highland lying above the 100 m contour. It is formed by the granitic Gunong Pulai massif, having a maximum elevation of 715 m a.s.l., and by a prominent ridge rising to an elevation of 332 m a.s.l. developed in metamorphosed rocks of the Gunong Pulai Volcanic Member. This ridge trends north-northwest, being separated by a valley from the mountain proper at its south end but tending to merge with it towards the north.

The Bukit Resam Clastic Member is characterized by a subdued hilly topography. Most of the hills are small and low and are arranged


Simpang Rengam
1. 174
2. 250
3. 100
4. 15
5.
6.
7.
8.
9.
10.
11.
12.
0 5km
Kulai
S. Sanglang
S. Pontian Besar
S. Ayer Hitam
Gunong Pulai
715
Artificial lake
Sekudai
Pekan Nanas
S. Pontian Kechil
Pontian Kechil
St. of Malacca
Kukup
S. Jeram Batu
S. Jeram Choh
1°45'
1°40'
1°35'
1°30'N
103°25'E
103°30'
190
100
73
108
174
116
250
15
40
3.5
4.5
6

around restricted highland cores with elevations ranging between 70 m and 200 m a.s.l. Some of the hills emerge as islands, isolated in the coastal plain. The interfluve grain shows distinct directions. The NNW-SSE direction is the most important one, followed by NE-SW and N-S. The first direction clearly reflects the major strike trend of the bedrock.

No important rivers drain the area. The Sanglang, Pontian Besar, Ayer Hitam, Pontian Kechil, Jeram Batu and Jeram Choh rivers, are all short coastal streams having their heads in the granitic highland and debouching into the Malacca Strait. The lowland penetrates the complex of hills along the streams. Only small remnants of a higher T_2 river terrace can be traced south of the Pontian Besar river. The transition between hillslopes and lowland is almost always marked by important footslopes.

2.4. Model of macro-landforms

The morphography of the three testareas reveals following common sequence of macro-landforms in the upland (Fig. 20) :

(1) *highland cores*, such as ridges and high hills, dominantly controlled in their distribution and form by the lithostructure of the bedrock,
(2) *low hills*, arranged in close relationship to the highland cores,
(3) *footslopes*, developed at the feet of highland cores and low hills,
(4) a higher *river terrace level*-T_2,
(5) a lower *river terrace level*-T_1,
(6) the *present riversystem*-T_0.

The relative importance of the landforms is different from one area to another. The footslopes are better developed in Padang Terap and Johor Bahru than in Kuala Pilah, where low hills show a higher

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Fig. 18. — Macromorphological outline of the Johor Bahru-test area.
1. Elevation a.s.l. in meters
2,3,4. 250m-, 100 m- and 15 m-contour-line
5. Highland
6. Highland core
7. Low hill
8. Trend lines of interfluve grain
9. Main rivers
10. Swamp
11. Principal roads
12. Principal places

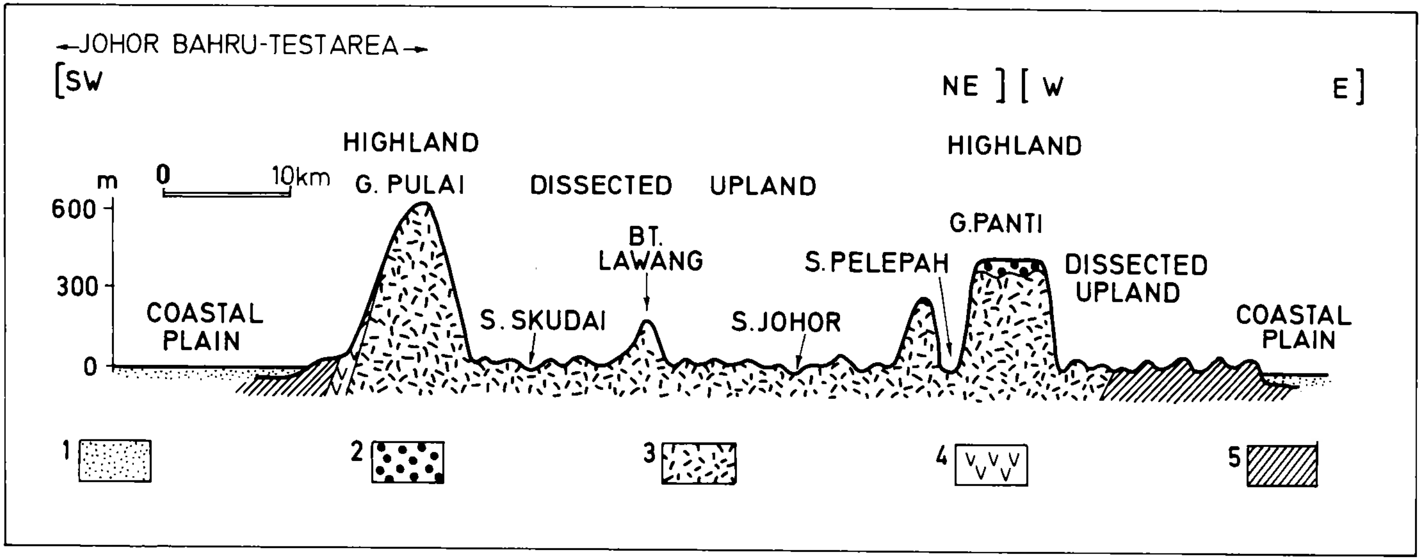


Fig. 19. -- Major morphological elements in Johor (after SWAN 1972).

1. Quaternary sediments
2. Cretaceous sandstone
3. Granite
4. Acid volcanics
5. Triassic sedimentaries

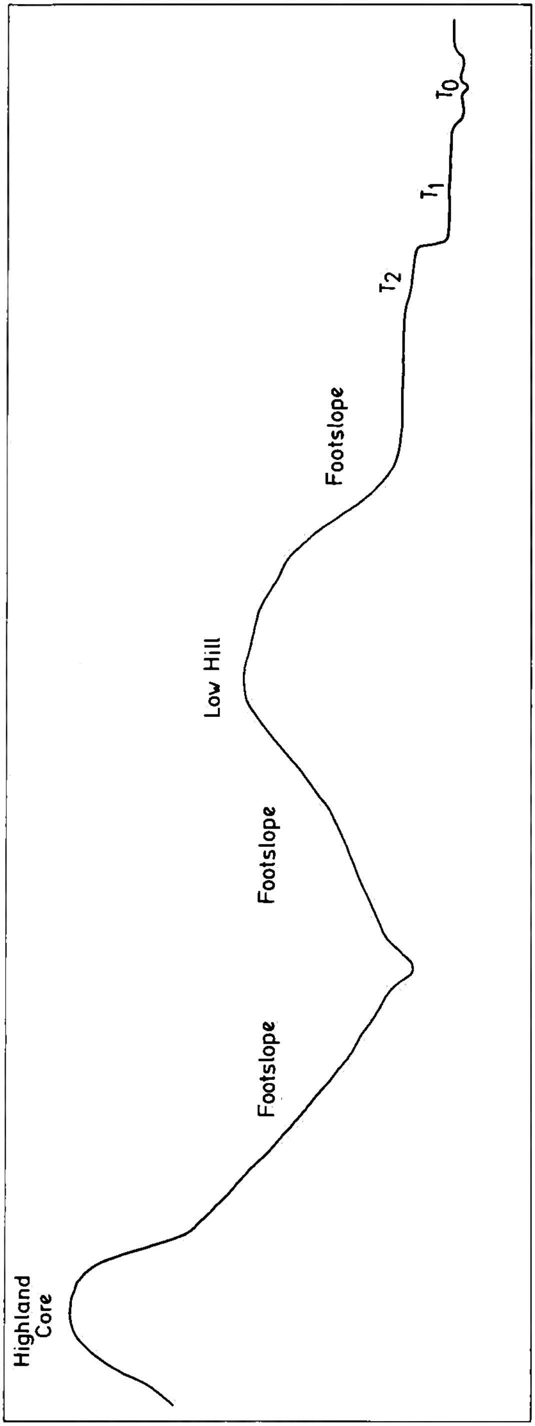


Fig. 20. — Model of the macrolandforms in the test areas.

density. In Padang Terap, T_2- and T_1- terraces are confined to narrow but continuous strips along the main rivers. T_2 forms a huge inland river plain in Kuala Pilah, whereas only remnants subsist in the Johor Bahru testarea.

In the following chapters attention will be focused on the morphogenesis and morphochronology of the footslopes, the river terraces and the low hills.

CHAPTER 3

GEOMORPHOGENESIS

3.1. Footslopes

3.1.1. Form

As was already mentioned in the previous chapter, distinct footslopes in most cases mark the lowest parts of the hillslopes and form the transition between upland and lowland.

In the Padang Terap area the foot of the steep ridges, sloping around 30°, is marked by an important concave slope break, that defines the onset of a long concave surface, sloping at values from 9.5° tot 2° (Figs 12 and 27) (Photo 1). A less conspicuous slope break also marks the foot of the low hills and confines shorter footslopes. Similar footslopes were reported for several other areas in the State of Kedah by ZAINOL (1984).

In the Kuala Pilah area most of the hillslopes grade over a narrow crestslope into a gently curving to rectilinear midslope, showing slope inclinations between 15° and 25°. A distinct but mostly smooth slope change line marks the transition of the midslope to the concave footslope showing inclinations gradually decreasing from 10° to 1° (Photo 2).

For the State of Johor, a detailed survey of landforms was worked out by SWAN (1970a, b, c, d, 1972). He recognizes three storeys in the landscape, very similar to the threefold division we proposed for the mega-landforms. The top storey consists of steep hills, ridges and mountains above 100 m a.s.l., while the middle storey, within 100 m a.s.l., consists of dissected lowlands that form associations of low undulating to rolling rises, ridges and hills whose gentler slopes decline. The bottom storey comprises lowlying depositional forms. Swan refers to the middle storey footslopes as piedmont slopes. In Johor the piedmont slope occurs in association with the hillslope and bottom storey clayplain, which idealised spatial relationship is expressed in Fig. 21. The piedmont slopes investigated by Swan have widths from 5 m to 900 m, while slope angles range from 9° to 1°, the profile being uniform to gently concave. The piedmont slopes give way to steeper slopes above through a nickzone where the mean maximum curvature per 7.5 m is 6.4°. A selected piedmont profile for the Kulai Young Estate, situated in the testarea at 4 km to the NW of Gunong Pulai, shows a piedmont slope separated by a nickzone from a 22° slope and declining from 7.3° to 3.8° (Fig. 21).

3.1.2. Pediments

The footslopes in the test areas show the following common form-elements :

1. They are developed at the foot of higher and steeper ground.
2. They have a characteristic transverse profile (i.e. normal to the hillfront) :
   a. The slope is at a low angle (less than or equal to 10°) relative to the steeper ground (15° to 30°) of which it is a footslope.
   b. The profile is smooth and in most cases concave, although rectilinear sections may be present.
   c. The nick between the footslope and upland is abrupt. However it is not necessarily perfectly angular and may comprise a short concavity in a nickzone.
3. They have a characteristic longitudinal profile (i.e. parallel to the hillfront) : it tends to be rectilinear and undulates only slightly where the footslope is dissected by streams having their head in the hillfront.
4. They have a characteristic shape when considered in three dimensions : they are generally planar low angle surfaces with a faint concavity.

Moreover, as will be further demonstrated, the footslopes are degradational landforms truncating lithological and tectonic variations and only covered by a thin veneer of loose superficial material.

The footslopes in the testareas therefore meet the requirements to be labelled pediments following the definition of WHITAKER (1979) : "A pediment is a terrestrial erosional footslope surface inclined at a low angle and lacking significant relief in all three dimensions. It usually meets the hillslope at an angular nickline, and may be covered by transported material". The definition given above is non-genetic, apart

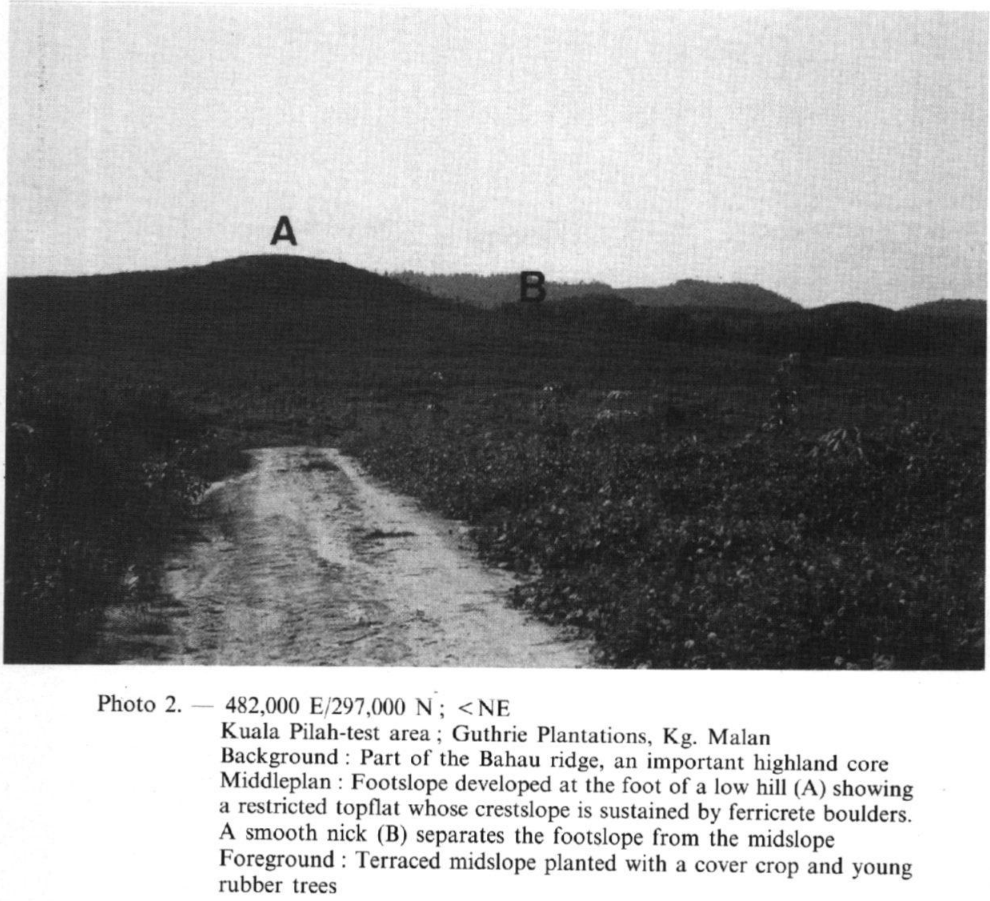


Photo 2. — 482,000 E/297,000 N ; <NE
Kuala Pilah-test area ; Guthrie Plantations, Kg. Malan
Background : Part of the Bahau ridge, an important highland core
Middleplan : Footslope developed at the foot of a low hill (A) showing a restricted topflat whose crestslope is sustained by ferricrete boulders. A smooth nick (B) separates the footslope from the midslope
Foreground : Terraced midslope planted with a cover crop and young rubber trees

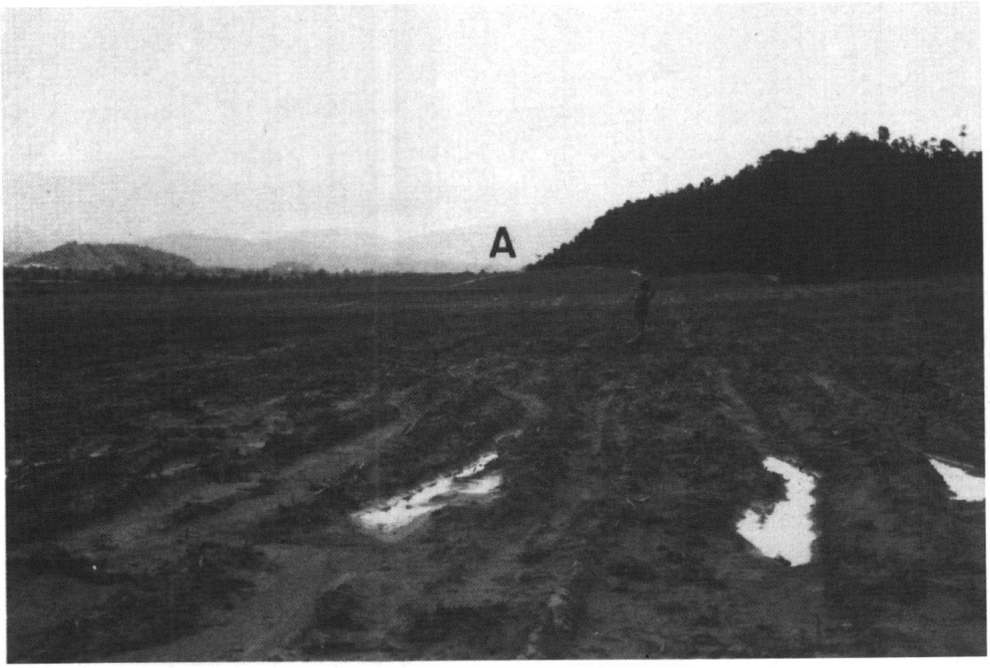


Photo 1. — 300,600 E/695,500 N ; <NNW
Padang Terap-test area ; Padang Terap Sugar Cane Plantation
Background : Highland surrounding the Padang Terap basin
Middleplan : Footslope developed at the foot of Bukit Ular Utara. A sharp nick (A) separates the footslope from the ridge, a local highland core
Foreground : Footslope after harvest of the sugar cane

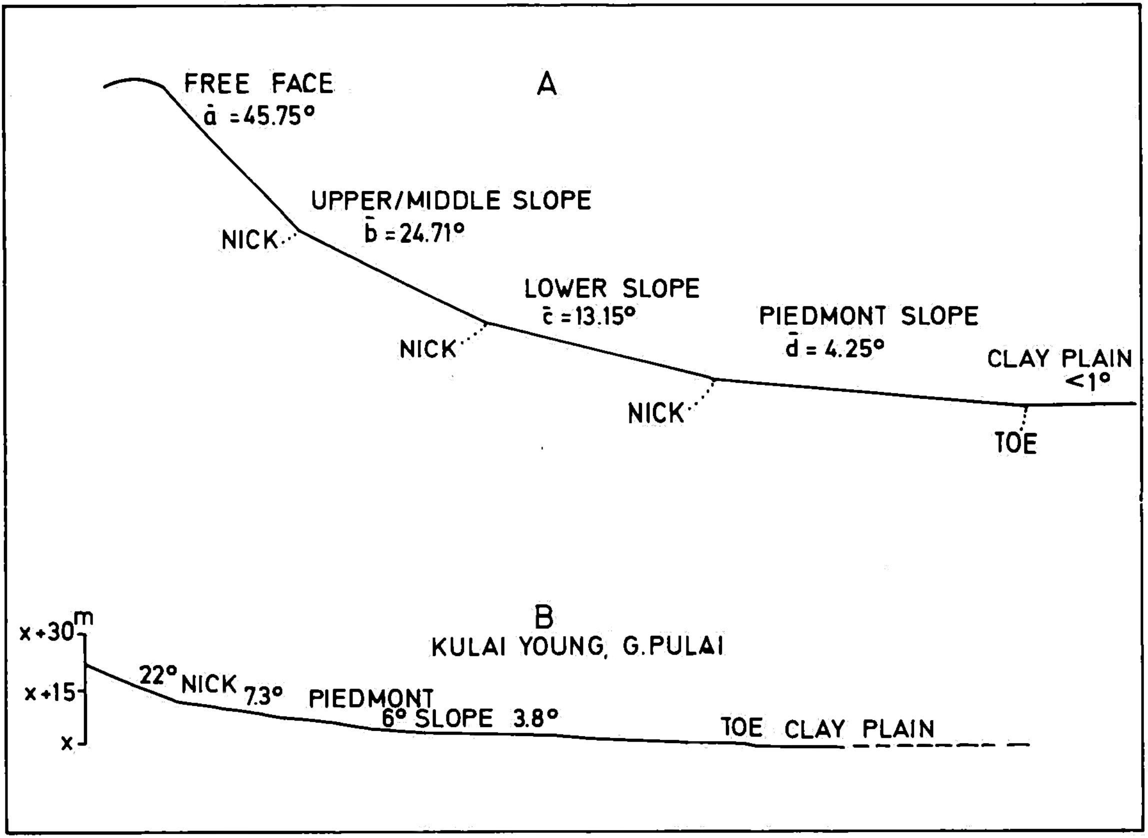


Fig. 21. — Model of the hillslopes in Johor (A) and selected piedmont profile in the Kulai Young Estate (B) (after SWAN 1970a).

from the exclusion of purely depositional, non-terrestrial and tectonic landforms. The pediment, defined as such, is not restricted to any process, lithology, structural setting, climatic environment, or size.

Pediments were reported for other parts of the peninsula (WHITAKER 1973), however in most cases with a genetical connotation, that will be discussed later. LOUIS (1959) describes footslopes (in German the author proposes the descriptive denomination "flache Fussfluren") of granitic inselbergs near Hua-Hin (12°34'N ; 99°58'E), West of the Gulf of Thailand. Comparatively flat piedmonts surrounding steep granitic hills are reported by NOSSIN (1964) for the vicinity of Kuantan (East Coast of West Malaysia). For Puchong (south of Petaling Jaya in Selangor), MORGAN (1973) describes undissected almost rectilinear piedmont slopes, declining from 11° to 4° and developed on steeply dipping alternating sandstones and shales.

3.1.3. Superficial layers on the pediments

In almost all cases the subaerial pediment surface is only separated from the bedrock pediment surface by a veneer of loose unconsolidated material, with a thickness rarely exceeding 3 m and showing a typical twofold layering.

The first layer above the bedrock is composed of pebbles (sensu FRIEDMAN & SANDERS 1978) with particle diameters usually ranging between 5 mm and 25 mm. In some cases the base of the first layer is marked by a pavement of cobbles, ranging in diameter size from 50 mm to 200 mm, and even rare boulders (Fig. 22). The gravel of the first layer is always imbedded in a fine earth matrix at varying proportions. The degree of packing ranges from sparse and matrix-supported to dense and clast-supported. The top layer is almost exclusively composed of fine grained matter. The boundary between gravel layer and top layer is always abrupt. The gravel is composed of weathering resistant elements such as vein quartz, metamorphic rock fragments and ironstone nodules (FAO, 1977). The last is always present in very large quantities.

The above depicted build-up of the superficial layers on gentle slopes is very typical for intertropical areas and was described by many authors. In his review of the literature on stone-lines and related phenomena VOGT (1966) preferred the neutral expressions « stoneline complexe », « recouvrement argilo-sableux », « stoneline au sens large » and « stoneline au sens étroit » to designate the whole of the superficial

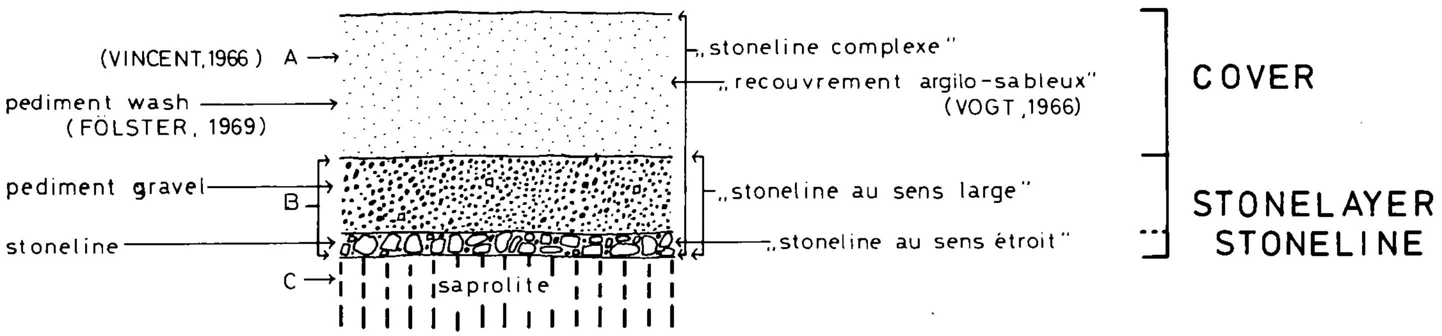


Fig. 22. — Nomenclature of the superficial layers on the pediments.

layers, the top layer, the gravel layer and the pavement respectively. Another neutral but less detailed subdivision was proposed by VINCENT (1966) who identifies the layers as levels A (top) and B (gravel) overlying C, the bedrock. Following Vogt's proposition we will use the terms cover, stone-layer and stone-line to designate the top layer, the gravel layer and the pavement respectively.

As a rule, the stone-line is a thin deposit. On rocks providing coarse debris (e.g. from quartz veins) in sufficient quantity the stoneline forms a continuous, twodimensional pavement. On fine-grained rocks, like shales, stone-lines are often discontinuous and may not be seen in individual profile pits or small exposures. The stone-layer and the cover run parallel to the surface, though with many minor irregularities. Undulations, irregular humps and runnel-like depressions of one to several tens of meters width characterize both the A/B- and the B/C-plane. As these irregularities do not conform on both planes, the thickness of A and B may vary considerably.

The bedrock is always weathered to a soft saprolite wherein original rock features such as bedding and quartz veins can still be recognized to varying degrees. The top of the saprolite is very often duricrusted by varying degrees of laterite formation. As was showed by the soil surveys in the test areas, in many cases a close relationship exists between the saprolitic bedrock, the stone-layer matrix and the cover (DEBAVEYE & ABDUL RAHMAN 1983, BOUCKAERT *et al.* 1984) (Fig. 23). The cover however tends to possess a somwhat lower clay content.

Detailed studies on soil-lithology-slope relationships were carried out by SWAN (1970c) in Johor, by MORGAN (1973) in Selangor and Negeri Sembilan and by LEOW (1979) in Singapore. They all implicitely recognize the close relationship between cover and saprolitic bedrock as they regard the superficial layer wherein the soil is developed as the product of an *in situ* weathering of the bedrock. Swan and Leow concluded from profile studies that the maximum sand and minimum clay contents occur in the uppermost layer, up to 35 cm below surface.

3.1.4. Genesis of the superficial layers

3.1.4.1. Autochthonous or allochthonous origin

Particularly within the tropics, stone-layers in weathering profiles have been the cause of considerable controversy. As they represent an obvious discontinuity separating the bedrock from the cover, the ques-

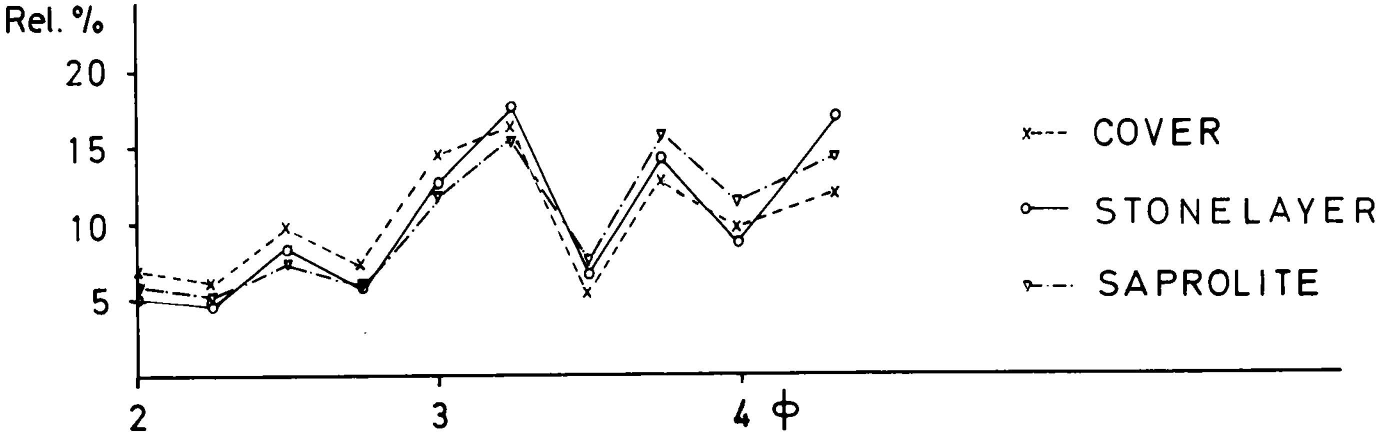


Fig. 23. — Typical particle size distribution of the 50-250 μm fraction of cover, stone-layer and saprolite.

tion arose whether the superficial layers are to be considered as the products of an autochthonous development, i.e. resulting from pedogenetic alteration of the bedrock *in situ,* or of an allochthonous one, i.e. resulting from erosional-depositional processes. Most of the original research on stone-layers and related phenomena was done by soil scientists and in the intertropical areas of Africa.

The fact that stonelayers are found blanketing virtually all landforms below residual relief and the striking similarity between cover and the weathered bedrock below, led many authors, especially those working in dense forest covered equatorial regions, to the conclusion that at least the stone-layer is an autochthonous product. LAPORTE (1962) is a typical representative of the "autochthonists". Working on very long trenches along the Comilog-railway in Congo, he concluded that the whole of the superficial layers was the result of *in situ* weathering. The stone-layer elements descended from the topographic surface or from within the cover through physical causes (gravitation, repeated wetting and drying), a process that was facilitated by the continuous reworking of the fine matter by the soil fauna. Most authors do not agree on the possibility of gravitational sinking. CAHEN & MOEYERSONS (1977) however recorded and proved experimentally the possibility of vertical subsurface movements of artifacts in Central Africa.

Semi-autochthonist authors consider the stonelayer to be a lag concentrate resulting from gravitational sinking in a soil creep layer. The only serious argument in favour of creep was the observation of quartz vein bending in slope direction (NYE 1954). However to this observation must be added the opposite one, i.e. of quartz vein bending upslope. Following STOOPS (1967) both features can in fact be observed next to each other on the same slope. The upward bending reflects the original shape of the vein and may result from the removal of material below the vein through dissolution or soil fauna activity.

Since stonelayers in most cases contain very large amounts of ironstone gravel, they are often considered as part of a developing pisolithic laterite profile (Fig. 24). The pisoliths are formed within the range of water table oscillation that is narrowed or broadened by climatic changes (ALEXANDRE 1978) or lowered by the progress of the weathering front itself (MCFARLANE 1976, 1983). At the top of the zone of formation pisoliths are concentrated and packed by the mechanical removal of inter-pisolith material by soil fauna, especially termites. Thus the inter-pisolith material is the source for the cover. Following McFarlane the cover material may also derive from the

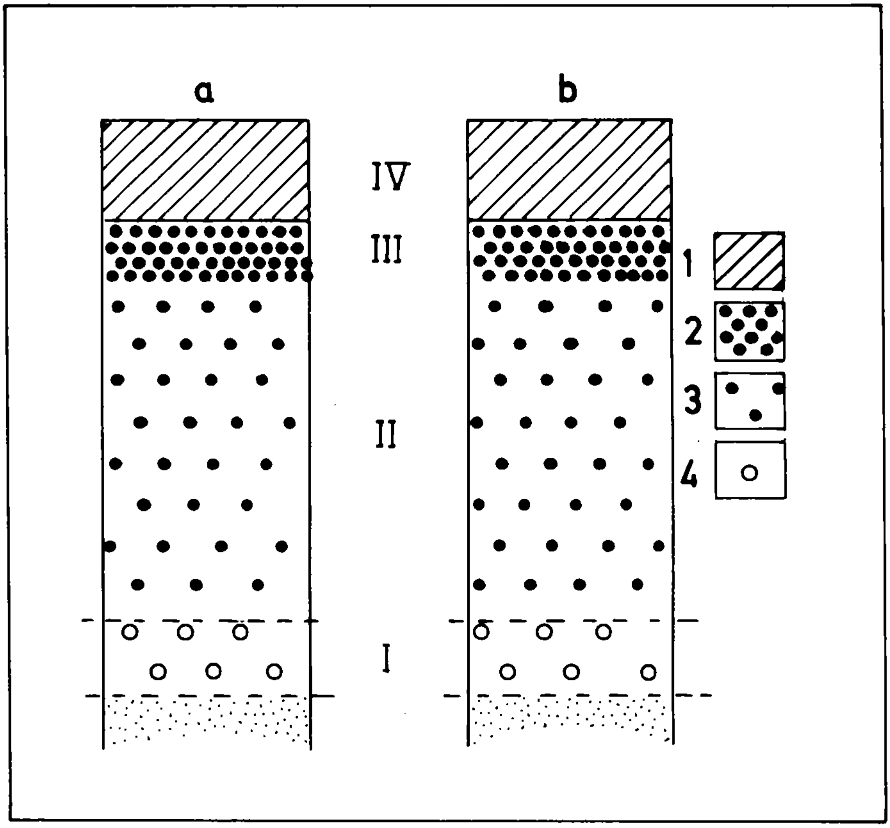


Fig. 24. — Two suggested interpretations of a typical pisolithic laterite profile (after McFarlane 1983) : (a) (i) pisolith formation within the narrow range of water table oscillation pertaining to the present climate ; (ii) spread of pisoliths in the vadose zone indicates a former climate with greater seasonality ; (iii) ' stone-layer ' of pisoliths indicates reduction of vegetation cover, possibly climatically controlled, and mechanical removal of inter-pisolith material ; (iv) return to wetter conditions and reburial by soil (after Alexandre 1978). (b) (i) pisolith formation within the narrow range of water table oscillation pertaining to the present climate ; (ii) spread of pisoliths in the vadose zone indicates the wake of the lowering water table ; (iii) packed pisolithic laterite in the base of the soil is a mechanical residuum resulting from removal of interpisolith material ; (iv) soil material derives from surviving inter-pisolith material and the breakdown of softer segregations. No climatic change need be involved (after McFarlane 1976).

1. Soil
2. Packed pisolithic laterite
3. Spaced pisolithic laterite no longer forming
4. Spaced pisolithic laterite presently forming

breakdown of softer segregations, a viewpoint very close to Laporte's purely autochthonist one.

Most authors working in savanna areas consider the stone-layer and cover to be of allochthonous origin. Their models were also widely accepted by workers in equatorial dense forest areas, who then invoke climatic changes leading to a considerable sparsening of the vegetation, to explain the original deposition of the superficial layers. Field evidence to support the allochthonous origin can be summarized as follows :

1. the multiple stratification of stonelayers,
2. the fairly sharp boundaries between different layers, unusual for pedogenic horizons,
3. the inclusion of allochthonous elements (i.e. transported some considerable distance from place of origin) in the stonelayer,
4. the abrupt truncation of petrographic features, especially quartz veins at the base of the stonelayer,
5. the occurrence of prehistoric implements of successive industries in different layers of the complex (FÖLSTER, 1969).

For the last evidence however the observations of CAHEN & MOEYERSONS (1977) have to be taken into account.

For WAEGEMANS (1953, Zaire) the stonelayer is a lag gravel due to the surface erosion of fines during an interpluvial phase, whereas the cover is a colluvium derived from the interfluves and trapped by the more dense vegetation of the following pluvial phase. RIQUIER (1969) comes to similar conclusions for stone-layer complexes observed in Congo and Madagascar. MARCHESSEAU (1966) and subsequently VINCENT (1966) consider the stone-layer in more detail and make a distinction between a « stoneline de type éluvial » (our stoneline) and a « stoneline de type colluvial » (our stone-layer without the stone-line). The former is a pavement resulting from surface wash of fine material by sheet floods and rills with simultaneous accumulation of coarse, detrital, autochthonous (rock, quartz) material too heavy for water transport. The latter is stone-line material being transported alone or together with covering material, by water or sliding along the slope (from 10 m to 1,000 m at most), causing an increasing depth of the stoneline downslope as well as the frequent irregularities in the A/B-plane. Following FÖLSTER (1969) the sheetwash-lag concept has severe limitations, because once a residual pavement has been formed no more fine material can be removed by surface wash. This restricts the possible depth of degradation, especially on rocks rich in coarse debris.

Moreover Marchesseau's and Vincent's model is complicated and vague because it supposes a second, more energetic, phase during which stoneline material becomes transportable and is moved downslope, and because all in all it gives no explanation for the presence of the stoneline which is supposed to be transported during the subsequent phase.

Most autochthonist authors however propose one or another form of pedimentation process, i.e. parallel retreat of scarps leaving behind a pediment, to explain for the layered build-up of the superficial deposits and the similarities between cover and underlying weathered bedrock. DECRAENE (1954), RUHE (1954) and subsequently LARUELLE (1961) and SYS (1961), all working in different parts of Zaire, proposed a two phase model. In a first stage laterite capped uplands are consumed by scarp retreat whereby the laterite is broken down and spread over the newly formed pediment surface to form the stone-layer. In a subsequent phase, after the protective duricrust has been eroded, the underlying saprolitic material is spread from the upland over the pediment surface mainly by colluviation. The result is a pedisediment showing material inversion, whereby saprolitic bedrock material, normally lying below the superficial layers, is placed on top of the stone-layer. Sys'model was applied by PARAMANANTHAN (1982) in West Malaysia to explain the lateritic stone-layers on the footslopes.

SEGALEN (1969), in a comparative study on stone-layers under savanna and under dense forest in West Africa, advances a similar model to explain the stone-layers on the savanna plains. In his model however stone-layer and cover are deposited during the same phase but show a lateral shift due to particle size differentiation. Segalen states that equatorial conditions are not favourable to form stone-layers but induce deformation of the later by chemical weathering resulting in the typical wavy aspect (Fig. 25). Segalen's conclusions were corroborated by the observations of COLLINET (1969) in Gabon.

FÖLSTER (1964a, b, 1969), working in Sudan and SW-Nigeria, considers the footslope deposits to be pedisediments and makes distinction between a stone-line, a pediment gravel and a hillwash (Fig. 22). The pedisediments were formed during morphogenic unstable phases by two different types of processes operating successively ;

1. Pedimentation, involving the retreat of a scarp, formation of a new basal surface of erosion, transportation of the displaced material over the new surface including partial sorting and deposition of coarse debris (stone-line and pediment gravel) (Fig. 26). The stone-

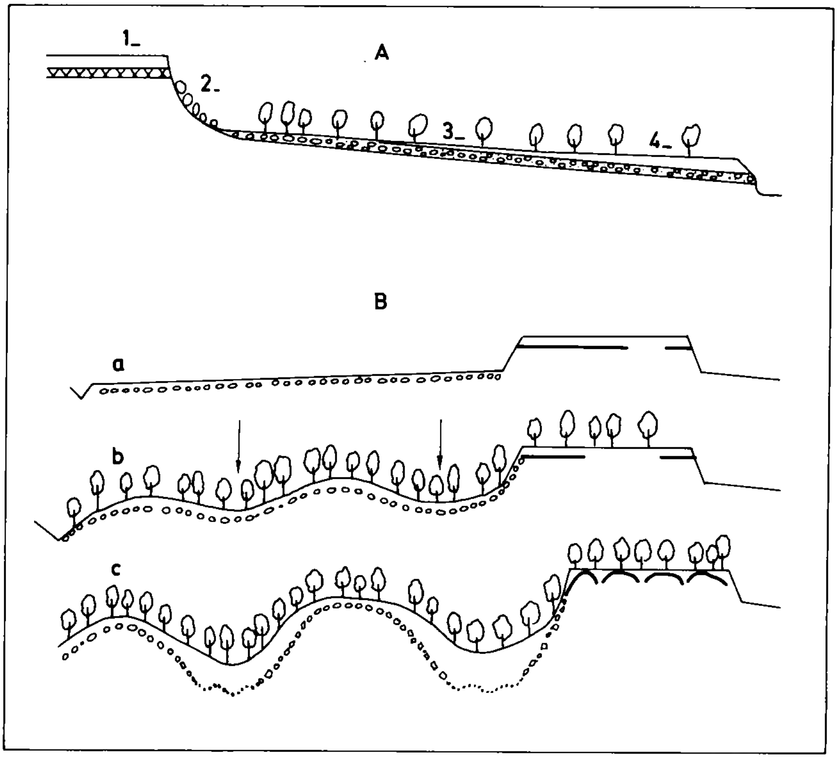


Fig. 25. — Model of formation and evolution of the stone-layer following SEGALEN (1969).

A. 1. Ferricrete *in situ*
  2. Ferricrete debris on retreating scarp
  3. Distribution of debris on pediment
  4. Covering of debris by fine material from below the ferricrete

B. a. Original evolution under tropical climate (cf. A)
  b. Under equatorial climate
  Undulations are formed by chemical erosion, accentuated on some favourable spots
  c. Accentuation of the process followed by festooning of the stone-layer and thickening of the cover in the thalwegs through creep under dense forest

line represents coarse debris, too heavy to be transported by water, that is deposited at the foot of the scarp or close to it. The pediment gravel is only transported over short distances and therefore rounding of the particles remains insignificant.

2. Deposition of fine material (hillwash) on parts of the slope, evening out existing irregularities of the new surface and its coarse pedisedi-

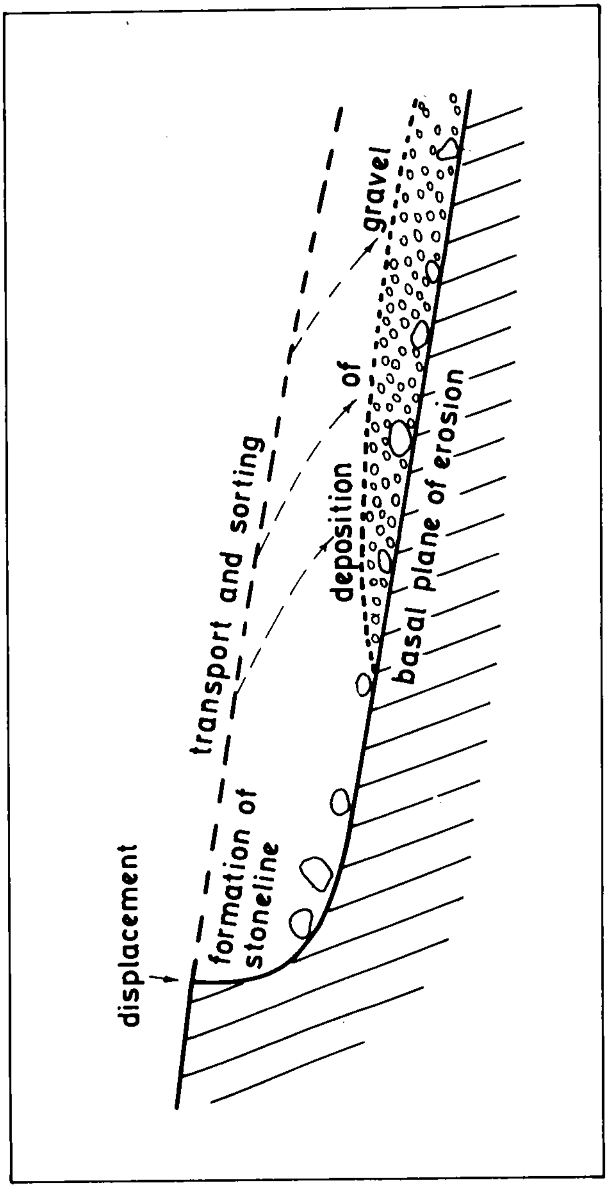


Fig. 26. — Model of the differentiation of stone-line and stone-layer below a retreating scarp following FÖLSTER (1969).

> ment cover. The hillwash is derived from the interfluves and is the product of unconcentrated wash of material on the soil surface by direct impact of rain and rill action.

Fölster emphasizes the fact that the two processes, although successive in time, operate within the same unstable erosional phase.

ROHDENBURG (1969) applied Fölster's model in several West African countries, especially SE Nigeria, but gives a clearer view on the scale of the landforms and the processes involved. He differentiates between stream pediments created by coalescing rock fans of streams issuing from the scarp face and slope pediments growing at the expense of an upland with a low scarp retreating on a flat slope and parallel to the hillfront and thus perpendicular to the issuing streams. The former are typical for arid and semi-arid areas and are formed in hard rock, whereas the latter are typical for wet-and-dry tropical areas and are formed in soft rocks such as saprolites. In the slope pedimentation model the pedimentation scarps are only 1 m to a few meters high, therefore the process is also referred to as micropedimentation. On flat slopes scarps are only developed after sufficient concentration of water. In case of low amounts of surface runoff such a scarp development will be limited to very small areas. Thus gullies are being found with their head scarp constantly moving upward but their side scarp remaining relatively stable. In case of greater surface runoff such side scarps would not be stable and the gullies would tend to merge with neighbouring gullies, thus forming a though ragged, yet complete slope pedimentation scarp. The coarse material left behind forms a stone-line on the pediment. The pediment gravel consists of a relatively fine type of transported coarse material. During the period that pedimentation took place it was a temporary sediment. It became fixed only when the process of micropedimentation weakened. Thereafter the pediments tended to become dissected by a dense system of flat streamlets. As a result the stonelayer complex runs on the whole parallel to the surface although it may do so in a markedly wavelike fashion. The cover is a hillwash consisting of fine grained material deposited by sheet wash and resulting, on the one hand from a moderate activity continuing on the pedimentation scarps and involving exclusively fine grained matter and, on the other hand additional material from lower horizons, which has been brought to the surface by earthworms and termites. Following Rohdenburg slope pedimentation activity in SW-Nigeria is very likely to have occurred during a dry phase characterized by a significantly less dense vegetation than the actual one. However, it does not seem to be necessary to postulate a semi-desert vegetation, since slope pedimentation is not stopped by savanna scrub, provided there is a sufficient runoff. The slope pedimentation model was applied by DE DAPPER (1981b) to explain for stone-layers on the sand-covered plateaux near Kolwezi (Shaba, Zaire).

The presence of rounded elements in the stone-layers led some authors to the conclusion (e.g. RUHE 1954) that their origin is partly fluvial. VINCENT (1966) recognizes a "stoneline de type alluvial" consisting of stone-layer material of usually greather depth (2-3 m) and deposited in the valleys through short distance creep (one to several tens of meters). STOCKING (1978) investigating stone-layers in Zimbabwe comes to the conclusion that they were deposited as lag gravels following repeated reworkings of the residual Karroo sandstone by gully erosion within recent times. THOMAS *et al.* (1985) recognized alluvially worn quartz pebbles in stone-layers of Sierra Leone and state that they are undoubtedly the remnants of former alluvial terraces which have been almost totally destroyed as morphosedimentary features, together with the landscapes of which they were a part. For some time the lateritic stone-layers on the footslopes in West Malaysia were considered in the Malaysian soil survey terminology as river deposits older than T_2 and thus labelled T_3 (e.g. GOPINATHAN, 1968).

As can be inferred from the review sketched above, most of the authors agree on the role played by the soil fauna in bringing up material from below the stone-layer to form a cover closely related to the bedrock saprolite. Especially the role played by epigeous termites, building their nests on the surface, is irrefutable (LEE & WOOD 1971).

The role of the soil fauna in building covers was already noted by PASSARGE (1904) for the Kalahari. J. DE HEINZELIN (1955), however, working in Zaire, was the first author to confirm the role of termites through precise observations on stone-layer formation. He estimated that a cover of 0.5 m could be formed by termite activity in 1,000 years. The observations of de Heinzelin were soon, at least qualitatively, corroborated by many investigators mainly working in Africa : NYE (1955, Nigeria), BRÜCKNER (1955, Ghana), TRICART (1957, Sudan), OLLIER (1959), SYS (1961, Zaire), FÖLSTER (1964a, Sudan), DE PLOEY (1963, 1964, 1965, Zaire), STOOPS (1967, Zaire), LÉVEQUE (1969, Togo). De Ploey indicates the relative importance of termite activity by stating that, although no observations exclude the intervention of termites, their activity is not indispensable to explain for the layering of the superficial deposits. Stoops however considers the whole α-layer (cover) as brought up by termites.

WILLIAMS (1978) stressed the importance of termites in stone-layer formation in the Northern Territory of Australia. The termites bring fines to the surface from where they are gradually lost to the valleys by surface erosion and creep ; the heavier clasts and unweathered minerals gradually accumulate in the lower parts of the soil layer. Once these gravels begin to accumulate they become a horizon of preferential soil water throughflow which accelerates the loss of fines. Following ROOSE (1980) working in West Africa these processes can produce stone-layers in less than 10,000 years.

A retort to the many hypotheses to explain stone-layers and related phenomena is that perhaps they suffer from "geomorphological equifinality" that is, no single hypothesis will provide a universal explanation and apparently similar stone-layer complexes may be formed as a result of different combinations of environmental circumstance (STOCKING 1978). This fact is illustrated by a stone-layer study effectuated by THOMAS *et al.* (1985) in Sierra Leone. Stone-layers there are explained by processes ranging from *in situ* downwasting to alluvial transport and the typical undulations of the stone-layer's lower boundary are attributed to farming, tree throws, bioturbations and rill formation. In no sense, therefore, can the stone-layer material be regarded as a fossil stratum but they do integrate a long period of landsurface denudation and environmental change of which they may be the sole remnants.

3.1.4.2. Application to the test areas

Individual soil profile pits or exposures provide a first approach to the study of the stone-layers on the pediments in the test areas. It reveals that, except for some vein quartz and bedrock fragments, the bulk of the stonelayer is composed of ironstone nodules of fine to coarse pebble size. Observations on the sorting, the macroscopic properties and the composition of the laterite gravel already gives several indications pointing to an allochthonous origin.

In a downslope sequence the ironstone nodules show a decrease in mean particle size and their shape changes from oblong to equidimensional and from angular and subangular to subrounded and rounded. For Padang Terap it was shown that :

1. the decrease in particle size is the result of physical desintegration initiated by shrinkage features following dehydration of the iron oxyhydrates ;

2. as they become smaller, the nodules derived from weathering shale or sandstone rock, show an increased residual accumulation of iron oxyhydrates and gradually loose the properties of the original material;
3. as the iron accumulation increases, the nodule colour becomes darker and its hardness and density increases (DEBAVEYE & DE DAPPER 1987).

On the lower segments of the pediments the laterite nodules are a mixture of spherical, medium to fine, dark brown, moderately hard and fine, red, soft and black hard particles. It was shown for Padang Terap that the red nodules are plinthite (SOIL SURVEY STAFF 1975) or groundwater laterite (MCFARLANE, 1983), derived from local weathering profiles. Micromorphologically they show an internal fabric similar to the fabric of the surrounding soil and clay coatings can be recognized. The dark brown and black nodules in some places have the internal fabric of shale or sandstone but more often they entirely consist of iron oxyhydrates. They are derived from an older higher duricrusted weathering profile.

Stone-lines, indicating sorting of the gravel, are best developed on the middle and lower segments of the pediments (Fig. 27). All those observations point to the fact that transport by water took place and that the energy involved was proportional to the length of the downslope path.

Observations in long sections however permit to add some nuance to the picture sketched above. In long continuous exposures, the undulated aspect of the superficial layers is obvious. The nature of the undulations however, is dependent on the orientation of the sections. In exposures parallel to the hillfront, i.e. cutting the pediment longitudinally, the undulations are always more regular and show a shorter wavelength than it is the case in those oriented in other directions (Figs. 28 and 29). The 50 m long longitudinal section, illustrated in Fig. 28, for example shows a mean regular wavelength of 5 m and amplitudes varying between 25 cm and 75 cm.

The orientation dependent nature of the undulations excludes tree throw and termite extraction pits as exclusive cause, as they would result in irregular undulations independently from the orientation they are cut. For the same reason preferential chemical suffosion (*sensu* TRICART 1965 and SEGALEN 1969), resulting in a kind of secondary irregular front of weathering (*sensu* OLLIER 1974), can be excluded as exclusive cause for the undulations. In some cases, as is illustrated on

Fig. 29, it is even very clear that the stone-layer does not follow the irregularities of the basal zone of weathering top.

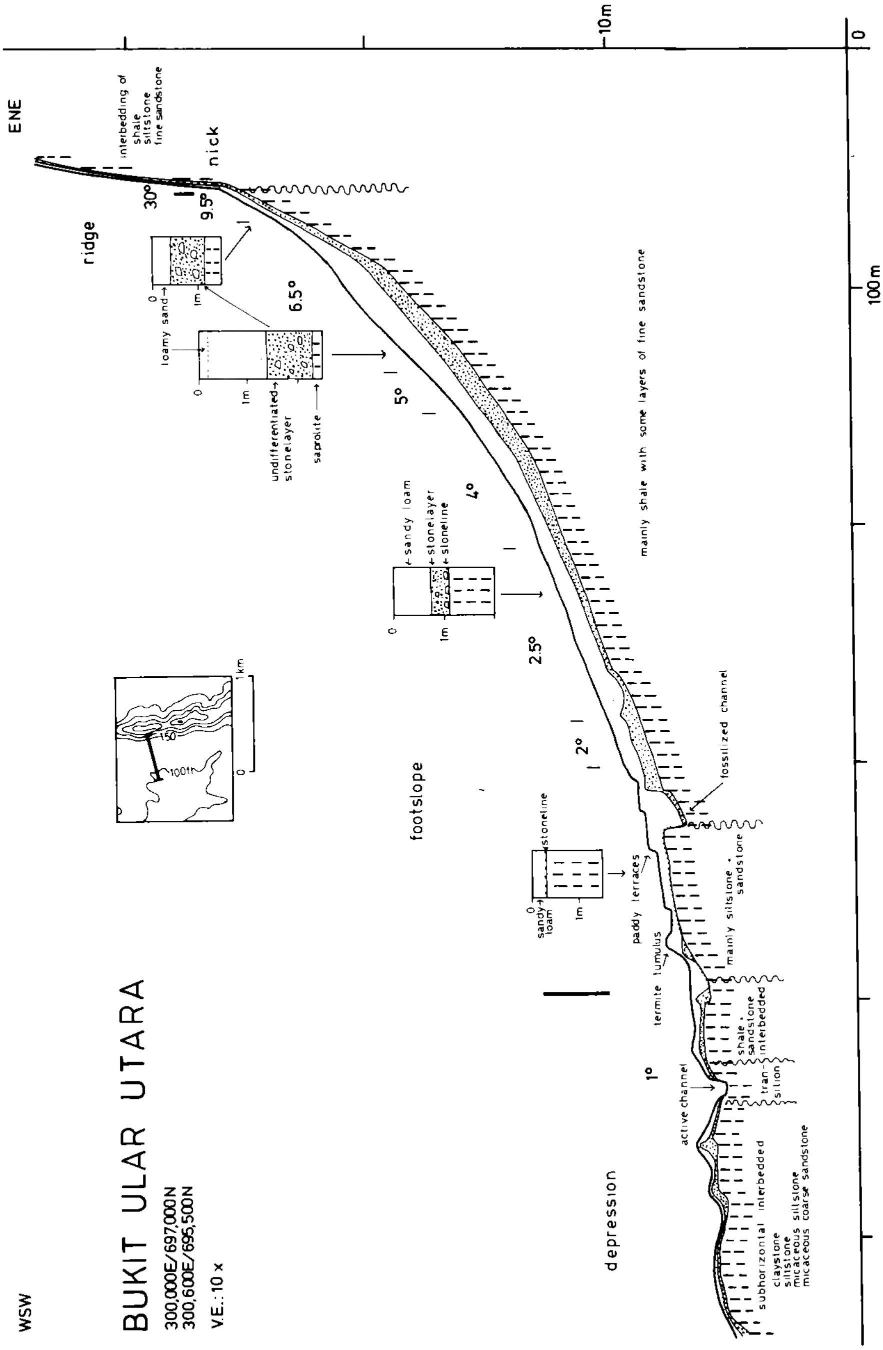
The wavy aspect is obviously due to long stretching almost parallel channels running on the pediments following directions transverse to the hillfront. According to the size, those channels most probably are gullies.

The most regular undulations (considered in sections longitudinal with regard to the hillfront) are found in the upper middle segments of the pediments (Fig. 28). Rock features such as quartz veins are cut in the channels bu they continue somewhat broken up in the interfluves, between channels, even if they are minor ones (Photo 3). The laterite pebbles in the channels mainly consist of subangular, medium, dark brown, moderately hard nodules quite similar to the nodules found in the interfluve stone-layer. It is obvious that the channel gravel is allochthonous but locally derived from an autochthonous stone-layer in the interfluves. The latter is very similar to STOOPS' (1967) B_2-layer ("grenaille latéritique" *in situ*).

On the lower middle segments of the pediments all minor rock features are cut by the stonelayer but larger rock features (e.g. sandstone beds and quartz veins with a thickness of 1 m and 0.5 m respectively, as illustrated on Fig. 30) continue in the interfluve stonelayer (Photo 4). In the centre of the channels a considerable thinning of the stone-layer is often observed.

On the lower segments of the pediments, all rock features are cut by the stone-layer, even the major ones (Fig. 31). Thinning of the stone-layer is often observed in the centre of the channels and sometimes the cover rests directly on the saprolite (Fig. 32). Stone-lines are often developed and in some cases concentrated in the major channels (Fig. 33). Sorting is also indicated by the concentration of fine black hard nodules on top of the stone-layer. It is obvious that here the whole stone-layer is an allochthonous deposit, a fact that is corroborated by the mixed nature of the laterite nodules. The fossilized gully nature of the channels is occasionally illustrated by the preferential outflow of groundwater perched on the saprolite even after a long dry period (e.g. Fig. 32, observations of the beginning of May 1981 after a relatively dry period lasting from December to March).

Fig. 27. — Transverse profile of a pediment developed at the foot of Bukit Ular Utara (Padang Terap). The co-ordinates refer to the RSO Grid (meters) of the topographical map on scale 1/63, 360 of the Directorate of National Mapping, Malaysia.


WSW
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footslope
depression
interbedding of shale siltstone fine sandstone
loamy sand
undifferentiated stonelayer
saprolite
0
1m
sandy loam
stonelayer
stoneline
sandy loam
stoneline
mainly shale with some layers of fine sandstone
fossilized channel
paddy terraces
termite tumulus
mainly siltstone + sandstone
shale + sandstone interbedded
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active channel
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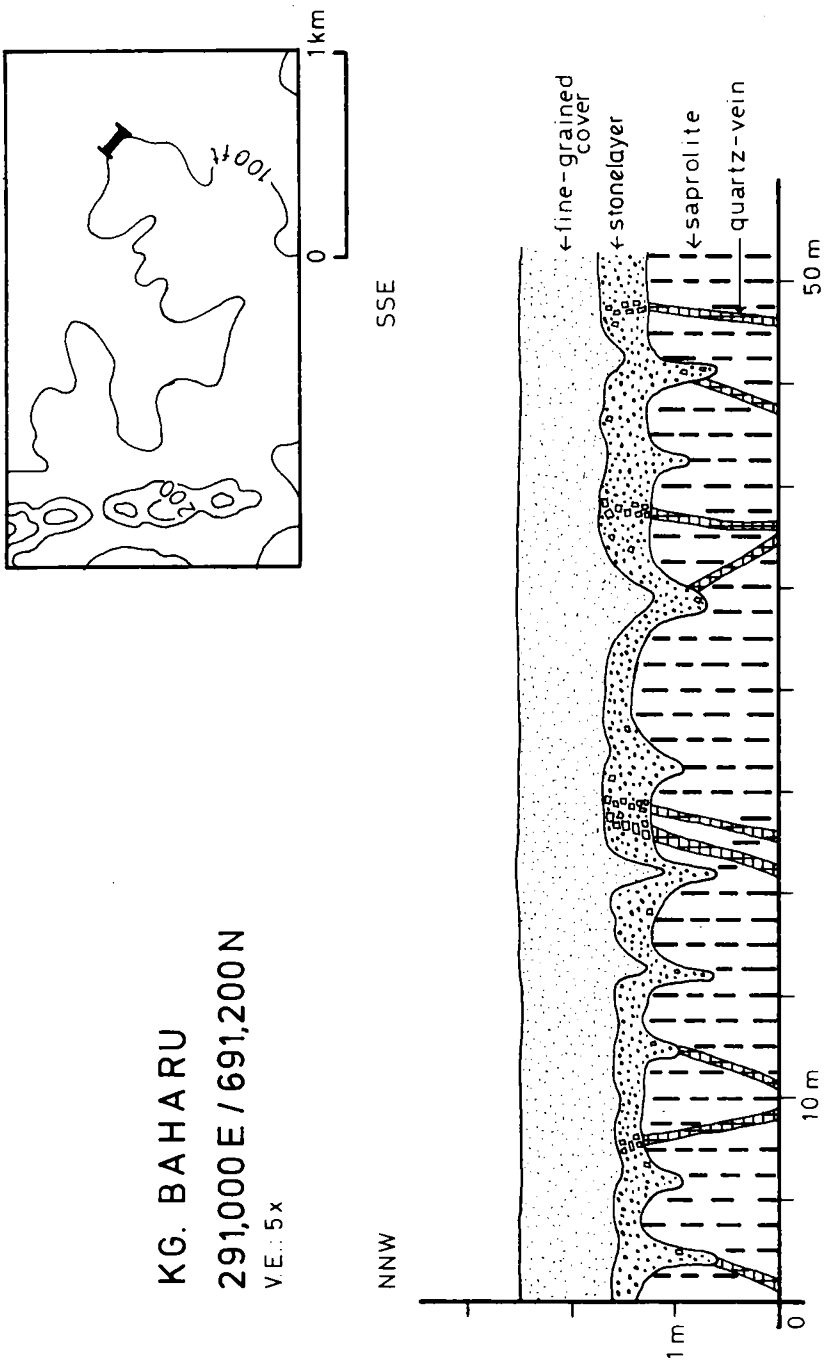

Fig. 28. — Longitudinal cross-section on the upper middle segment of a pediment near Kg. Baharu (Padang Terap).

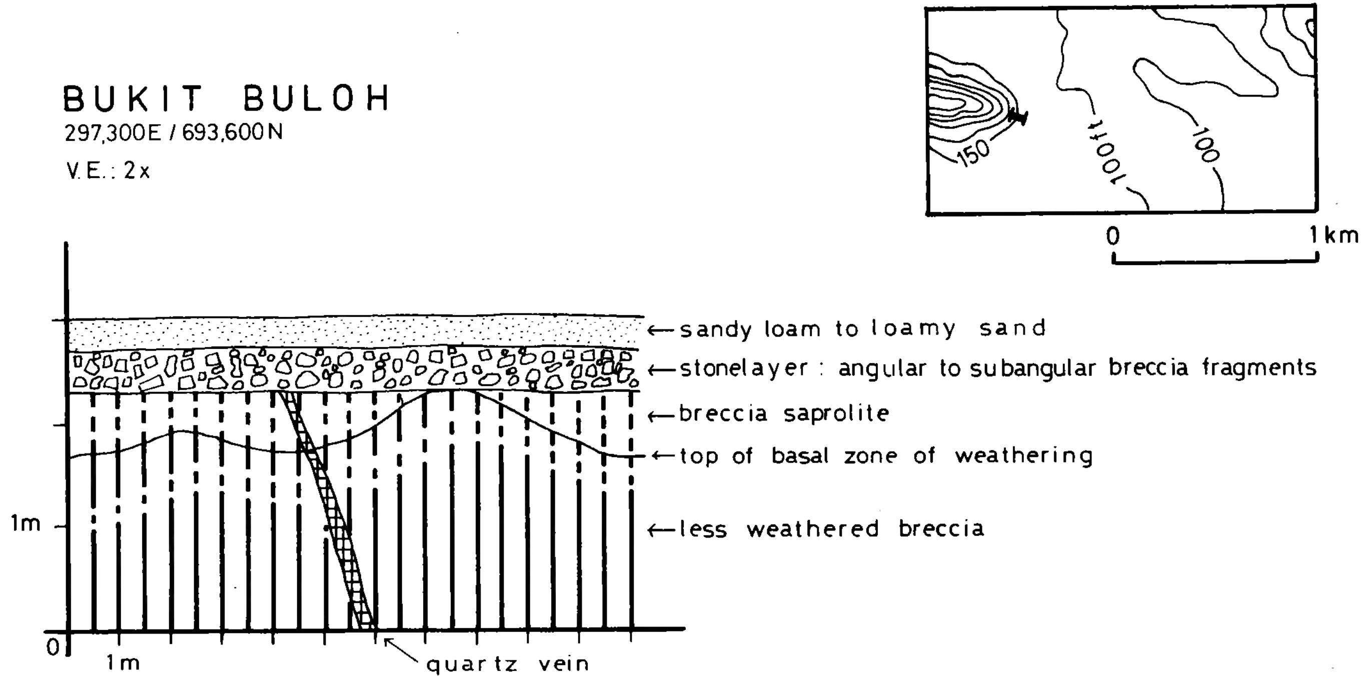

Fig. 29. — Transverse cross-section on the upper middle segment of a pediment developed at the foot of Bukit Buloh (Padang Terap).

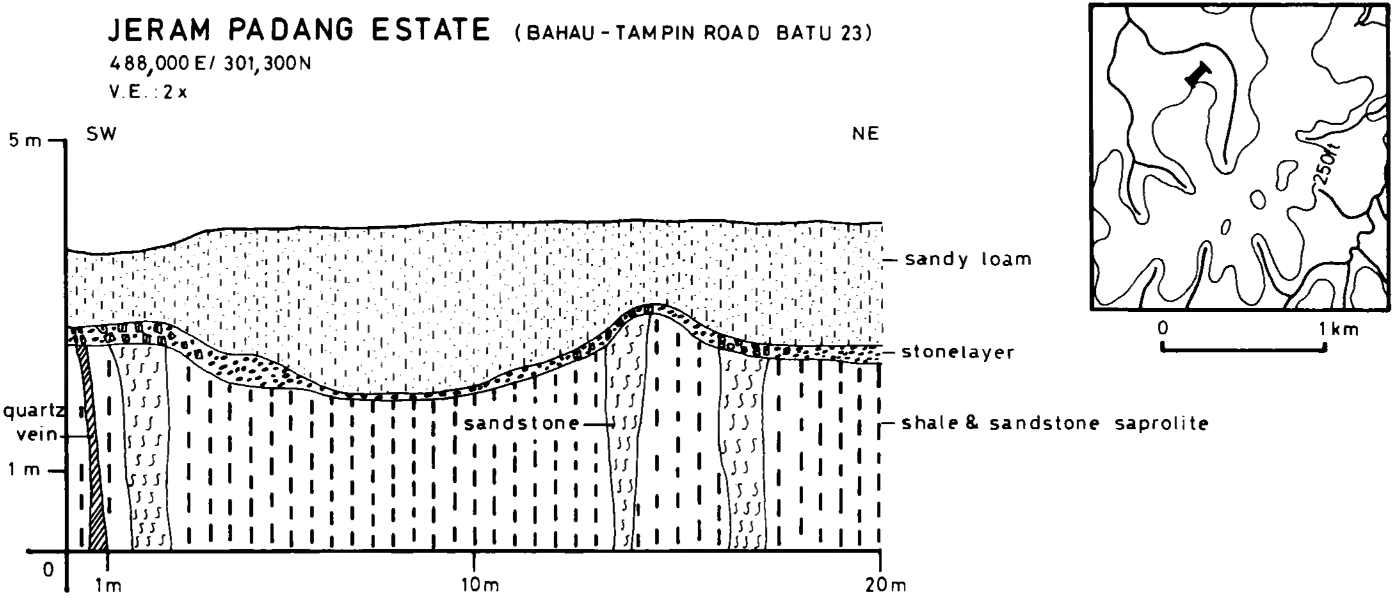

Fig. 30. — Longitudinal cross-section on the lower middle segment of a pediment in Jeram Padang Estate (Kuala Pilah).

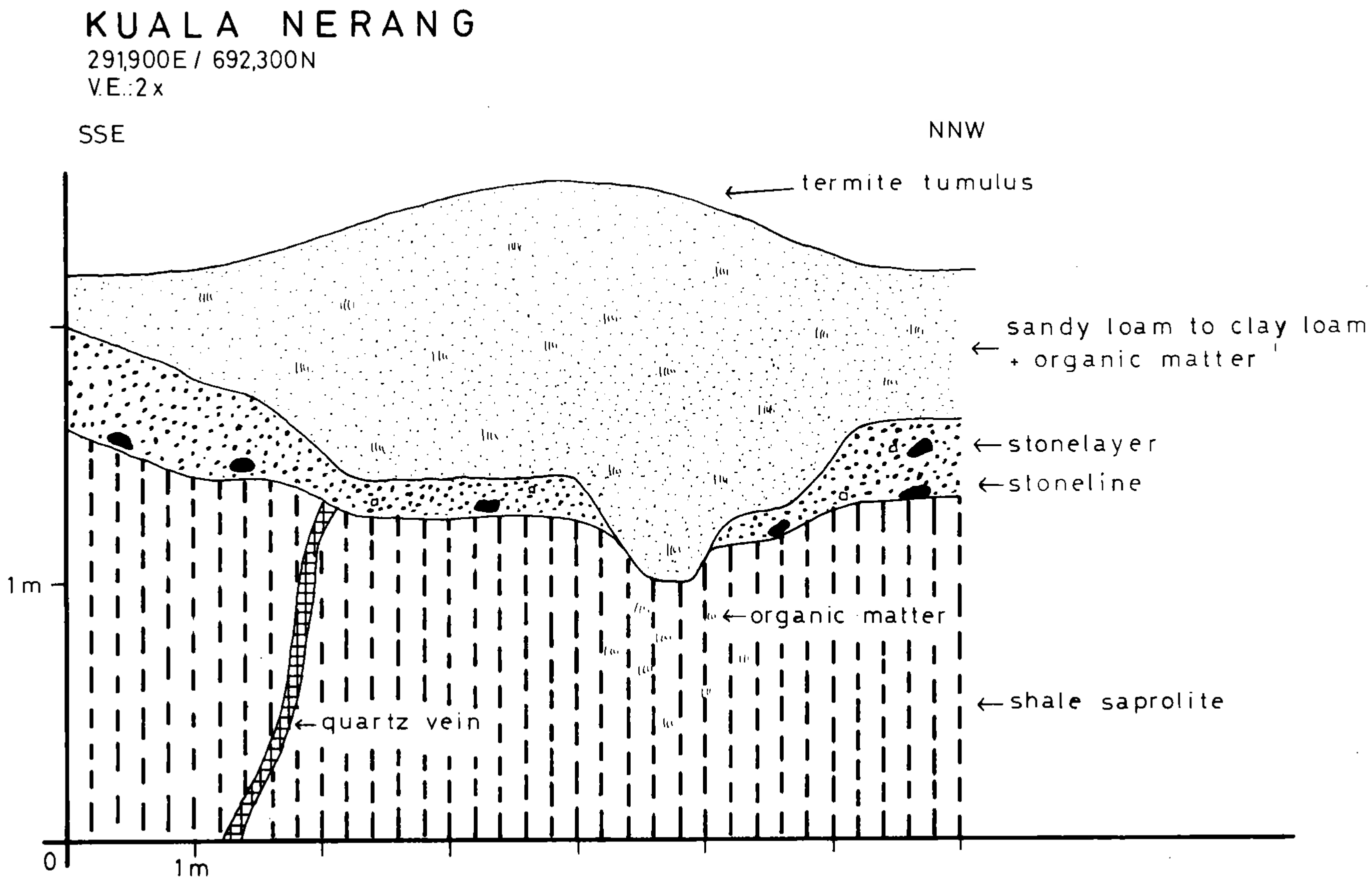

Fig. 31. — Longitudinal cross-section on the lower segment of a pediment near Kuala Nerang (Padang Terap).

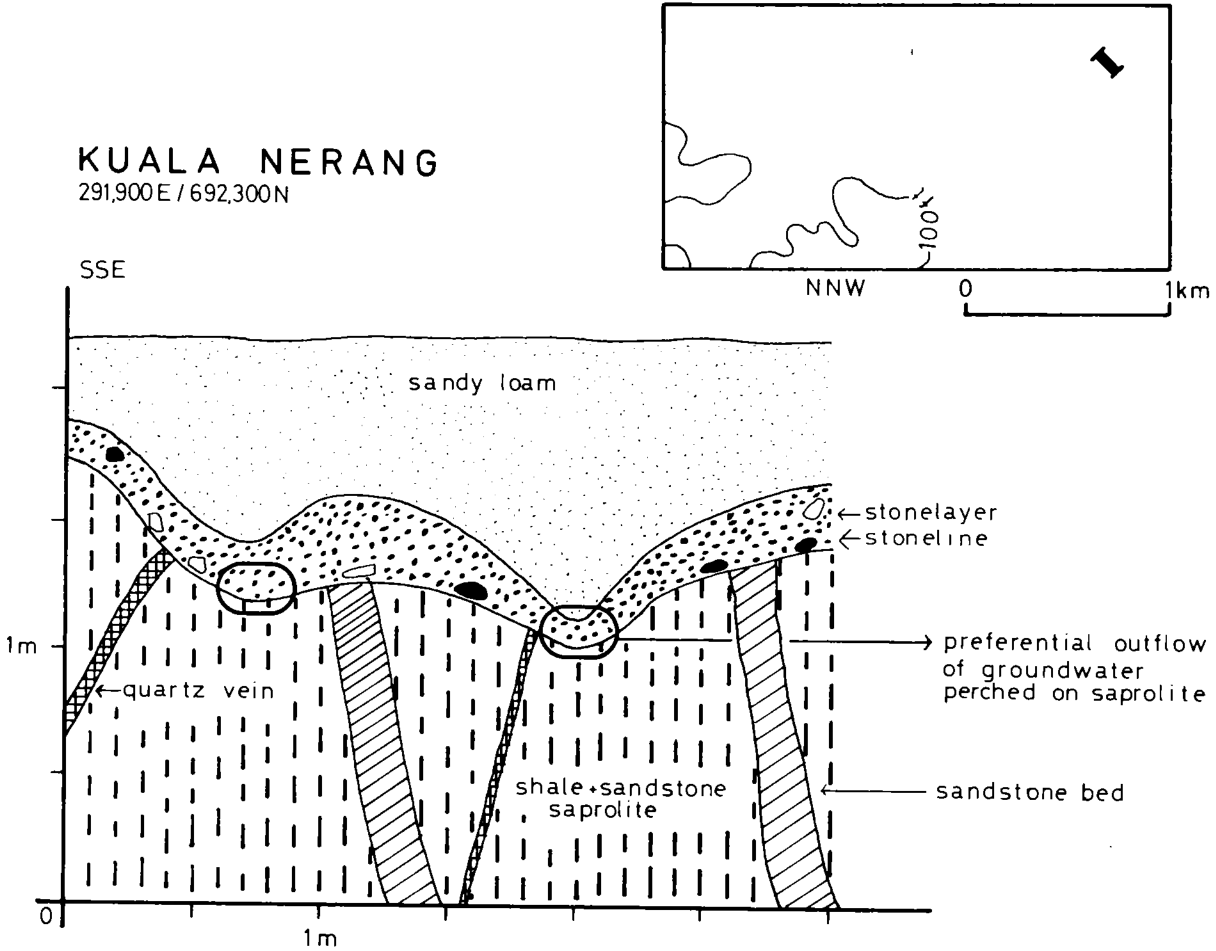

Fig. 32. — Longitudinal cross-section (detail) on the lower segment of a pediment near Kuala Nerang (Padang Terap).

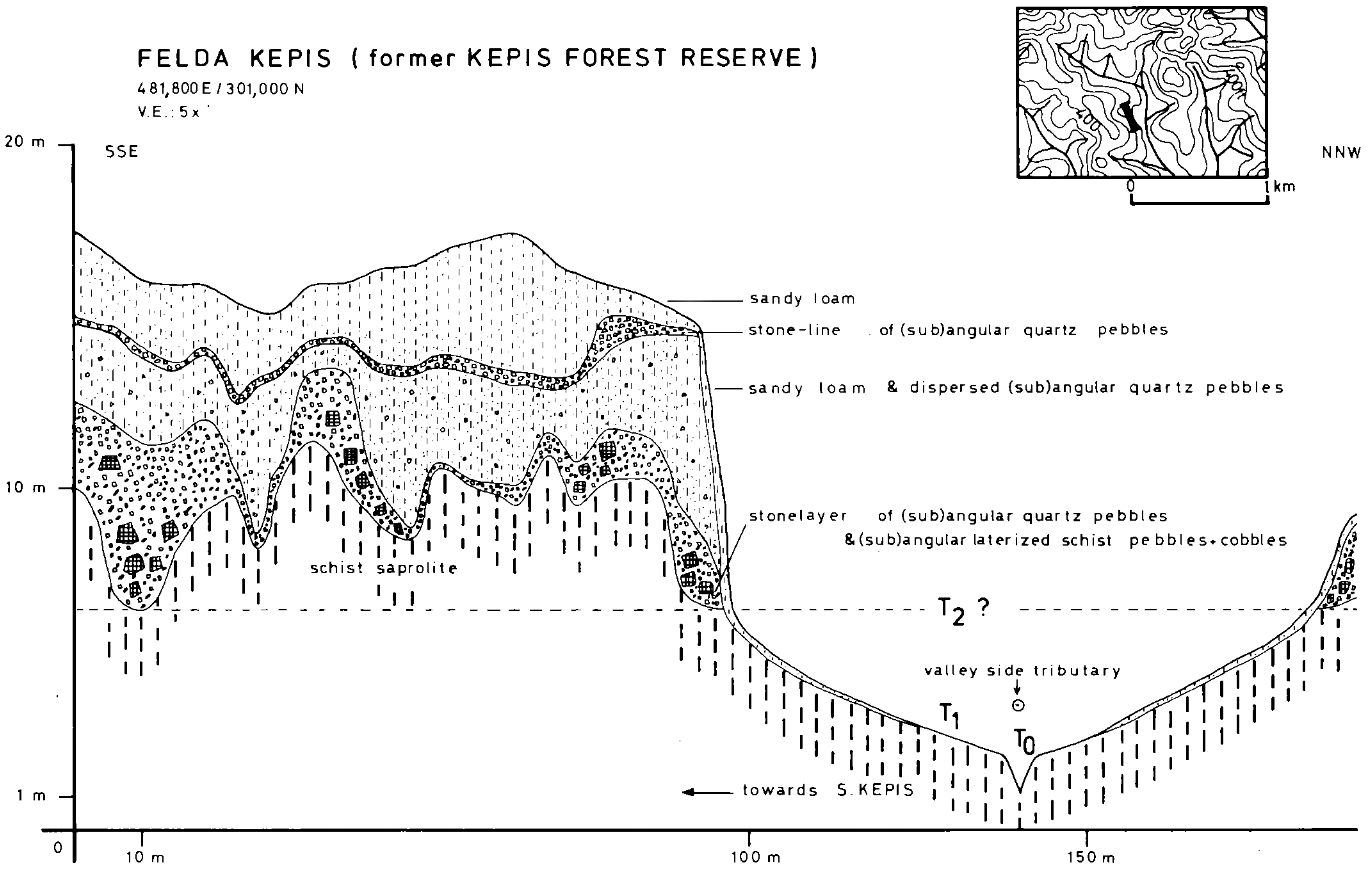

Fig. 33. — Longitudinal cross-section on the lower segment of a pediment in FELDA Kepis (Kuala Pilah).

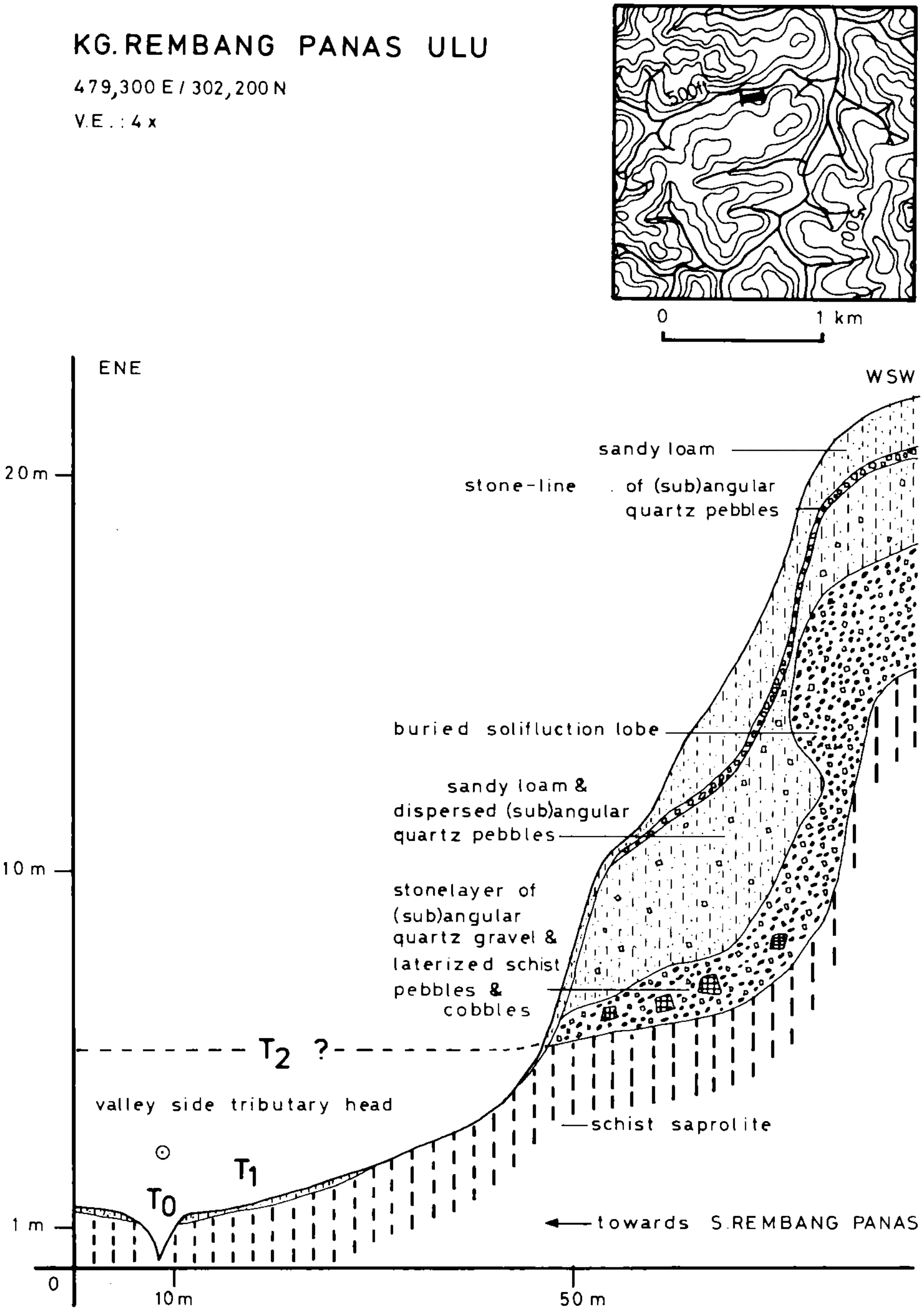

Fig. 34. – Longitudinal cross-section on the lower segment of a pediment near Kg. Rembang Panas Ulu (Kuala Pilah).

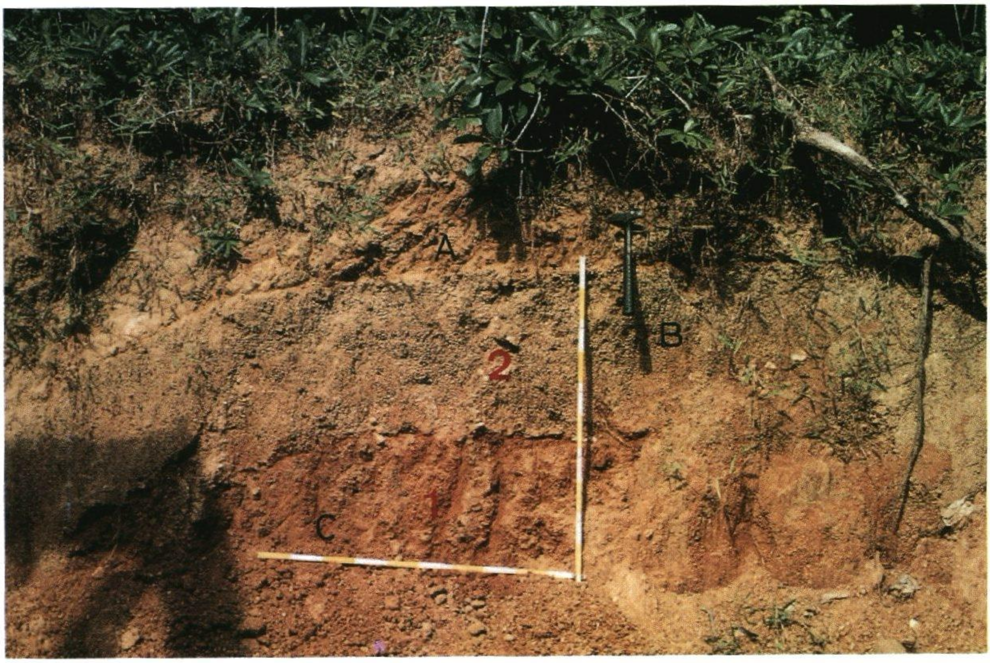

Photo 3. — 291,000 E/691,200 N
Padang Terap-test area ; Kg. Baharu
Detail of a longitudinal (i.e. parallel to the hillfront cross-section on the upper middle segment of a pediment
A quartz vein (1) in the shale bedrock saprolite (C) continues (2) in a rise of the wavy stone-layer (B). The whole is veneered by a cover (A) of sandy loam.

Photo 4. — 299,200 E/701,500 N
Padang Terap-test area ; Bukit Tok Janggut.
Detail of a longitudinal (i.e. parallel to the hillfront) cross-section on the lower middle segment of a pediment. The bedrock (C) is a saprolite of shale interbedded with sandstone. Minor sandstone beds (1) are cut by the stone-layer (B), while major ones (2) continue in the stone-layer "interfluves". The whole is veneered by a fine grained cover (A).

In most cases the top of the cover, i.e. the subaerial pediment surface, hardly reflects the undulations of the stone-layer. The cover evens out the irregularities of the bedrock pediment surface. The presence of solifluction lobes affecting the stone-layer and leaving cover features undisturbed (e.g. on Fig. 34, a secondary stone-line is not affected) show that the stone-layer was exposed to the air for some time. In a micromorphological study ZAUYAH & BISDOM (1983) observed features, interpreted as iron encrusted fungal hyphae in ironstone nodules from Kedah. This finding may imply that the nodules at some time occurred at or close to the surface. Those observations lead to the conclusion that the cover was deposited after the stone-layer formation or that it was at least locally reworked after its deposition. The reworked nature is corroborated by the occasional presence of a secondary stone-line in the cover (Figs. 33, 34, 35, 67). It represents a thin lag layer mainly composed of very fine to fine quartz pebbles and clearly derived from the underlying cover material. Unconcentrated runoff and splash may be responsible for their formation. However, the close genetical relationship between cover and stone-layer is indicated by the fact that secondary stone-lines in most cases follow the undulations of the latter (e.g. Fig. 33).

Geomorphologically important termite activity was mainly observed in the Padang Terap testarea. Termite tumulus densities of 16 to 30 ha^{-1} were observed, tumuli cover 4 to 17 % of the surface and take up total volumes of 176 to 596 $\mathrm{m}^3.\mathrm{ha}^{-1}$ (Table 4) (Figs. 36 and 37) (DE DAPPER 1981a, DE DAPPER & DEBAVEYE 1989). In most cases termite tumuli are located on top of the stone-layer channels (Fig. 31). This

TABLE 4. — Characteristics and termite tumuli at different stations in the Padang Terap-test area (after DE DAPPER 1981 ; DE DAPPER & DEBAVEYE 1989).

	Density of tumuli ($\mathrm{N.ha}^{-1}$)	Surface covered by tumuli as % of total surface	Total volume (m^3, ha^{-1})
Kg. Bukit	30	7.3	382
Kg. Tekai 1	30	9.9	289
Kg. Tanjong Seberang	25	4.2	176
Kg. Datok	22	16.8	278
Kg. Sireh	21	9.6	392
Kg. Tekai 2	18	7.9	596
Kg. Bkt. Payong	16	8.9	579

observation may lead to the false impression that they are termite extraction pits. It is plausible however that the termites chose the fossilized gullies to locate their nests because of the local better soil moisture conditions. Similar observations were made by DE DAPPER (1978) in Zaire. In some cases however the reworking and removal of stone-layer material is obvious (Fig. 37). For the Padang Terap area one can conclude that the role of termites in bringing up and mixing cover material may be important but that they are not the exclusive cause of the wavy aspect of the stone-layer.

None of the classical models as sketched above can fully account for the fieldobservations in the testareas. Especially the presence of conjointed allochthonous and autochthonous stone-layers in the middle segment of the pediments is not explained. An adapted form of ROHDENBURG'S (1969) slope pedimentation model may however provide the best explanation for the observed phenomena (Fig. 38).

In the eo-stage of an unstable morphogenic phase, sheet and rill erosion on the upper segments of the footslopes initiates a dense network of parallel gullies running down the middle and lower segments and evacuating into the main drainage lines. The gully sides are steep and can act as pedimentation scarps. The saprolitic bedrock, lateritisized to some degree, is exposed on the gully scarps. By local lowering of the groundwater table, due to the incision, processes of irreversible hardening can start or are accelerated on the exposed ironstone nodules. The side scarps of the gullies remain relatively stable but the headscarps are undercut and move rapidly backwards parallel to themselves (Fig. 39).

During the pleni-stage, as runoff increases, also the side scarps of the gullies become unstable. The gullies widen and grow close to each other until only a narrow interfluve remains. In the upper middle segments those interfluves are conserved because of lack of erosive runoff, due to a reduced and insignificant catchment area. On the top of the interfluves fine material can be removed mainly by splash and throughflow (cf. WILLIAMS 1978 and ROOSE 1980) that is easily evacuated by the gullies. As a result the laterite nodules are packed and local lithosomes such as quartz veins are broken but conserved as recognisable features. The stone-layer on these small interfluves can be considered as a « stoneline de type éluvial » (*sensu* VINCENT 1966). On the lower middle and lower segments of the pediments, greater amounts of runoff water are involved and there even the interfluves are eroded, except where they are sustained by very thick resistant rock features.

As a result of the gully scarp retreat saprolite is eroded. On the upper middle segments, due to the low capacity of the waterflow, almost no transport takes place. The fine matter however is washed out, resulting in a relative accumulation of ironstone nodules. That stone-layer material is very similar to the one on the interfluves and forms a transition between Vincent's « stoneline de type éluvial » and « stoneline de type colluvial ». On the lower middle and lower segments transport and sorting are more important. Coarse debris such as cobble and boulder size vein quartz, fragments of iron-cemented or metamorphic bedrock, too heavy to be transported by water, are dumped close to the foot of the gully scarps and form a stoneline. Relatively fine gravel of vein quartz and large amounts of hardened ironstone nodules, together with fine matter, are susceptible to short bedload transport by running water. As a result they are mixed, broken and their shape becomes somewhat rounded. As the gully scarps retreat, the finer gravel is deposited on top of the already present stoneline. The finest gravel and the fine earth however will be partly sorted out of the stone-layer. The former will be deposited in local lenses at the top of the pediment gravel, the latter can undergo a relatively long transport as suspended load. Part of it is evacuated to the rivers, part of it is temporarily deposited, probably under the form of microfans, on the already deposited stone-layer and fills the voids between the coarse fragments in the stone-layer top. During the transport of the fine material a further sorting takes place. Silt and clay particles will be more easily evacuated, resulting in a relative enrichment in sand particles.

During the fini-stage, runoff weakens again until it reaches stable phase conditions. Only fine-grained material can be transported and also the pediment gravel becomes fixed. Redistribution of the temporarily deposited fine earth and continued supply of wash material from the backing upland, results in a covering by fine sediments and a levelling of the microrelief resulting in a very gently undulating subaerial pediment surface that is stabilized during the following stable morphogenic phase.

The above sketched process also accounts for the fact that the cover, although very similar to the saprolite, in most cases is somewhat sandier than the latter. This trend sometimes lasts into the upper part of the stone-layer matrix (Fig. 40). Other processes such as pedogenetic clay eluviation (LEOW 1979), lateral removal of clays by subsurface wash or throughflow (SWAN 1970c, MORGAN 1973) and soil fauna activity (STOOPS 1967) are not excluded but only contribute to the same effect.

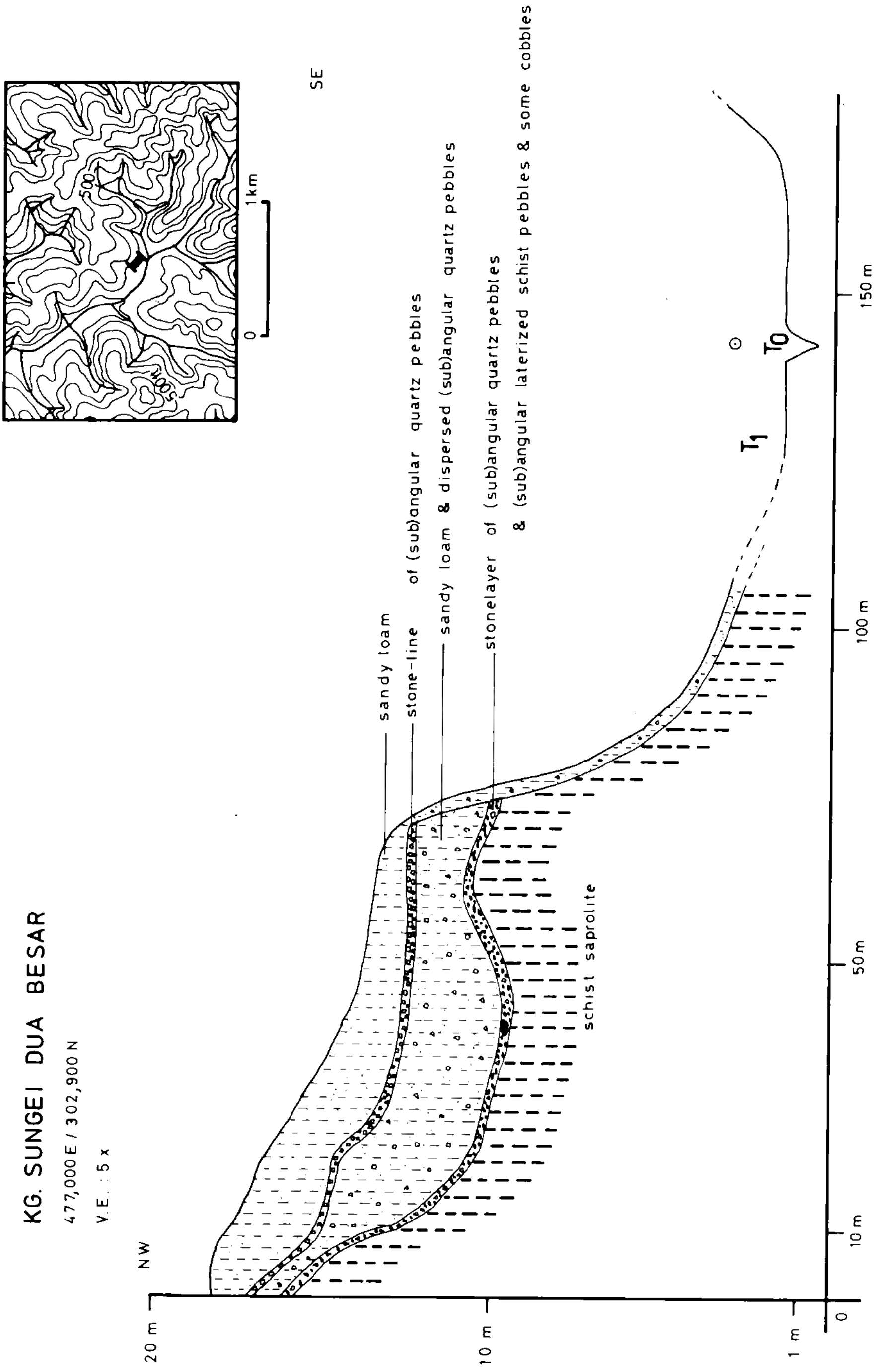

Fig. 35. — Longitudinal cross-section on the lower segment of a pediment near Kg. Sungei Dua Besar (Kuala Pilah).

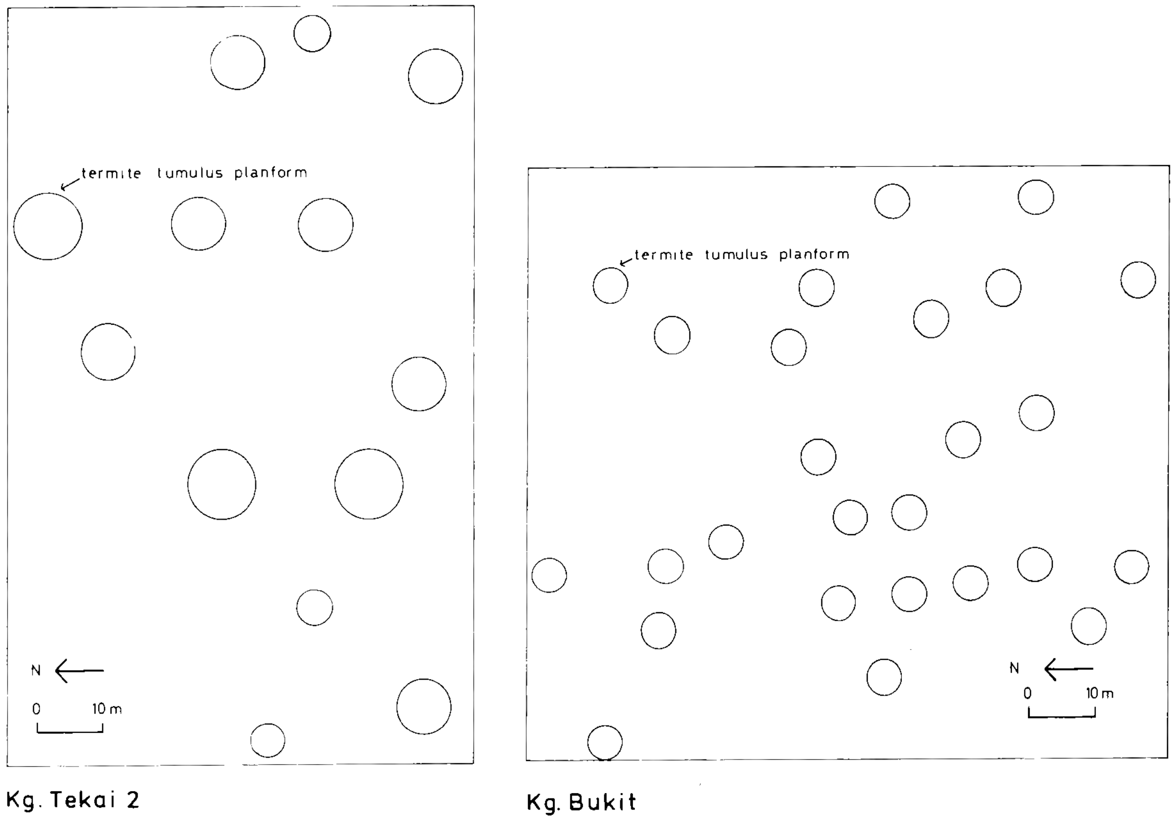

Fig. 36. — Distribution pattern of termite tumuli at two selected sites in the Padang Terap-test area (cf. Table 4).

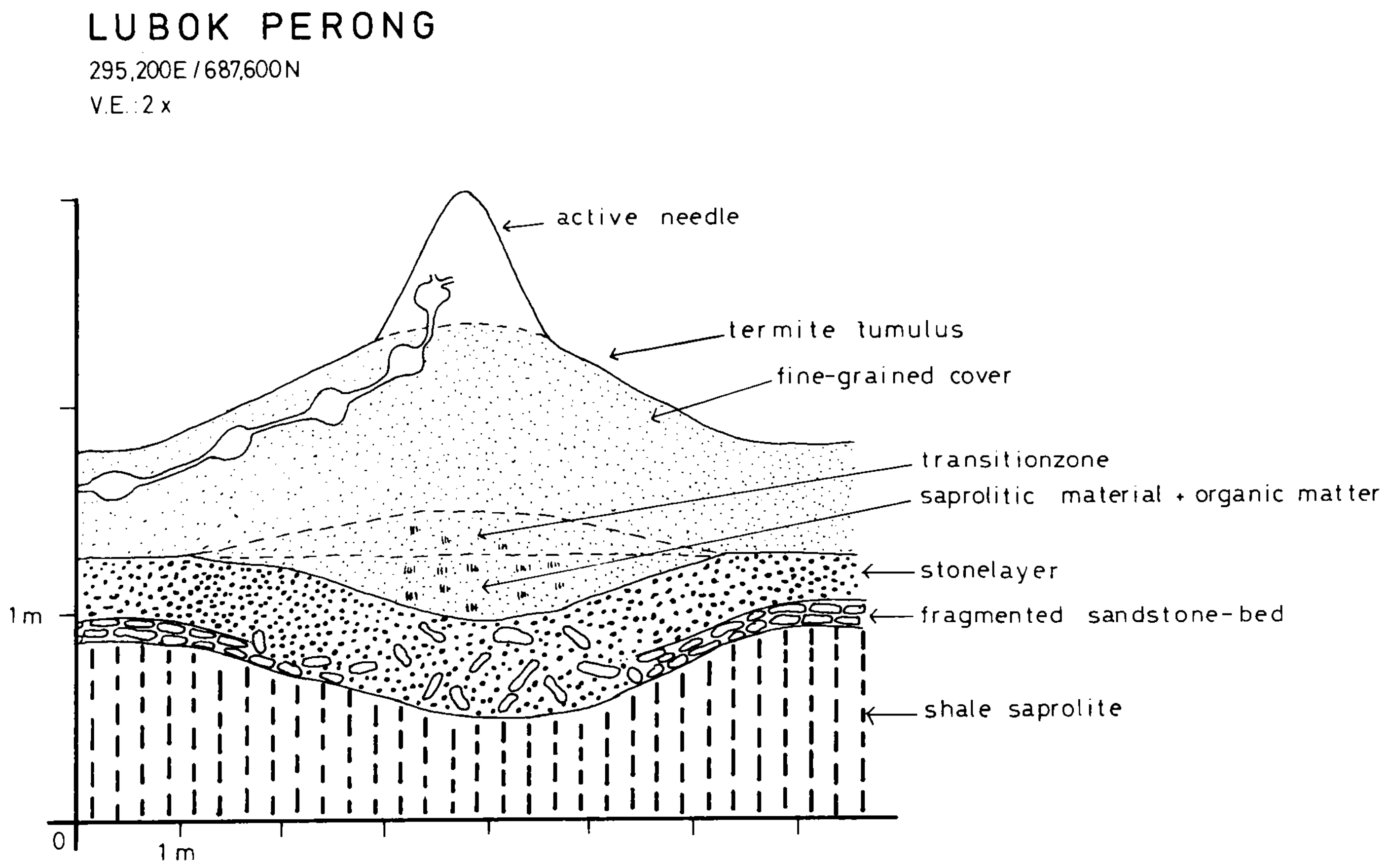

Fig. 37. — Termite activity on a stone-layer near Lubok Perong (Padang Terap).

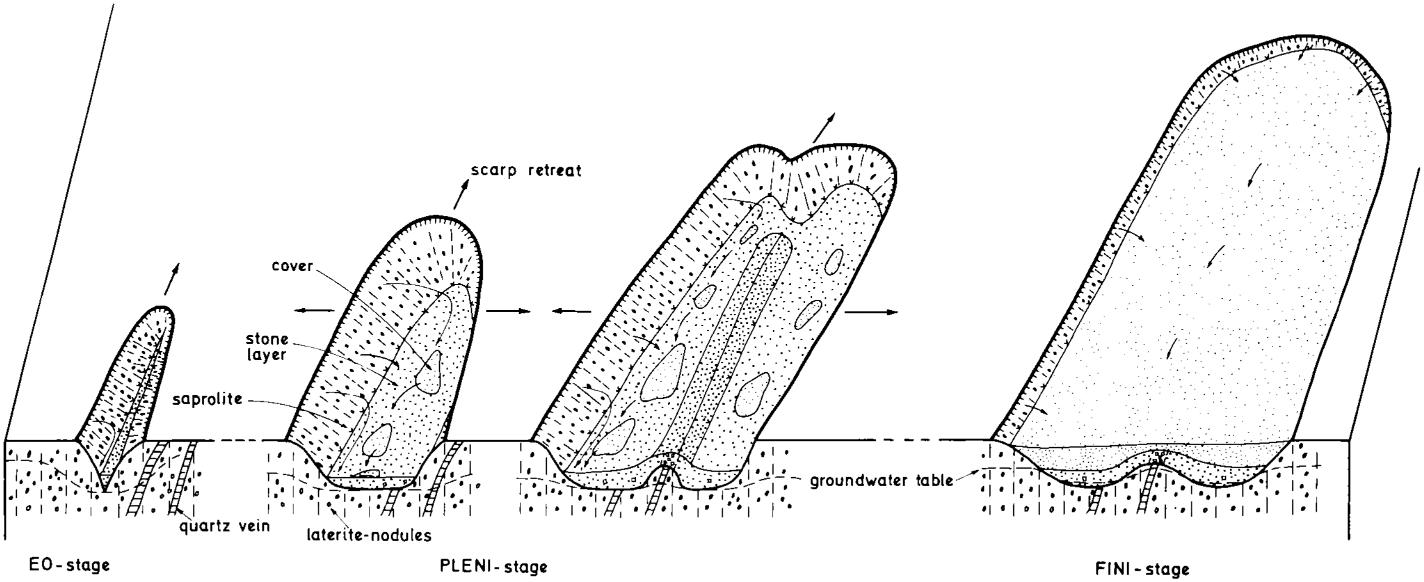

Fig. 38. — Model of slope pedimentation in the test areas.

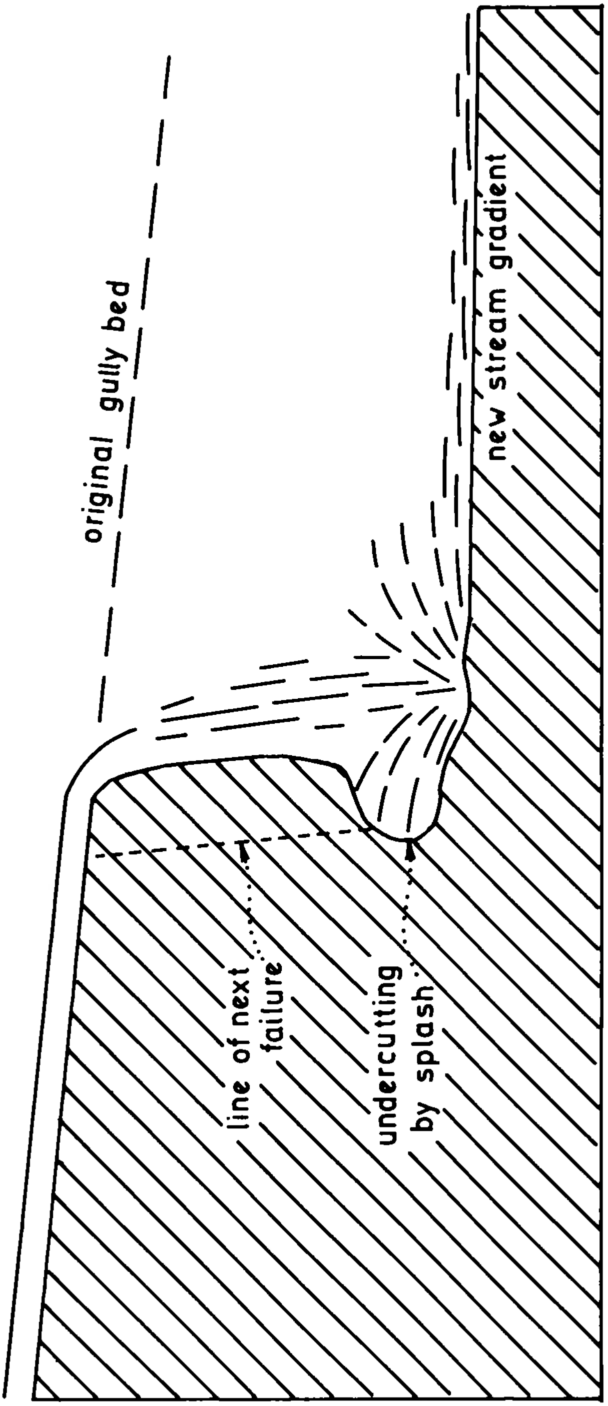

Fig. 39. — Deepening and extension of gullies by step-erosion.

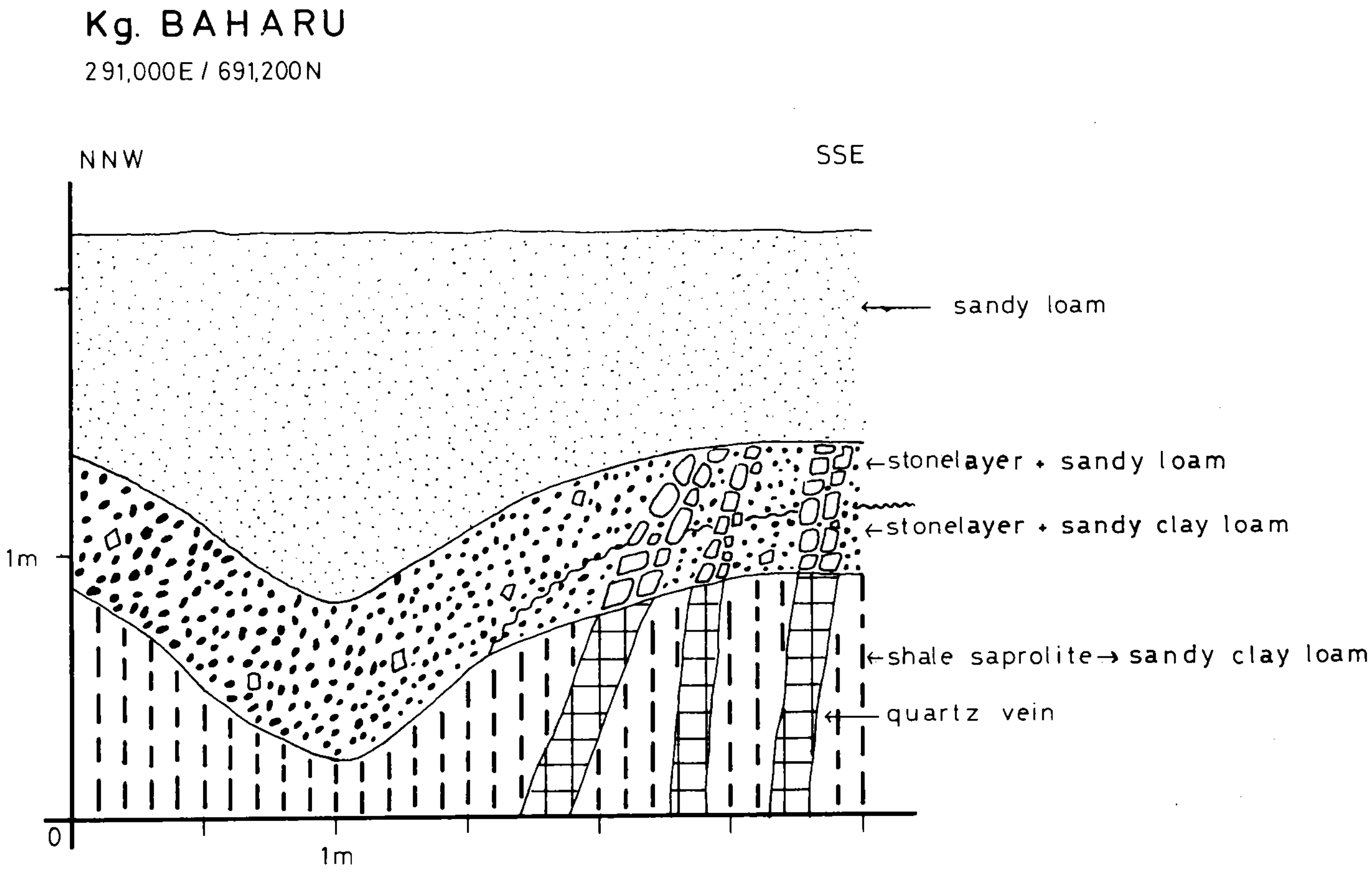

Fig. 40. — Differentiation of the matrix in a stone-layer near Kg. Baharu (Padang Terap).

3.2. River Terraces

3.2.1. Padang Terap-area

In the Padang Terap testarea the occurrence is limited to the main rivers. Remnants of two terraces, T_2 and T_1, form narrow discontinuous strips with a total width ranging between 50 m and 100 m. The river channel is seamed by an almost continuous T_0 terrace that corresponds to the present-day floodplain showing an actively built morphology of levees, backswamps and cutt-offs.

Fig. 41 shows the location of a number of typical cross-sections illustrating the terrace levels and their alluvial deposits (Figs. 42 to 47). The local relief and the distance between the most upstream and the most downstream section are 25 m and 40 km respectively, representing a mean talweg gradient of 0.06 %. One section (Kg. Lengkuas) is located at the boundary of the coastal plain. The others are located upstream of Kuala Nerang where the waters of the Pedu and the Tekai are confluent with those of the Padang Terap river.

T_2 is located between 5 m and 9 m above the river channel, T_1 between 2 m and 5 m and the T_0 floodplain between 1 m and 2.5 m. Floods can become very important during the rainy season and peak levels of 5 m above the talweg are not uncommon as can be concluded from D.I.D.-records (*) and observations of mud stains and trash trapped in the riparian vegetation. As a result the T_1-surface can occasionally be affected. Termite tumuli were observed on the T_2-surface but never on the T_1 or T_0.

The T_2-bed is rock cut in all cases ; for the T_2-fill thicknesses between 1.25 m and 6 m were observed. In the most upstream sections (e.g. Padang Sanai) the T_2-alluvium consists of a matrix supported gravel mostly composed of subangular to subrounded fine to very coarse quartz pebbles. In downstream sections the alluvium consists of a loamy sand to sandy loam (U.S.D.A. texture triangle, cf. appendix) without stratification. In most cases the base of the fine fill is lined by a thin (always less than 1 m thick) layer of clast supported lag gravels, almost exclusively composed of subrounded to rounded fine to very coarse quartz pebbles. Traces of current bedding were occasionally observed in the lag gravel (e.g. Kuala Tekai).

(*) Drainage and Irrigation Department of the Ministry of Agriculture of Malaysia.

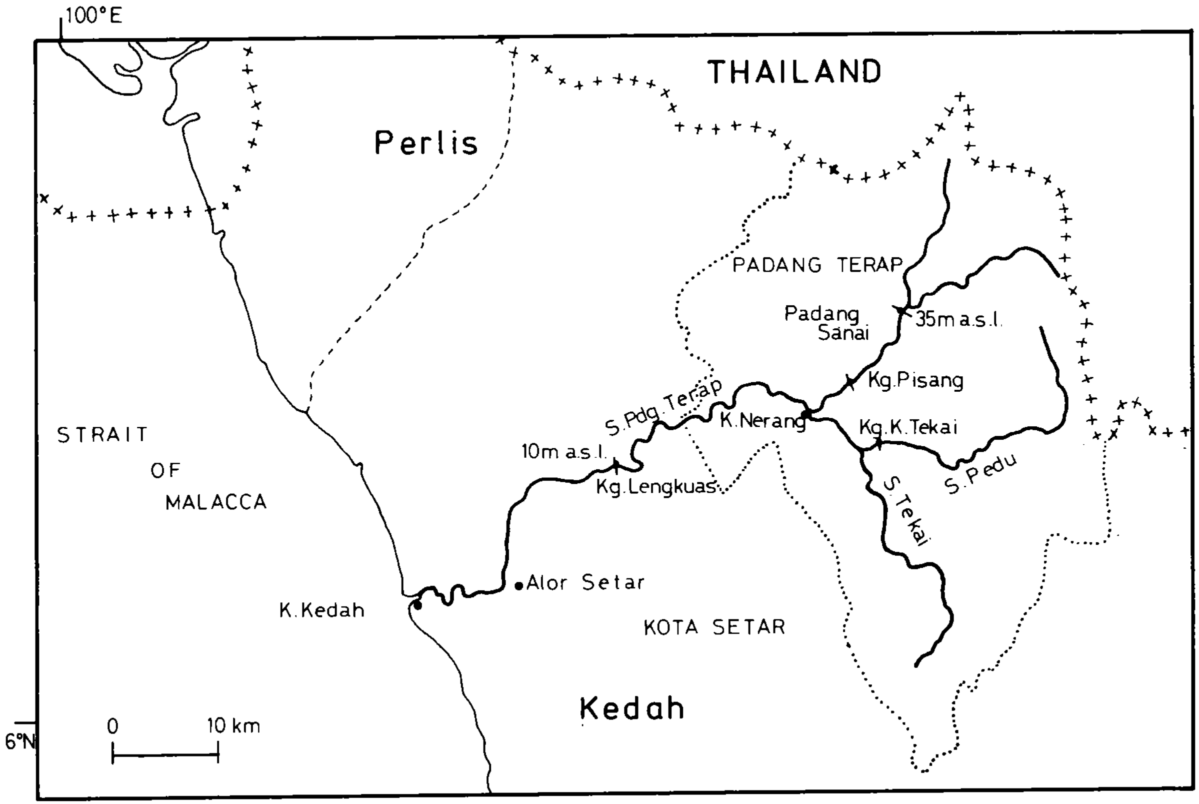

Fig. 41. — Location of selected river terrace sections in the Padang Terap-test area.

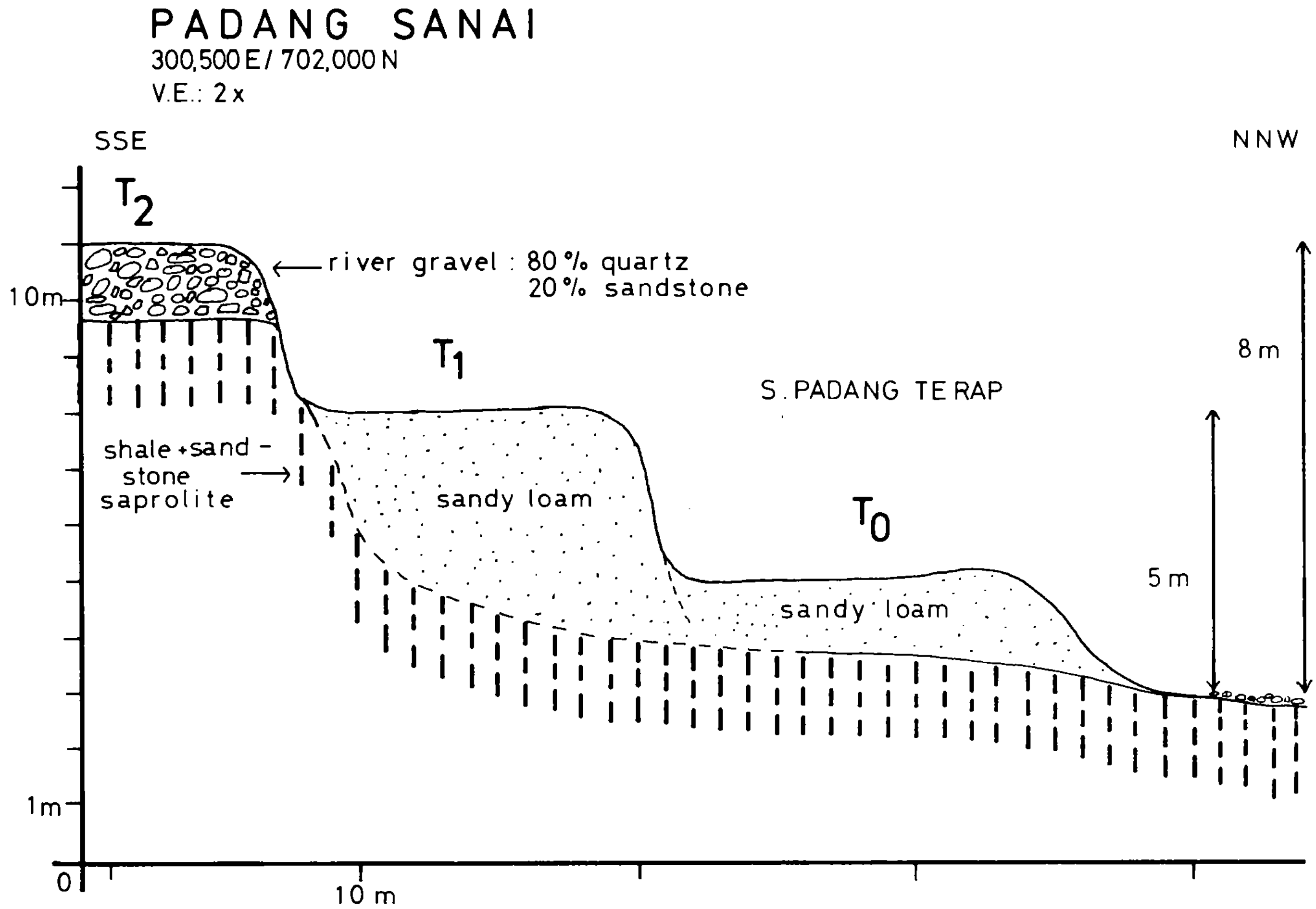

Fig. 42. River terrace section near Padang Sanai (Padang Terap).

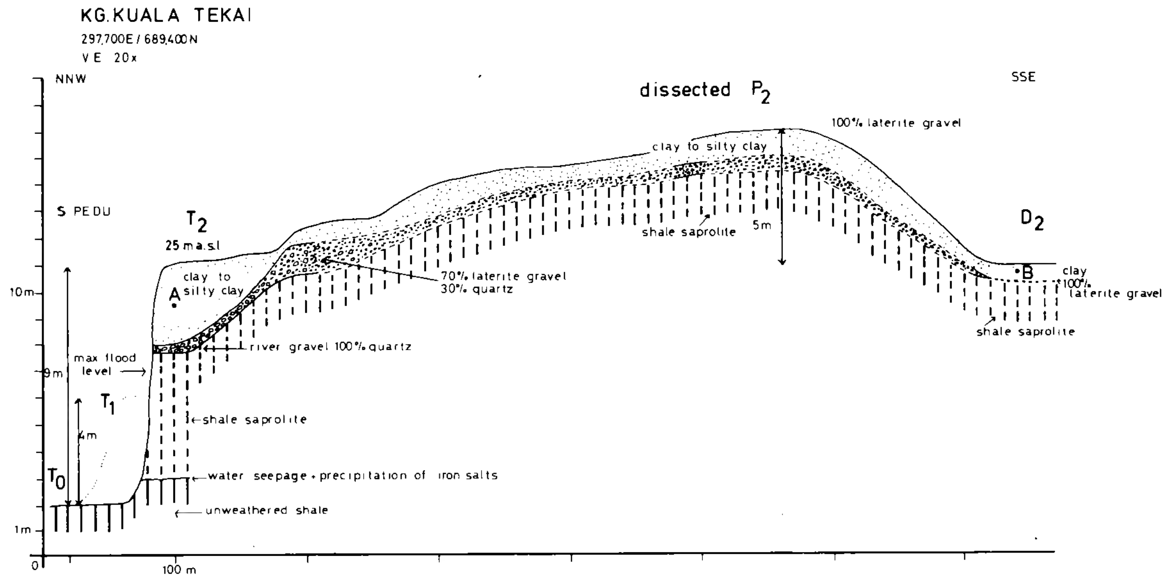

Fig. 43. — River terrace section near Kg. Kuala Tekai (Padang Terap). A and B refer to the particle size distribution curves on figure 44.

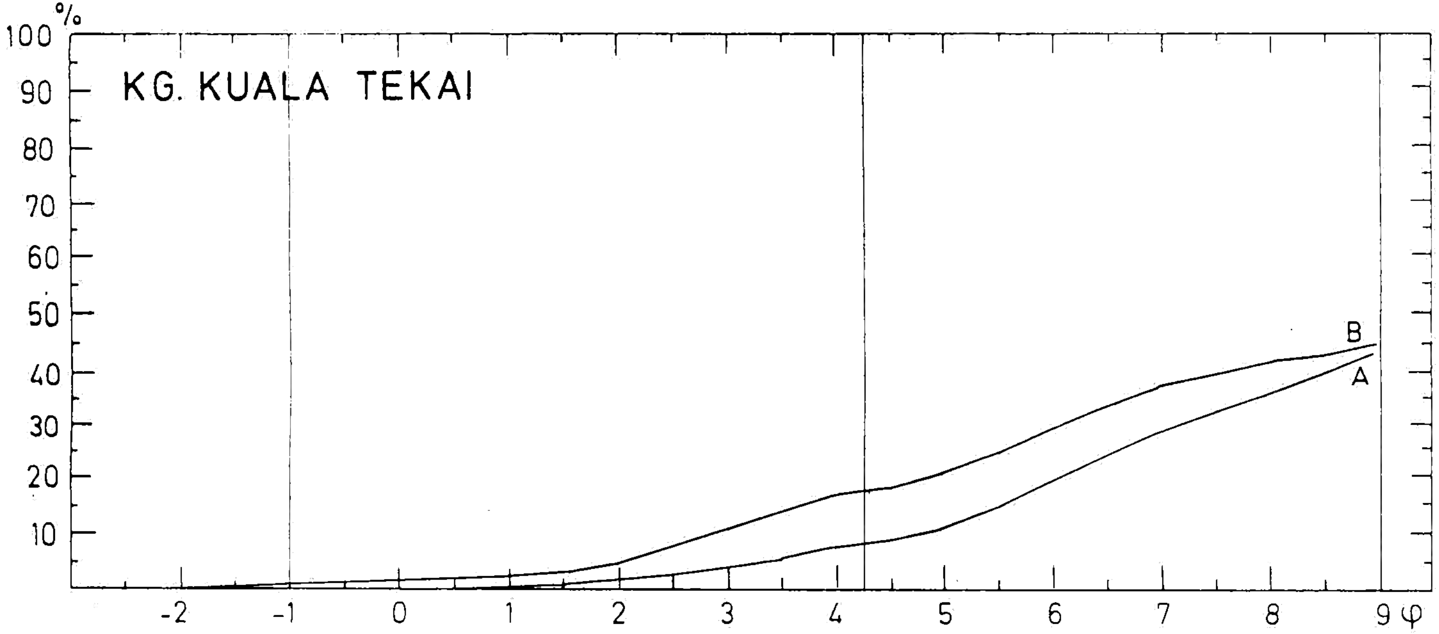

Fig. 44. — Particle size distribution curves referring to figure 43.

Close to the ridges, i.e. close to watergaps, the T_2-surface may be locally covered by a thin veneer (thickness rarely exceeding 1 m) of colluvial clay.

The T_1-bed is rock cut in upstream sections (e.g. Figs. 42 and 43) but fill cut in downstream ones. The T_1-alluvium is partly derived from the T_2-fill and shows a very similar texture. However, rapid alternations of thin finer and coarser layers and the presence of muscovite flakes are often observed.

In most cases the river channel is cut in the bedrock ; gravel bars are often observed.

The interridge area is drained by a dense network of shallow depressions (Fig. 48). The planform is very irregular and shows broad lobe shaped parts connected by narrow stretches. They connect directly with the T_2-level and are hardly incised. The thickness of their fill rarely exceeds 2 m and in most cases is around 0.75 m. The fill represents a local alluvium with very fine texture ranging from sandy clay to heavy clay (Figs. 43 and 44). At the base occurs a thin stone-layer (thickness rarely exceeding 0.2 m) or a mere stone-line of subrounded to rounded laterite nodules in the fine to medium pebble size. In some cases the lower part of the local alluvium shows a more loamy texture and contains dispersed laterite nodules; in those cases a secondary lag stoneline separates the lower part from the clayey upper part (Fig. 49).

3.2.2. Kuala Pilah-area

As it is the case in the Padang Terap area, remnants of two geomorphic riverterraces, T_2 and T_1, can be traced. The T_2-surface occupies a vast area in the Juasseh plain but narrows along the Middle-Muar (Figs. 15 and 50). T_1 in all cases forms a narrow to broad (widths between 15 m and 900 m were observed) belt along the main river channels that are seamed by an almost continuous T_0 present-day floodplain.

Figure 51 shows the location of a number of typical cross-sections and drill-holes, illustrating the terrace levels and their alluvial deposits. Most of them are located in the Juasseh plain (Figs. 52 to 62).

In the Juasseh plain the T_2-surface is, except for a varied microrelief, nearly flat and nearly horizontal only sloping some 0.13 %. The thickness of the T_2-deposits varies between 5 m and more than 10 m. Their lithostratigraphy shows a remarkable uniformity. In

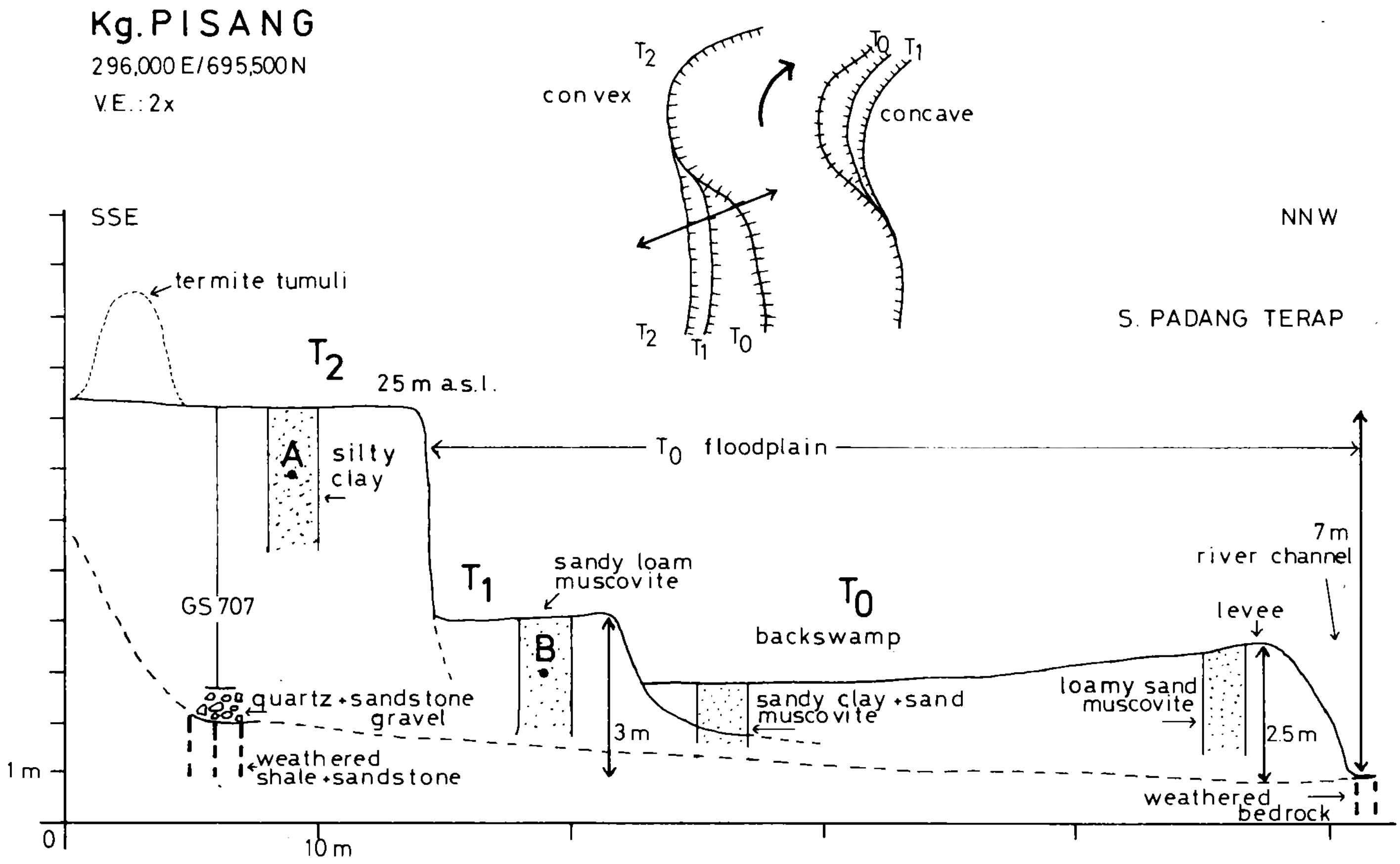

Fig. 45. — River terrace section near Kg. Pisang (Padang Terap). A and B refer to the particle size distribution curves on figure 46.

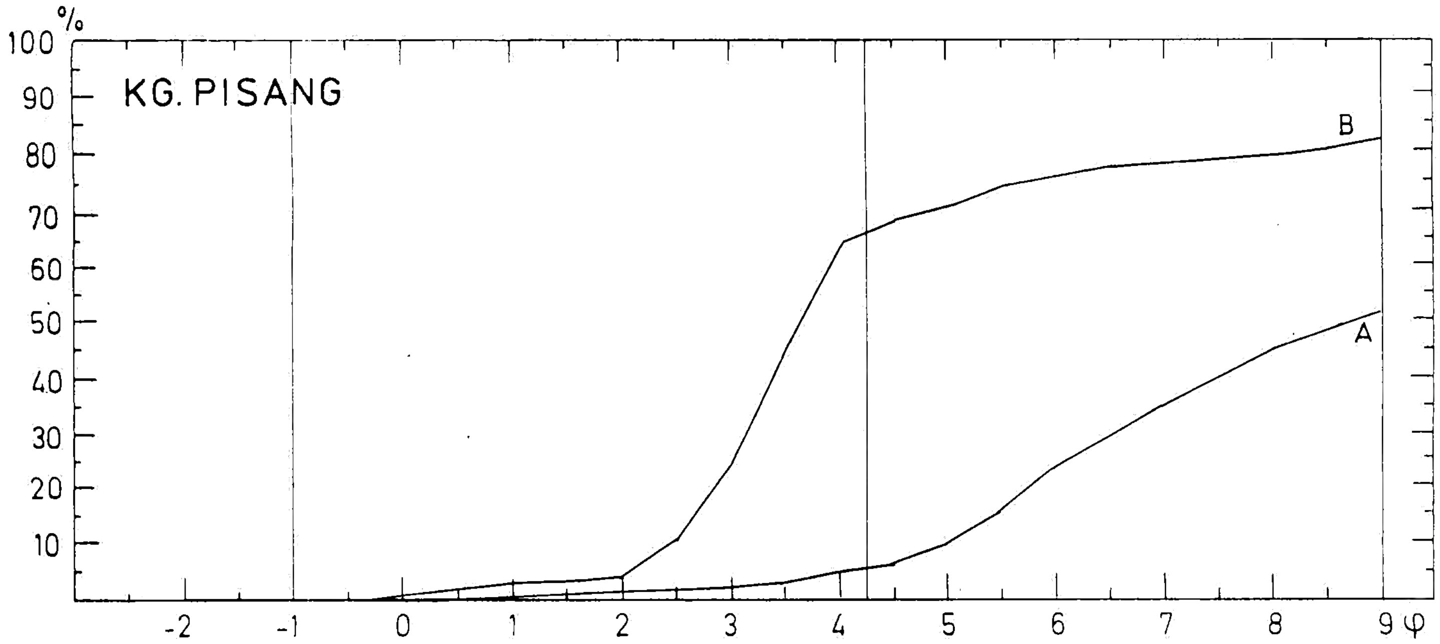

Fig. 46. — Particle size distribution curves referring to figure 45.

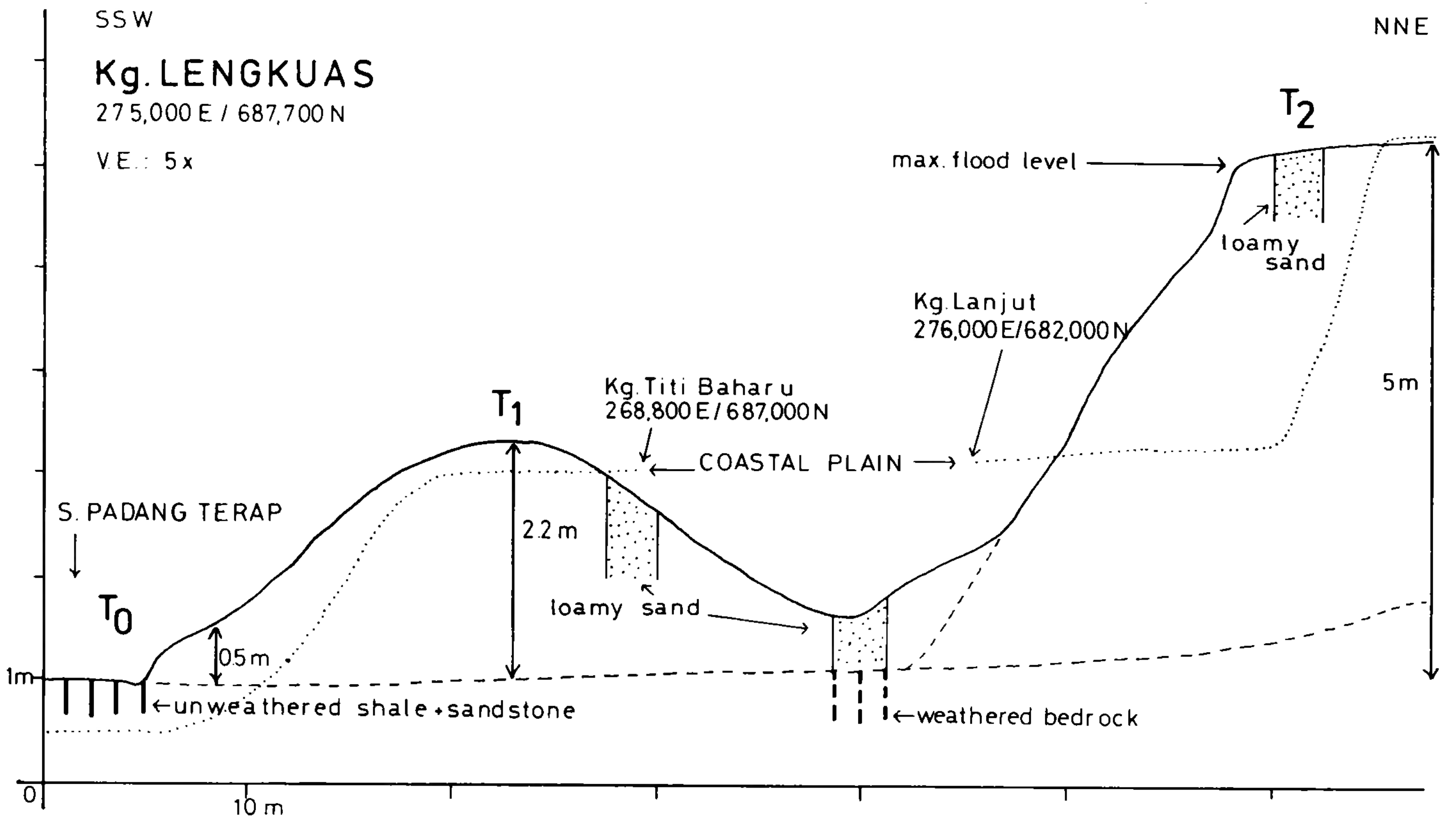

Fig. 47. — River terrace section near Kg. Lengkuas (Padang Terap).

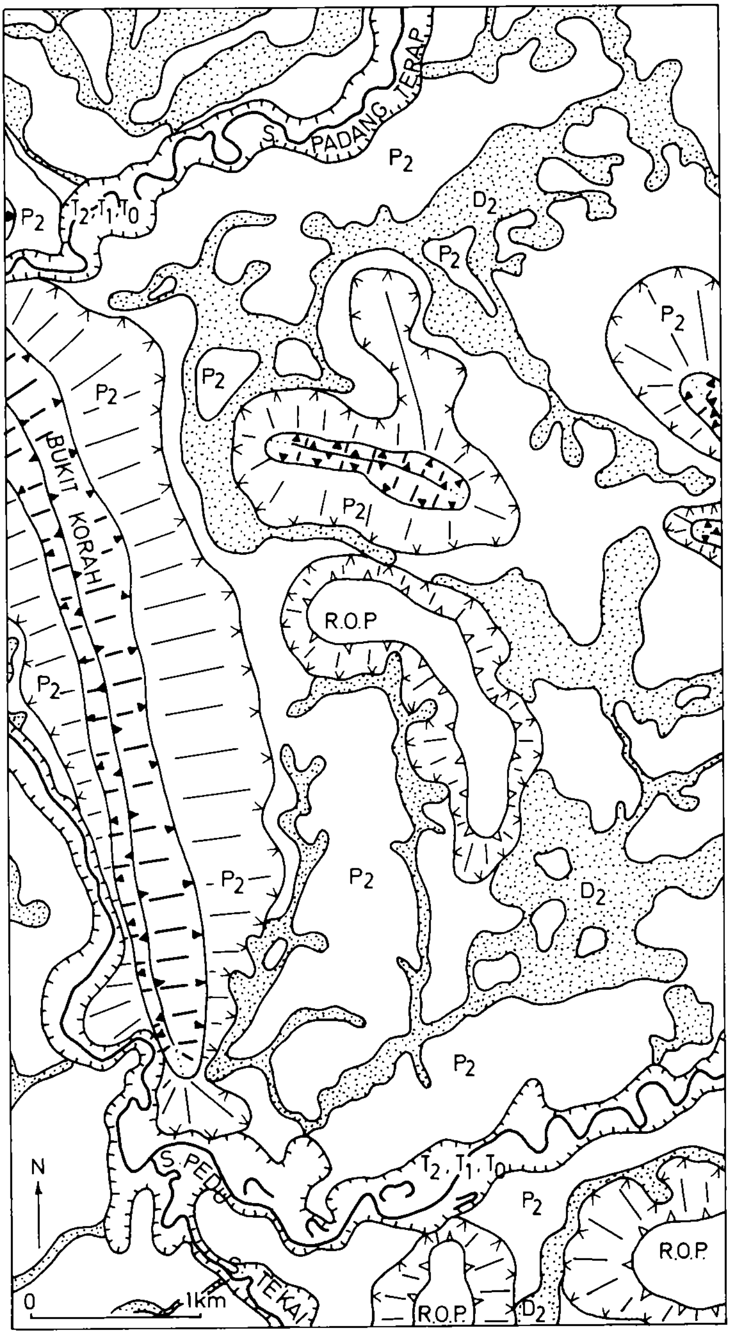

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Fig. 48. — Map, based on aerial photographs, of the landforms near Bukit Korah (Padang Terap).

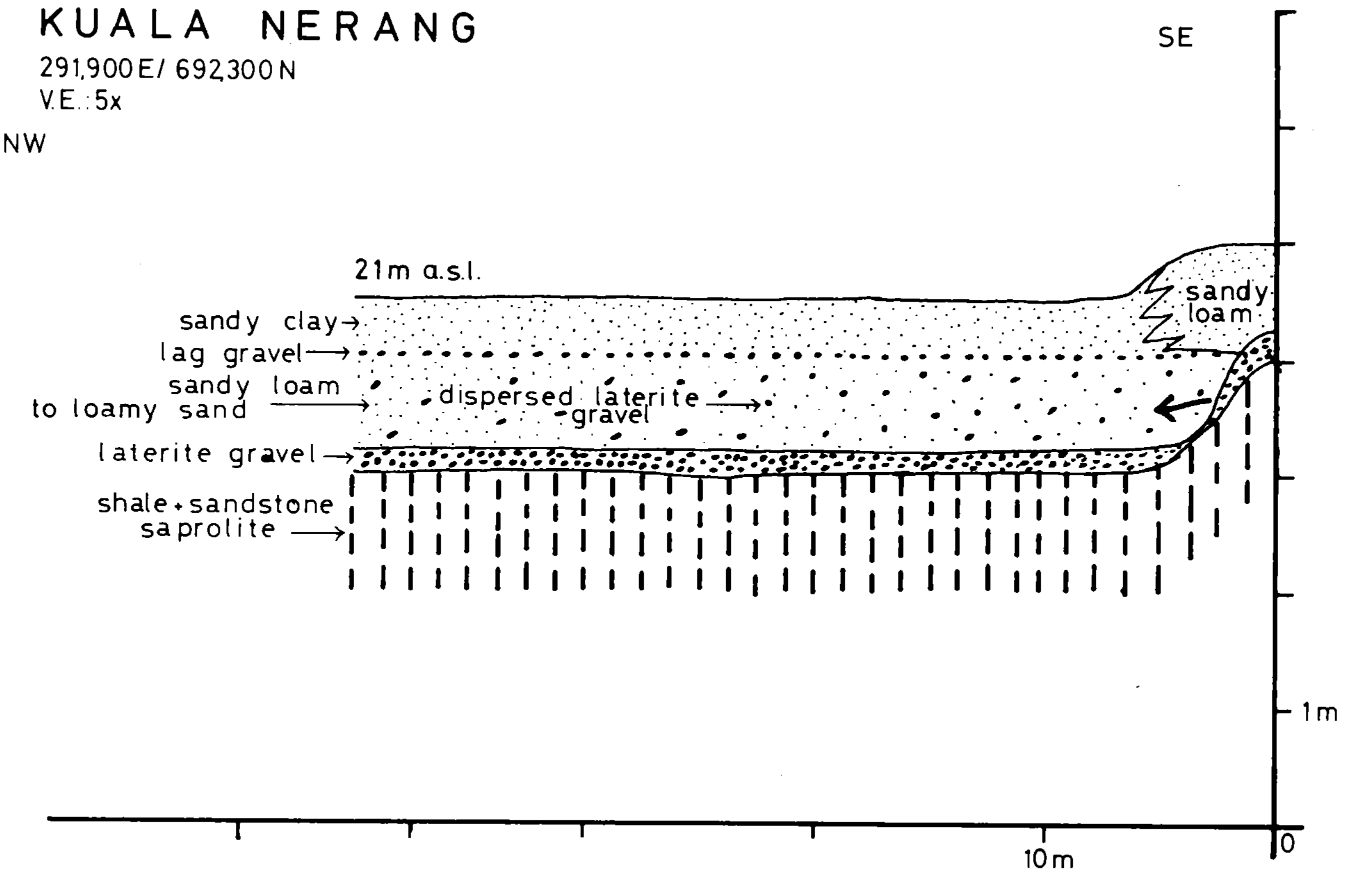

Fig. 49. — D_2 section near Kuala Nerang (Padang Terap).

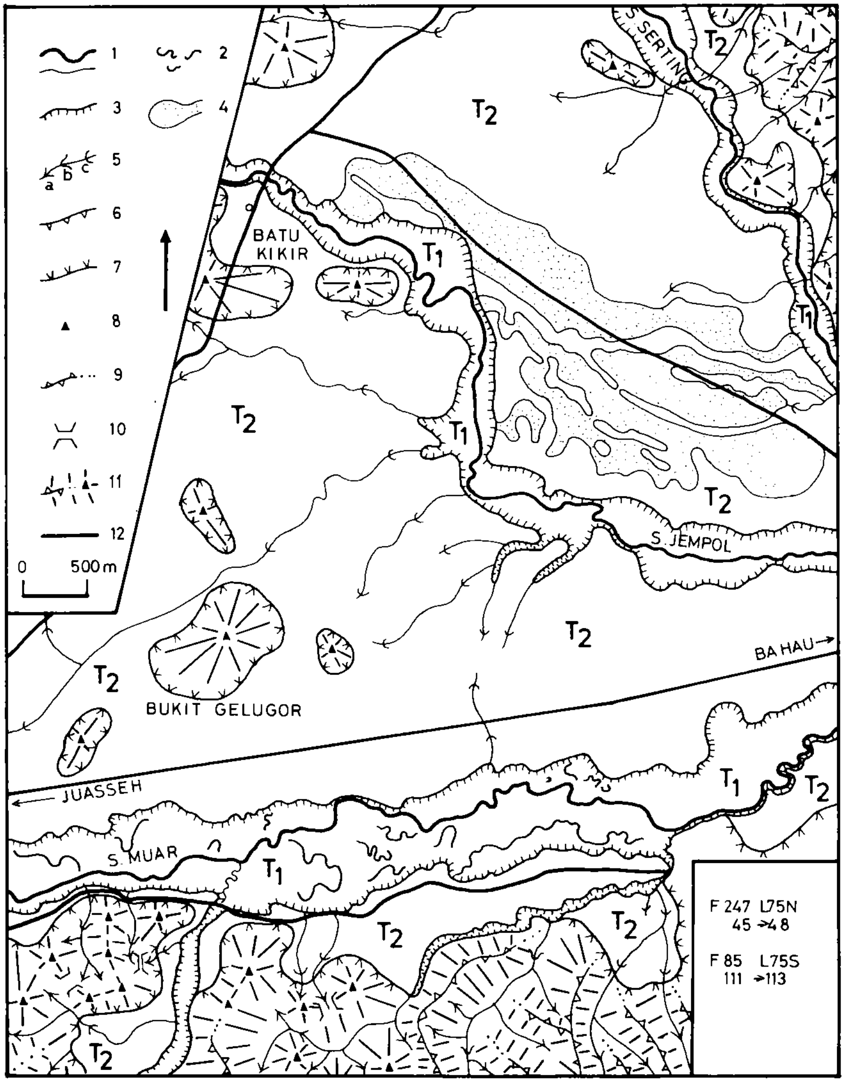

Fig. 50. — Map, based on aerial photographs, of the landforms in the Juasseh-plain (Kuala Pilah).

1. River channels
2. Oxbow
3. Terrace bank
4. Shallow depression
5. Transverse valley profiles
    a. wing-like
    b. bell-like
    c. arch-like
6. Convex slope change
7. Concave slope change
8. Low hill topflat
9. Ridge
10. Windgap
11. Hillslope
12. Important road

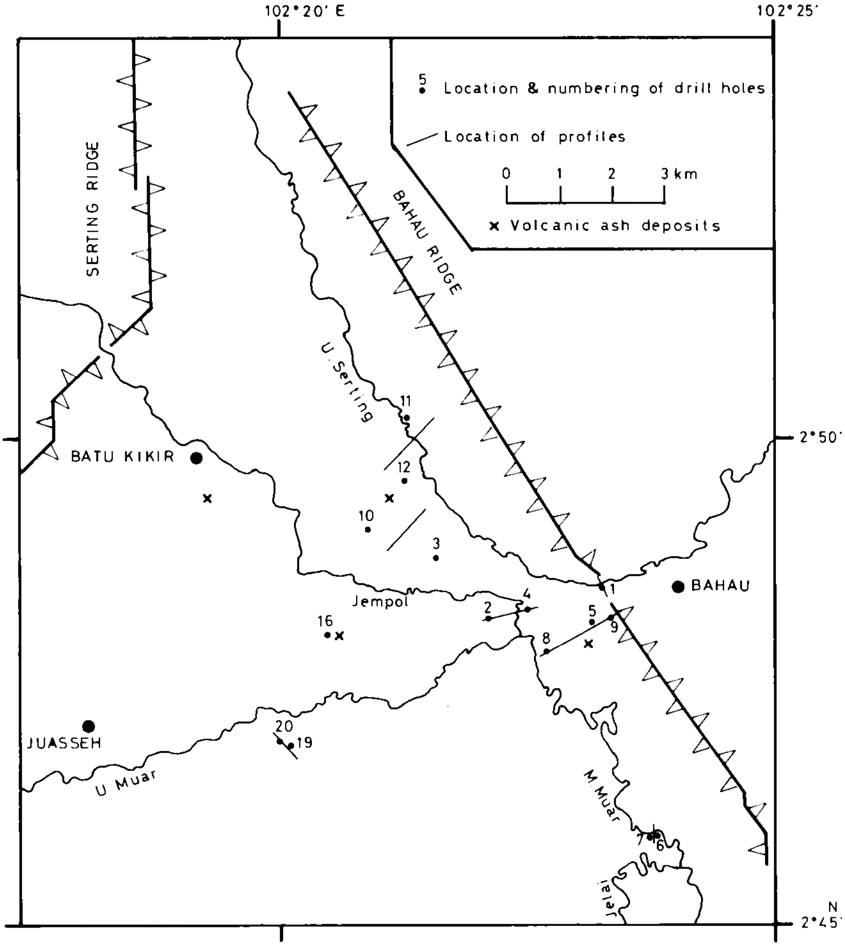

Fig. 51. Location of volcanic ash deposits and of selected drill holes and river terrace sections in the Kuala Pilah-test area.

a complete section (e.g. Figs. 52, 53, 58 and 59), three members (*) can be distinguished from base to top: Jempol-sand, Chachar-clay and Tebat-sand.

For the Jempol-sand member thicknesses of 1 m to more than 4.6 m were observed. The typical texture is a slightly gravelly sand (adapted U.S.D.A. texture triangle, cf. annex) with almost 90 % of the

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(*) The term member is used in an informal sense and refers to lithostratigraphical units easily recognisable in the field and named after drill-hole locations where the unit is typical.

particles in the sand and gravel range and 3 % of clay. In most cases upward fining to a gravelly clay texture (40 % of sand and gravel, 50 % clay) was observed. Throughout the member the coarse sand to fine pebble fraction is important and varies between 30 % and 35 %. The bulk of the coarse fraction is composed of subangular to subrounded quartz and is derived from granite grus.

The thickness of the Chachar-clay member ranges between 2 m and more than 4 m. It is composed of a stiff silty clay loam (35 % clay) to heavy clay (60 % clay). Granite grus may be mixed to some degree (up to 12 % but mostly less than 5 %). The clay member can be slightly peaty and muscovite flakes associated with thin layers of very fine to fine sand were observed.

For the Tebat-sand member a minimum thickness of 4.2 m was observed. The proportion of sand and gravel size particles is constant about 85 %. As it is the case in the Jempol-sand member, the coarse sand to fine pebble fraction, derived from granite grus, is always important and takes between 45 % and 75 % of the texture. Upward fining is observed whereby textures range from a loamy sand (7 % clay) to a sandy loam (16 % clay). Peat fragments and clay balls derived from Chachar-clay were occasionally observed.

Where observable the Jempol-sand in most cases rests directly on the saprolite bedrock. Near the rim of the Juasseh-plain and close to important isolated hills (e.g. Bukit Gelugor on Fig. 50), a basal layer of slack, water soaked fine sandy clay with a thickness of up to 2.3 m is intercalated between the bedrock and the Jempol-sand. The transition from Jempol-sand to Chachar-clay is quite gradual; the top of the latter however is truncated and shows an abrupt change to Tebat-sand.

The above described lithostratigraphy for the T_2-alluvium is not limited to the Juasseh-plain. It was also observed during a drilling reconnaissance survey in the Sungei Sabaling Estate, 10 km NE of Bahau and drained by the Pahang system, and in the FELDA Palong 12 scheme, 24 km ENE of Bahau and drained by the Muar system. Drillings for a tin-placer survey effectuated by the Geological Survey of Malaysia (*) in the Ulu Jempol area, developed upstream of the Serting ridge watergap (cf. Fig. 15) and surrounded by granite country, showed T_2-alluvia, with thickness of 7.6 m to 12.8 m, to have the same lithostratigraphic sequence.

(*) The survey was effectuated in 1979. Records were consulted at the Quaternary Geology Department, Geological Survey of Malaysia, Ipoh.

The regular alternation of such contrasting lithologies as clay and sand, has important morphological consequences. Mottling and direct observations in drill holes show that important fluctuating perched groundwatertables are developed in the Jempol- and Tebat-sand. They largely contribute to the presence of springs and seepage lines on valley sides. The morphological effect of the latter is particularly clear near Kg. Kuala Jempol (Fig. 52) where the Jempol river breaks through the T_2-deposits by a 200 m broad watergap. The channel segment runs parallel to the general strike of the T_2-deposits. Consequently seepage and associated retreat of the Tebat-sand is more important on the WSW-valleyside resulting in an outspoken asymmetric transverse profile.

The T_2-surface is drained by a sparse network of shallow rivulets (up to 40 m wide) with arch-like transverse profiles. The poor development of that network is mainly due to the high infiltration capacity of the Tebat-sand (Fig. 54, Kg. Baharu Serting Ilir). In the riverplain-section between the Upper Serting and the Jempol, part of the network is developed on the Chachar-clay (Fig. 50). Incision and extension of tributary rivulets was hampered by the clay body but Tebat-sand was easily removed, resulting in an irregular network of shallow, broad (up to 700 m wide) depressions. Those depressions are mainly under padi and the kampongs are settled on the narrow, low (up to 4 m high) Tebat-sand interfluves (Fig. 56).

The level difference between the T_1- and T_2-surface becomes more important from N to S at riverplain-level and in downstream direction on the level of a single river :

	river	*location*	*level* difference	
N	Serting	Kg. Baharu Serting Ilir	2 m	Fig. 54
↓	Jempol	Kg. Kuala Sialang	2.5 m	
		Kg. Kuala Jempol	7 m	Fig. 52
S	Muar	Kg. Terusan Seberang	5.5 m	Fig. 58
		Kg. Jambu Lapan	7 m	Fig. 60
		Kg. Kuala Jelai	> 12 m	Fig. 62

In almost all cases T_1 is cut and filled into the T_2-deposits. On the Middle-Muar, downstream the Jempol-confluence, however, T_1 is cut into saprolitic bedrock (Fig. 60, Kg. Jambu Lapan) and even fresh limestone (Fig. 62, Kg. Kuala Jelai).

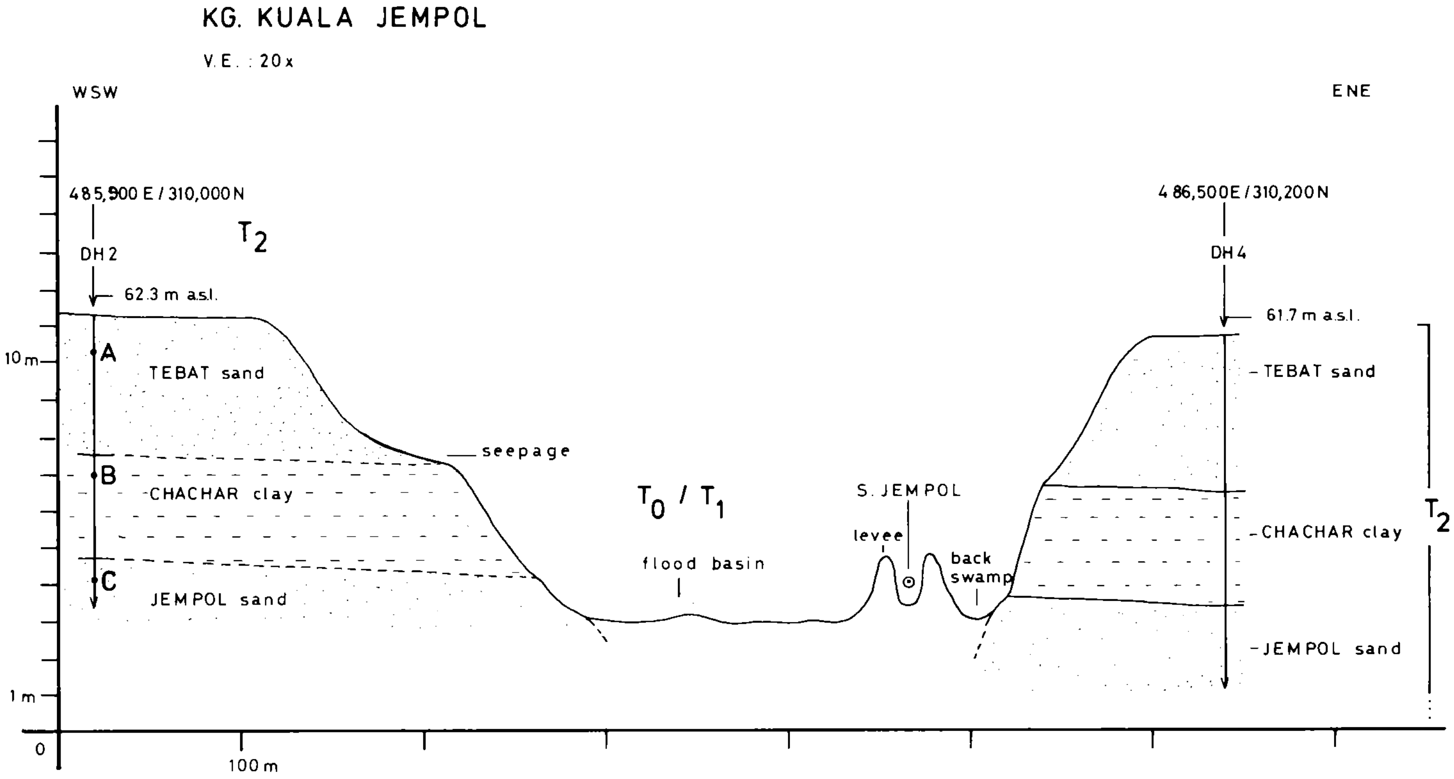

Fig. 52. — River terrace section near Kg. Kuala Jempol (Kuala Pilah). A, B and C refer to the particle size distribution curves on figure 53.

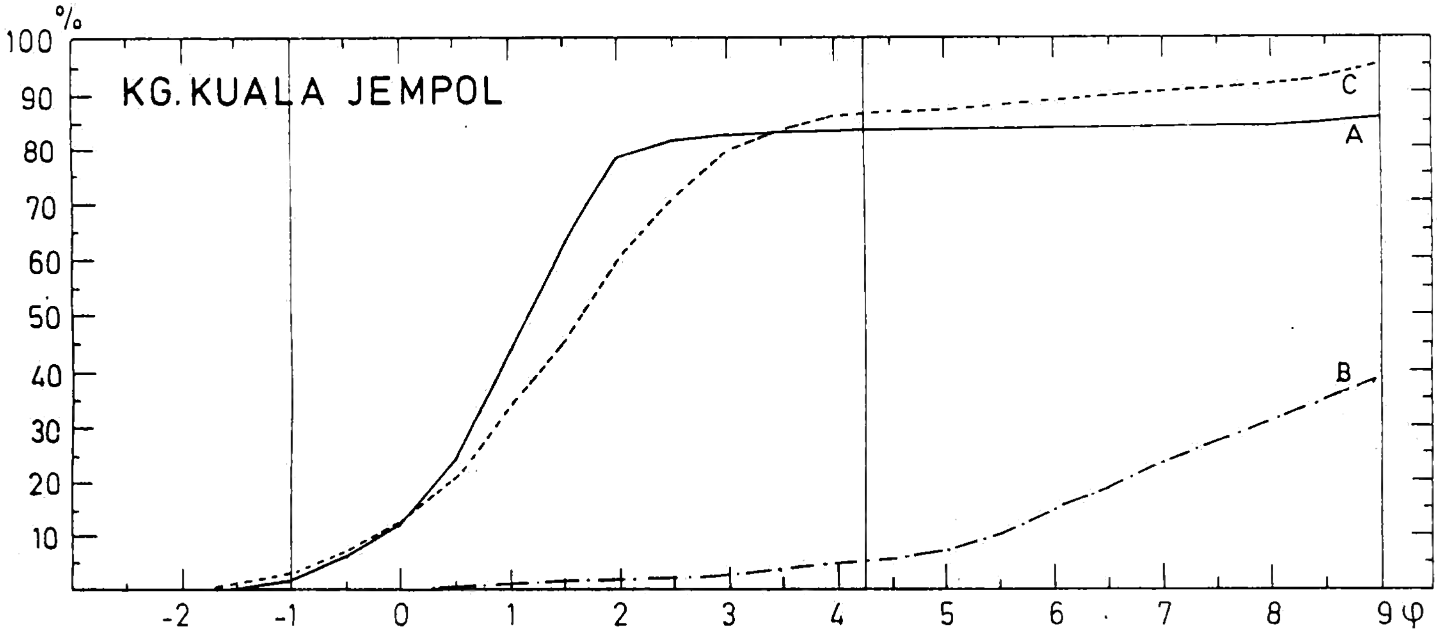

Fig. 53. — Particle size distribution curves referring to figure 52.

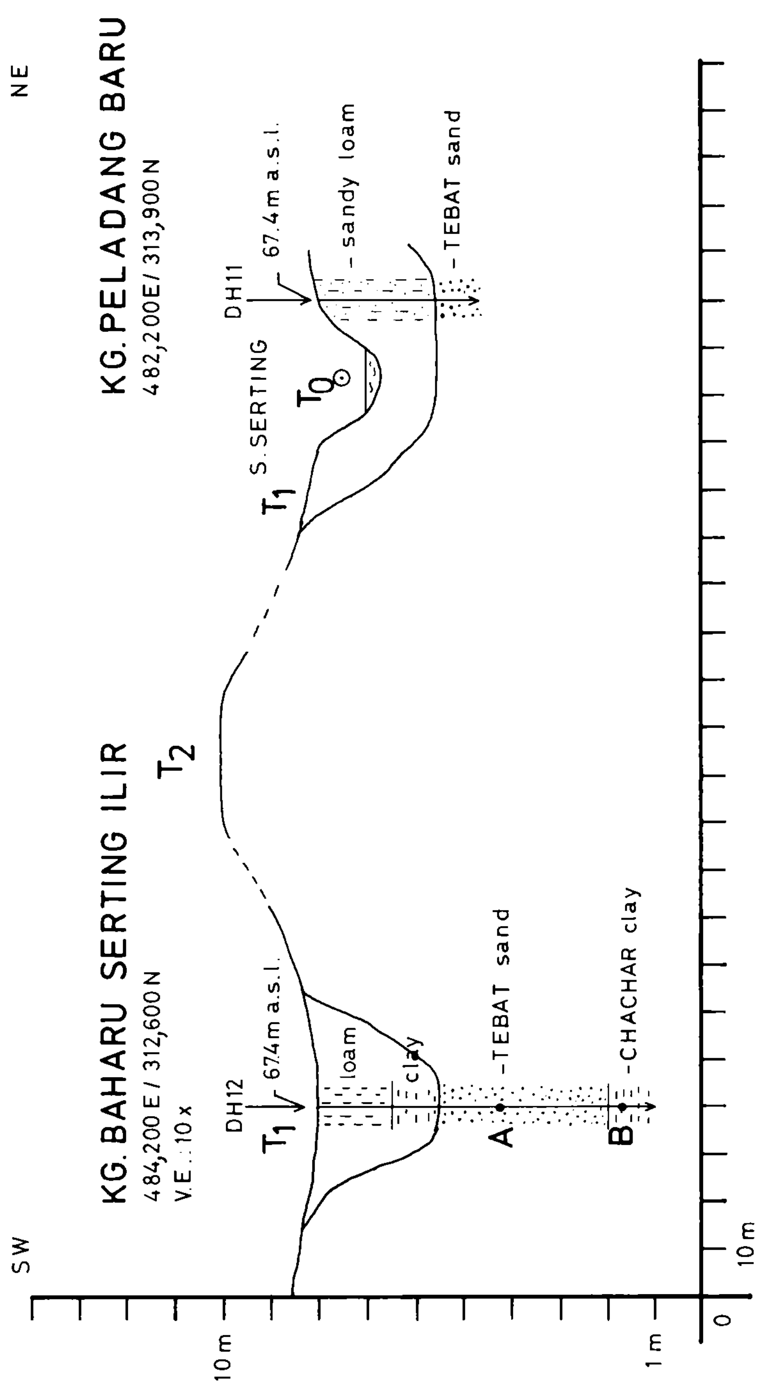

Fig. 54. — River terrace section near Kg. Baharu Serting Ilir (Kuala Pilah). A and B refer to the particle size distribution curves on figure 53.

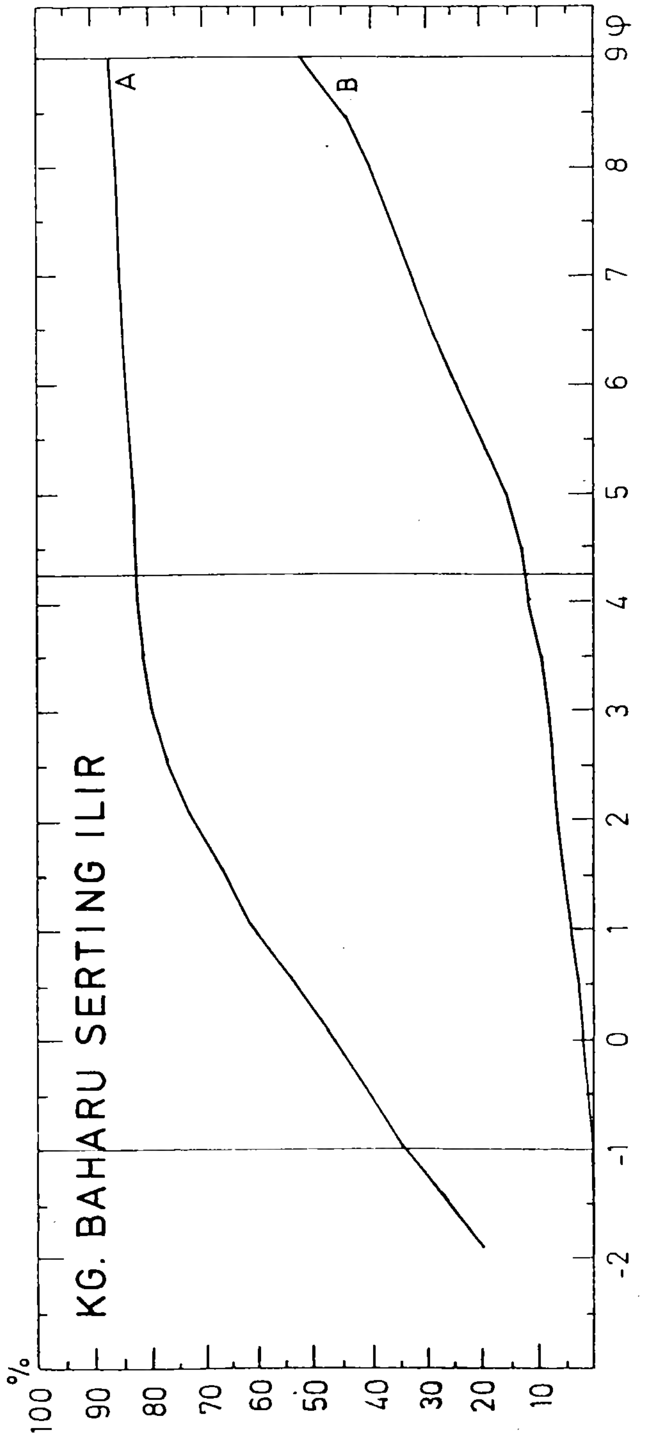

Fig. 55. — Particle size distribution curves referring to figure 54.

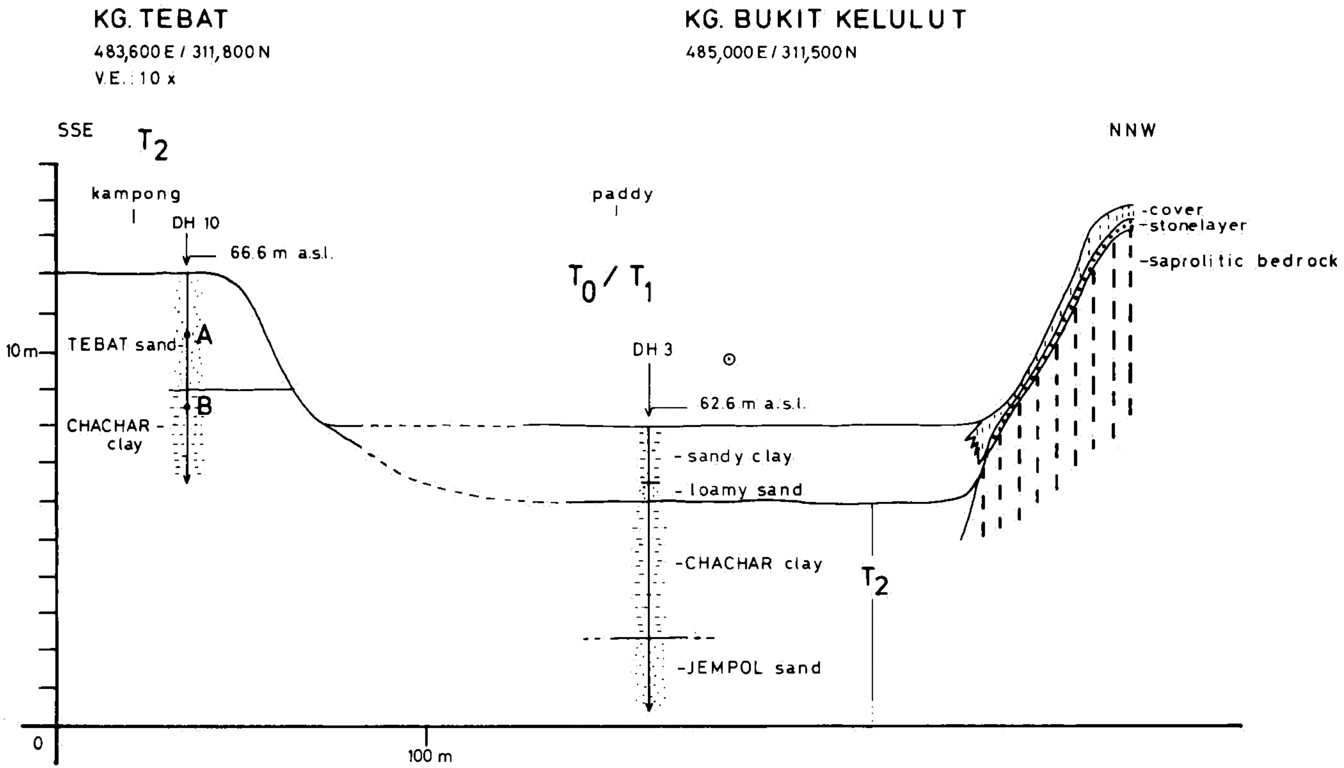

Fig. 56. — River terrace section near Kg. Tebat (Kuala Pilah). A and B refer to the particle size distribution curves on figure 57.

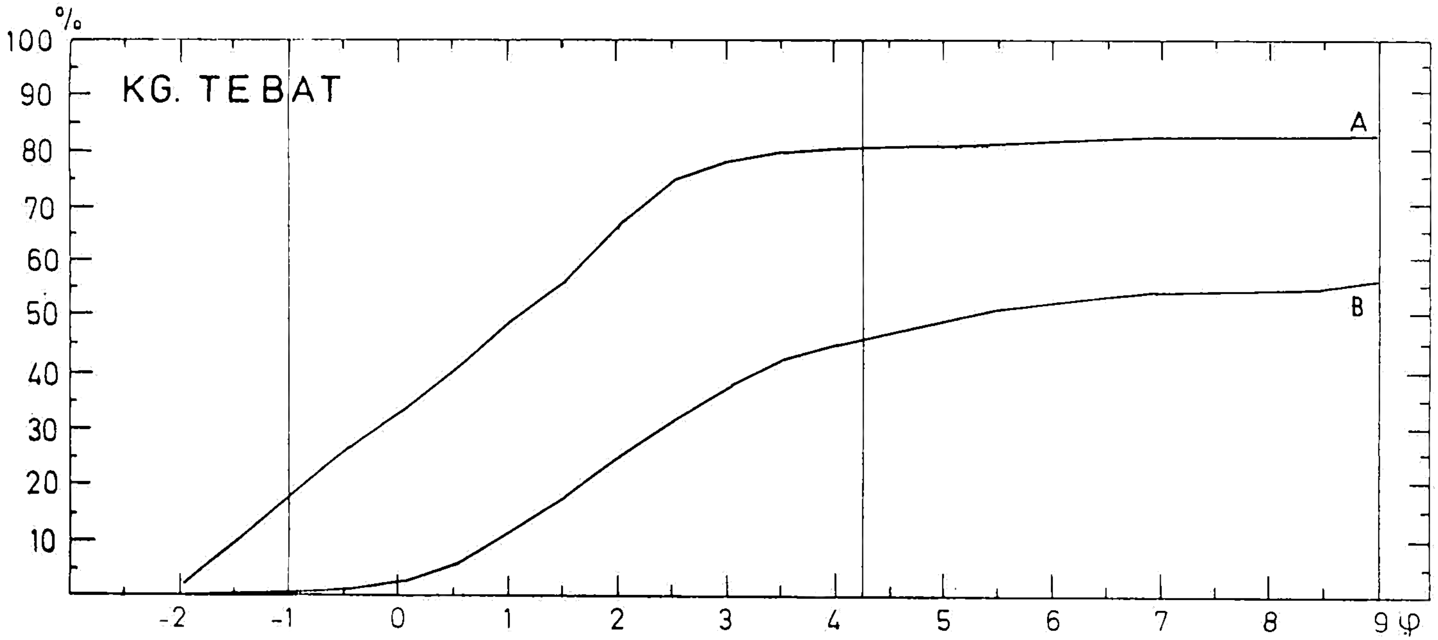

Fig. 57. — Particle size distribution curves referring to figure 56.

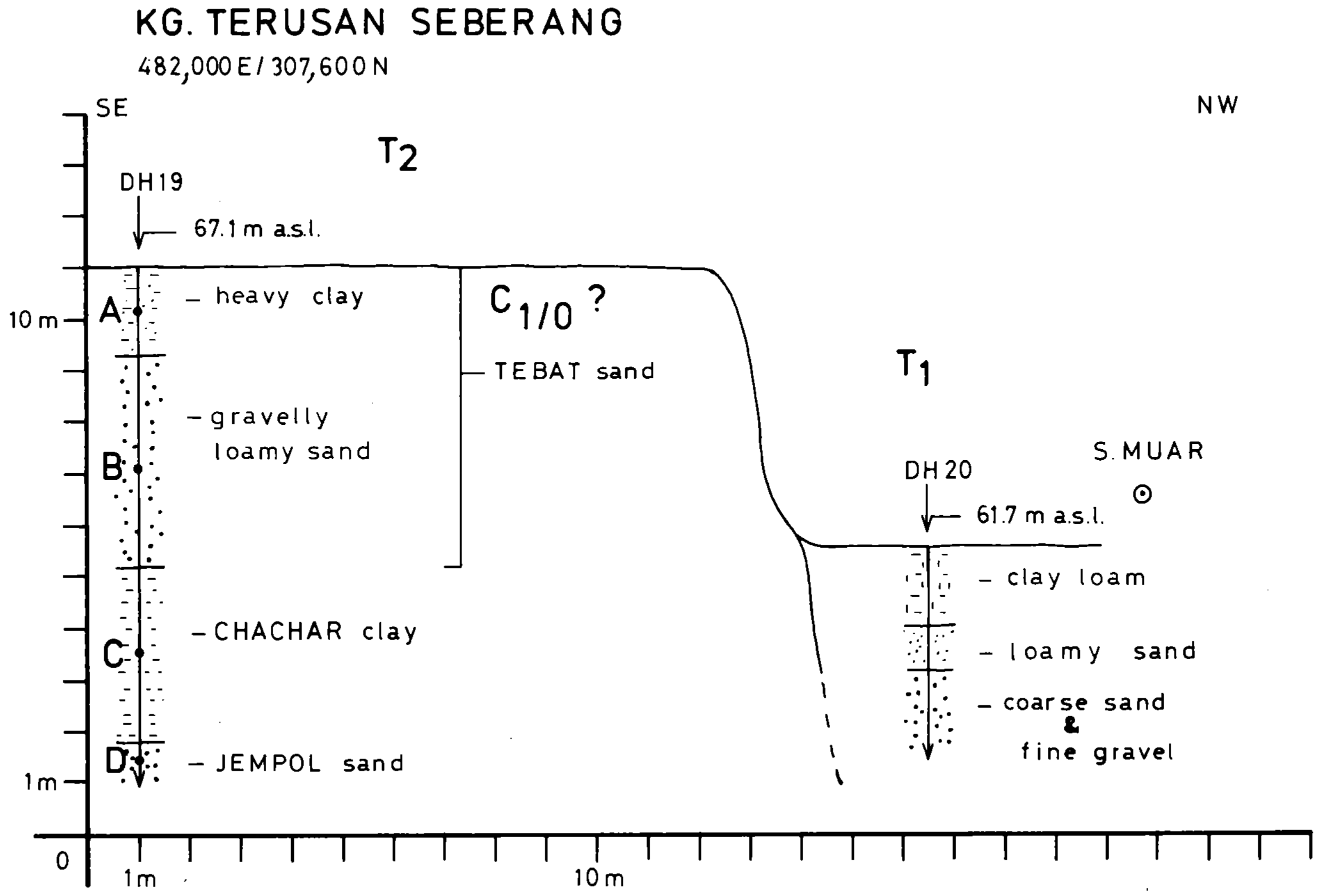

Fig. 58. — River terrace section near Kg. Terusan Seberang (Kuala Pilah). A, B, C and D refer to the particle size distribution curves on figure 59.

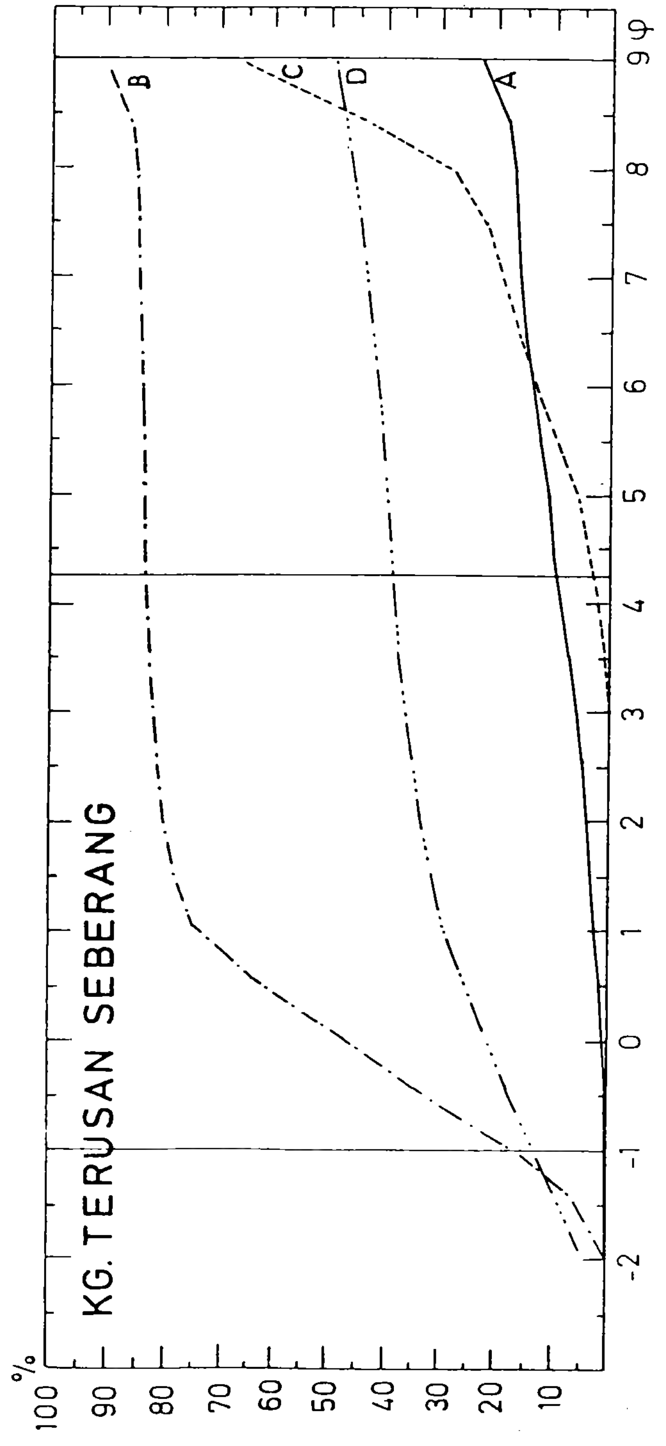

Fig. 59. — Particle size distribution curves referring to figure 58.

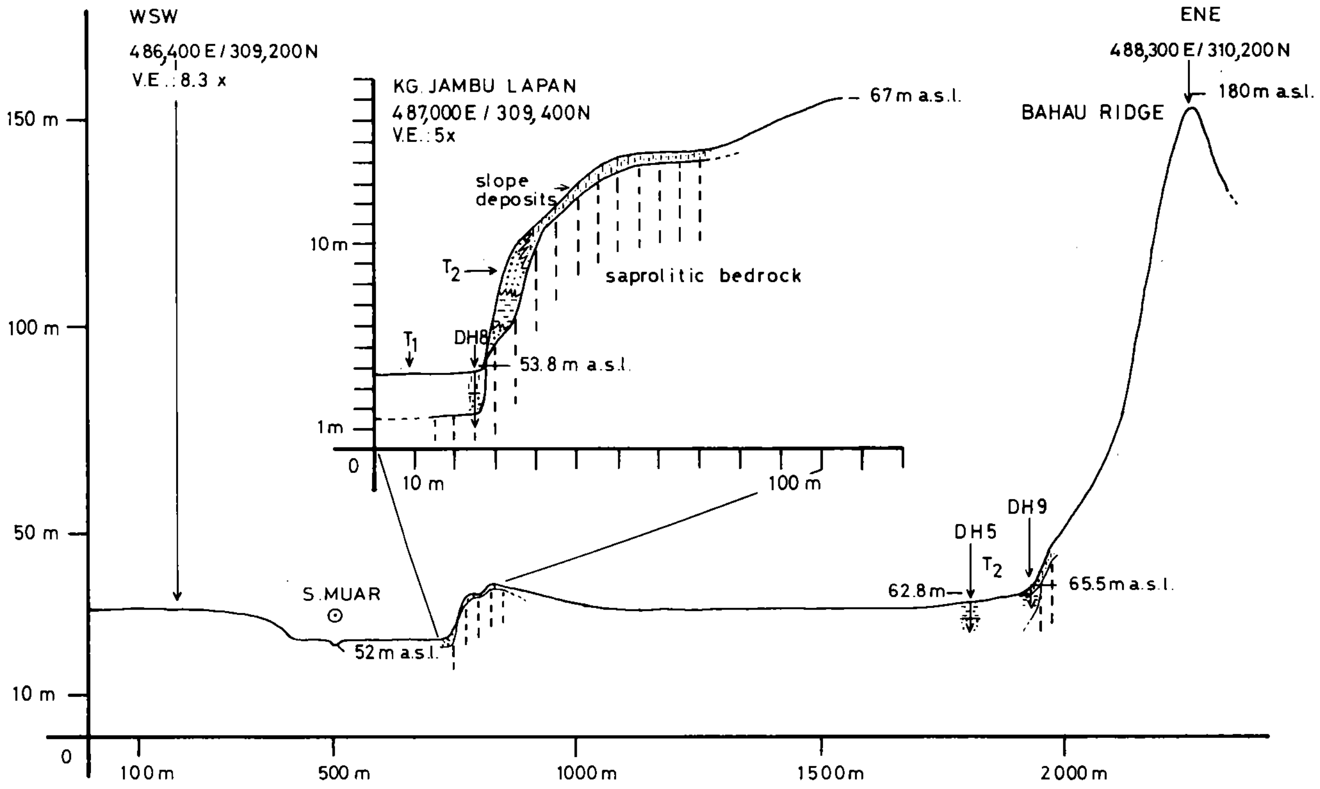

Fig. 60. — River terrace section near Kg. Jambu Lapan (Kuala Pilah).

The T_1-deposits are characterized by a rapid alternation of lenses of fine gravel, sand, silt and clay (e.g. Fig. 61). The deposits are often slightly peaty and muscovite is almost always present in the sandy fraction. The fine gravel and coarse sand are derived from granite grus and most probably reworked from the T_2-deposits. In almost all cases the top of the deposits (0.5 m to 2.5 m) is composed of clay and silt. The same deposit characteristics are found in the Ulu Jempol area.

The present-day T_0-deposits consist of sandy levees and silt-and-clay veneers in the floodbasins partly developed on top of the T_1-deposits. Floods can become very important during the rainy season. Peaks of 3.5 m above the channel were noted in Kg. Kuala Sialang and 7.3 m on the Serting watergap in the Bahau-ridge (Fig. 61).

Isolated hills, standing as islands in the riverplain, suggest the thick alluvial deposits mask an important basin bedrock relief. In some

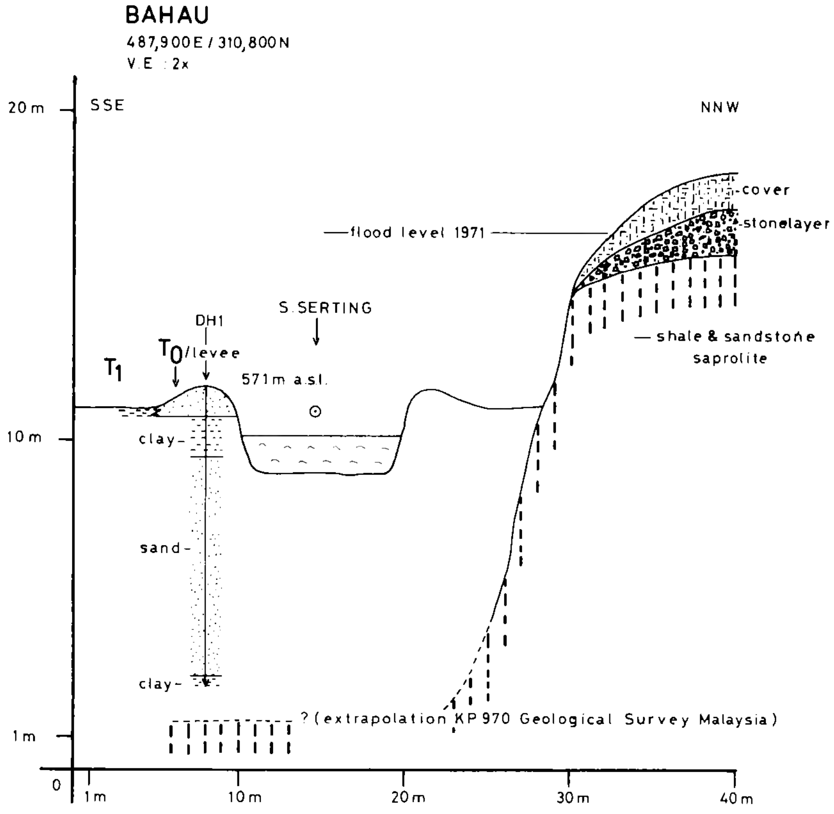

Fig. 61. — River terrace section in the Bahau watergap (Kuala Pilah).

cases it obviously directs the rivercourse as it is the case near Kg. Jambu Lapan (Fig. 60) where the Middle-Muar is lead by a low and narrow ridge, parallel to the Bahau-ridge and partially masked by T_2-deposits.

Close to pediments the T_2-surface is often locally covered by a veneer of colluvial clay (e.g. DH5 and DH9 on Fig. 60). Thicknesses of 4 m were observed, but in most cases it is less than 1.5 m. The fact that the colluvial clay is not found on parts of the T_2-surface isolated from the upland by river incision (e.g. the interfluve between the Upper Serting and Jempol, Fig. 50), lets suppose the colluviation is mainly posterior to the T_1-incision.

In most of the stream valleys, alluvial terrace deposits only occupy narrow, discontinuous strips or are absent. However, the most important fossilized gullies on the lower pediments (Figs. 33 and 34) reach a same level that corresponds to a break of slope on tributary valley

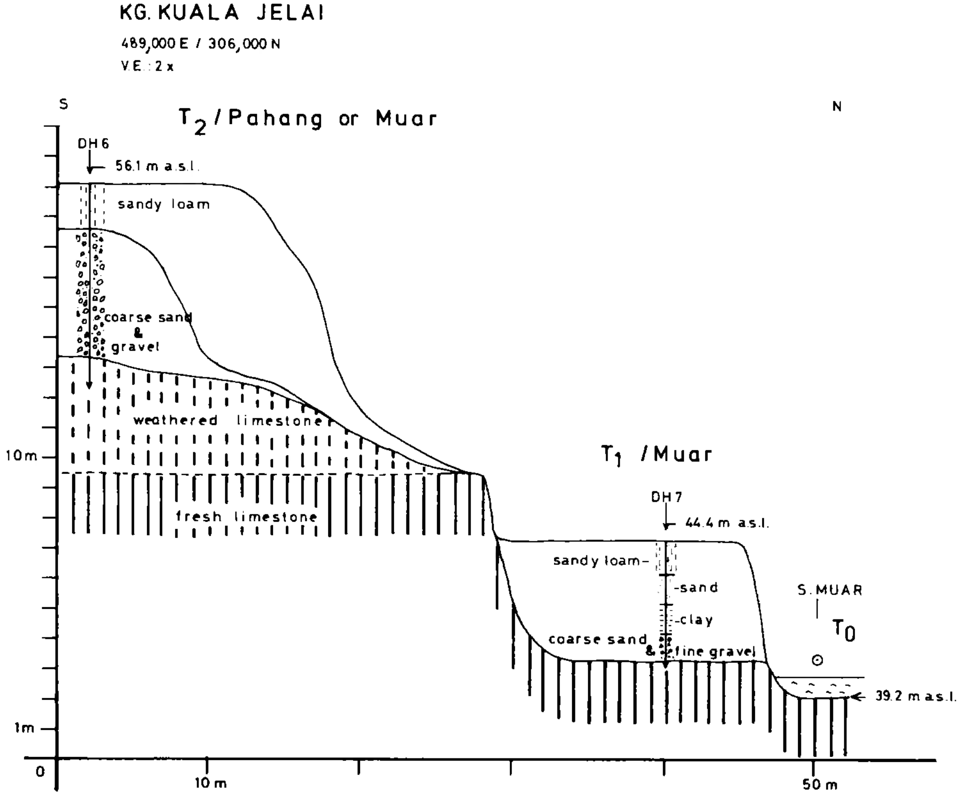

Fig. 62. — River terrace section near Kg. Kuala Jelai (Kuala Pilah).

sides. That level probably corresponds to the T_2-talweg and in that case the T_1/T_0-incision reached some 5.5 m.

Some field evidence points to the fact that part of the headwaters of the Serting (Pahang-basin) was captured by the headwaters of the Muar (Fig. 63) :

— the Jempol shows an elbow of capture ;

— two windgaps testify to abandoned sections of the Muar and Jempol ;

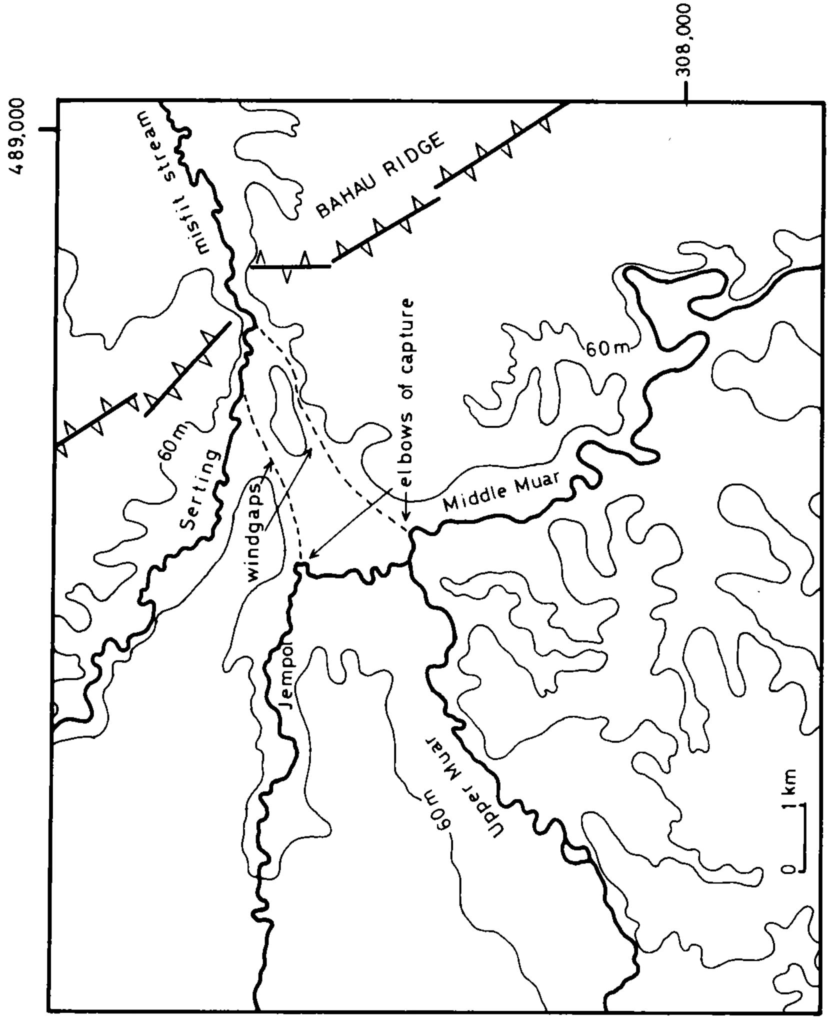

Fig. 63. — Capture of the headwaters of the Serting (Pahang) river by the Muar river in the Kuala Pilah-testarea.

- the Serting is misfit in the Bahau watergap, the T_0-incision was not able to scour the fill (Fig. 61);
- the Jempol, downstream of the elbow of capture, crosses the T_2-deposits in a narrow watergap (Fig. 52);
- the Middle-Muar shows features of rejuvenation, the channel is deeply incised into fresh, unweathered, hard bedrock (Fig. 62);
- rejuvenation is also reflected in the fact that W of the Bahauridge the hills are better developed (average local relief of 50 m) than it is the case E of the ridge (average local relief of 25 m).

As to the field evidence the capturing took place after formation of the T_2-surface. The Lower-Muar most probably first captured the Middle-Muar, which consequently captured the Upper-Muar, followed by the Jempol. As a consequence the stream direction must have been reversed in part of the Middle-Muar. Further detailed field investigations on the terrace-deposits could corroborate the hypothesis.

3.2.3. Johor Bahru-area

As it is the case in the Padang Terap and Kuala Pilah areas, remnants of two riverterraces, T_2 and T_1 can be distinguished. The T_2-surface only covers a small area situated around 15 m a.s.l. and limited to the headwaters of the Ayer Hitam, Pontian Kechil and Jeram Choh rivers at the western and southern fringes of the Gunong Pulai massive (cf. Fig. 18). T_1 forms an extensive flat and near horizontal surface with a mean gradient of 0.13 %. The bulk of it is occupied by the coastal plain that extends into the hill complex in narrow riverplains. The present-day T_0 floodplain is hardly developed along the short coastal rivers that drain the area. At the coastward edge the level difference between the T_2- and T_1-surface is some 10 m. Towards the river heads however the level difference becomes smaller and the T_2-surface disappears as a geomorphic feature as it merges into the T_1-surface.

Fig. 64 shows the location of a number of typical cross-sections and drill-holes, illustrating the terrace levels and their alluvial deposits (Figs. 65 to 70).

For the T_2-deposits a thickness of up to 4 m was observed and only one member (informal lithostratigraphic unit cf. the Kuala Pilah-area), the Melayu Raya-sand, could be distinguished (Figs. 65 and 66). The typical texture is a gravelly sandy loam (adapted U.S.D.A. texture triangle, cf. appendix) with 80 % of the particles in the sand and gravel size and about 15 % of clay. Upward fining was observed, as the proportion of coarse sand and fine pebbles gradually changes from 60 % to 30 %. The bulk of the coarse fraction is composed of subangular to subrounded quartz and is derived from granite grus. In an excavation 3 km N of Pekan Nanas (612,300 E ; 175,000 N) parallel lamination of finer and coarser particles was observed (Photo 5). Where the base was observable, the Melayu Raya-sand rests directly on the bedrock (Fig. 65).

Several lithostratigraphic units could be distinguished in the T_1-deposits. As the drillings reached the bedrock only occasionally, the picture is not complete. In almost all cases the lowermost observed unit is the Kulai-sand member for which thicknesses up to 5 m were noted. It is composed of a gravelly loamy sand (85 % sand and gravel, 6 % clay) fining upward to a gravelly sandy clay loam (75 % sand and gravel, 22 % clay) ; the proportion of coarse sand and fine gravel is about 45 % throughout the member. The coarse fraction is very similar to the one of the Melayu Raya-sand. It is very likely that part of the Kulai-sand is reworked from the Melayu Raya member. It is even plausible that in the river heads both are in fact the same, the Kulai-sand constituting a truncated T_2-surface buried by T_1-deposits (e.g. Fig. 67 in the Kulai Oil Palm Estate). Where the Kulai-sand base was observed it was found lying directly on the bedrock or on a water-filled sandy clay.

The Kulai-sand is topped by a clayey member, the Ulu Benut-clay. It is a riverine heavy clay (90 % clay) often organic (e.g. 7 % O.C., cf. Figs. 67 and 68) and often mixed with some sand. Towards the coast, the Ulu Benut-clay gradually changes into an estuarine facies (Jeram Batu-clay) and a marine facies (Pontian Kechil-clay). The Jeram Batu-clay has a grayish blue color and often contains mangrove peat fragments. The Pontian Kechil-clay shows greenish blue colors and often contains small shell fragments. Both have a silty clay to heavy clay texture and show jarosite stains upon drying. For the Ulu Benut-clay and Jeram Batu-clay members thicknesses up to 2.5 m were observed. The base of the Pontian Kechil-clay was never observed in drillings reaching 8 m. Near Pontian Kechil the bedrock was reached at 20 m depth in a D.I.D.-survey drilling (cf. Fig. 17).

Large parts of the coastal plain are covered by peat. The Paya Lepas-peat member is composed of a hemistic to fibristic peat ; very organic clayey layers are sometimes included. Thicknesses of up to 6 m were observed.

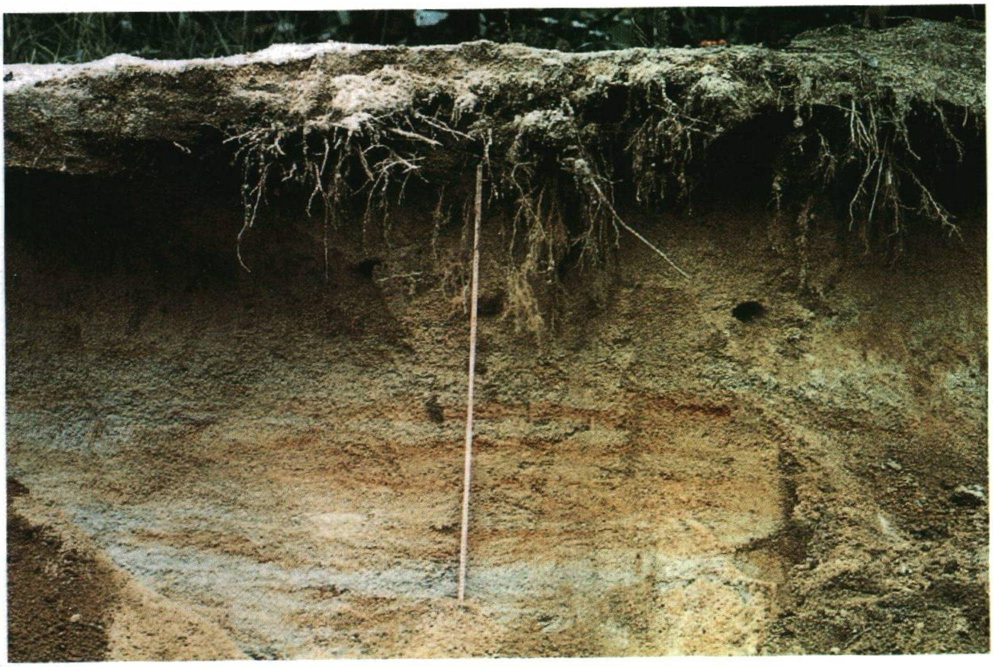

Photo 5. — 612,300 E/175,000 N
Johor Bahru-test area ; 3 km N of Pekan Nanas.
Section in a T_2-terrace. The Melayu Raya-sand is a gravelly sandy loam. The bulk of the coarse fraction is composed of subangular to subrounded quartz derived from granite grus. A parallel lamination of finer and coarser particles is observed.

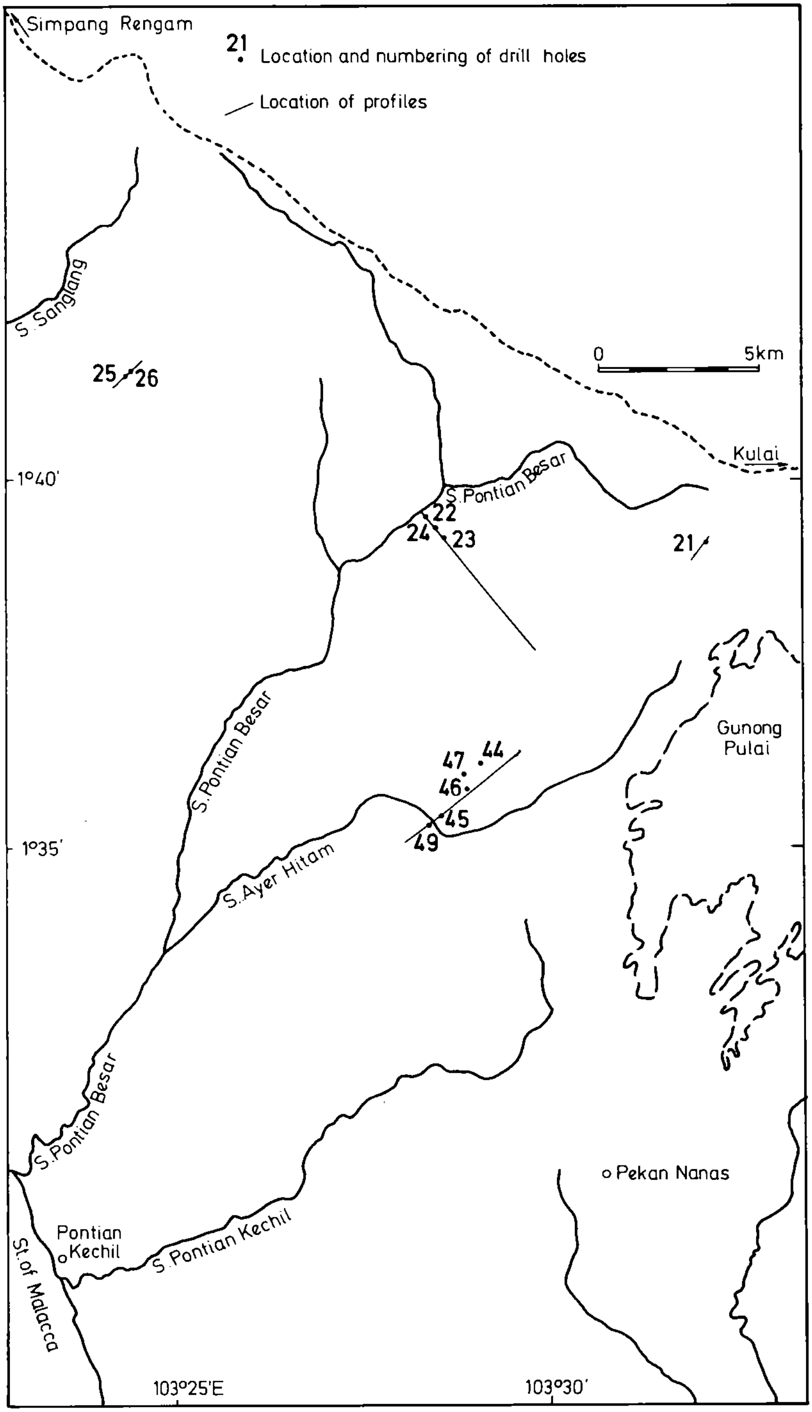

Fig. 64. — Location of selected drill holes and sections in the Johor Bahru-test area.

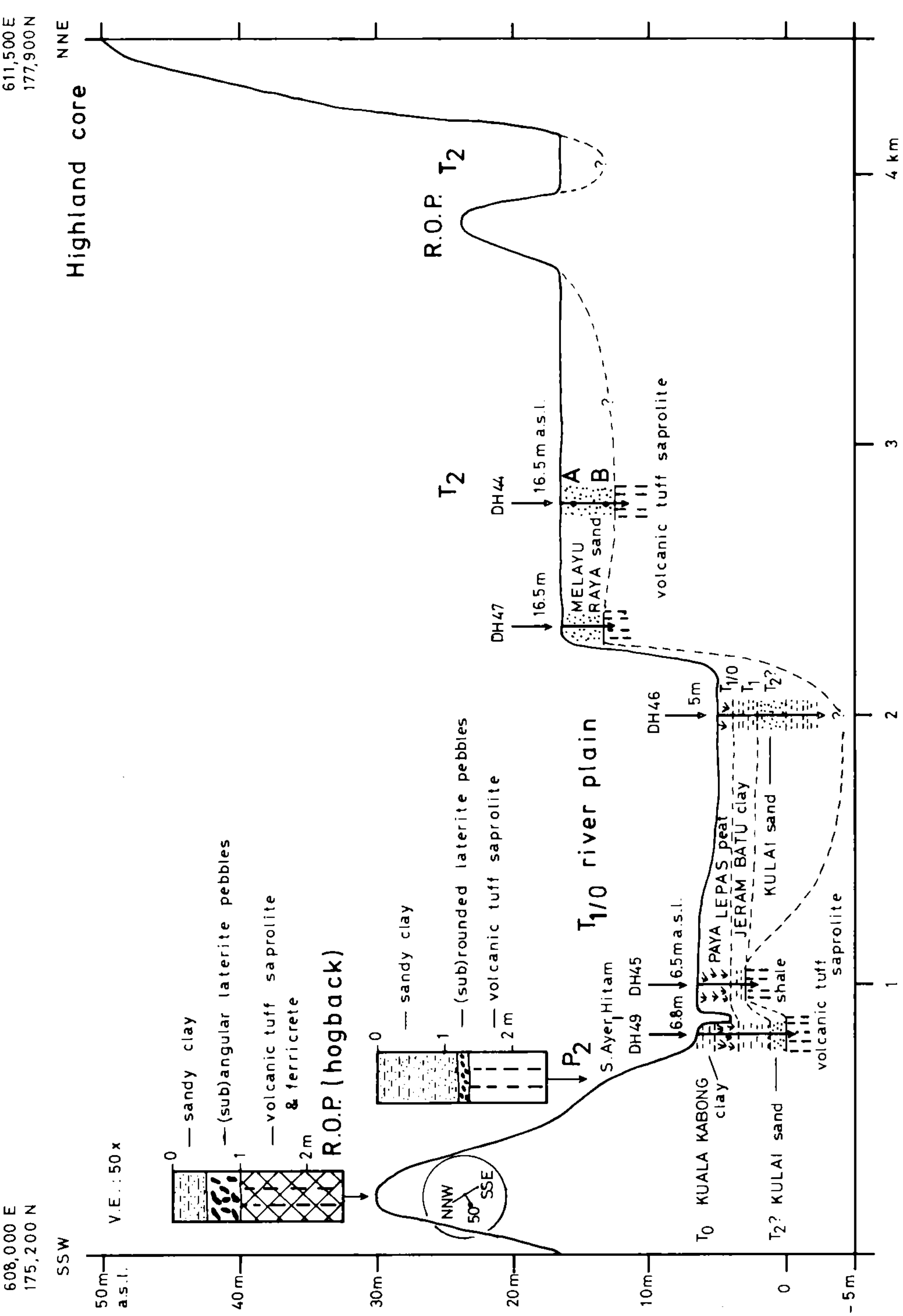

Fig. 65. — River terrace section near Kg. Melayu Raya (Johor Bahru). A and B refer to the particle size distribution curves on figure 66.

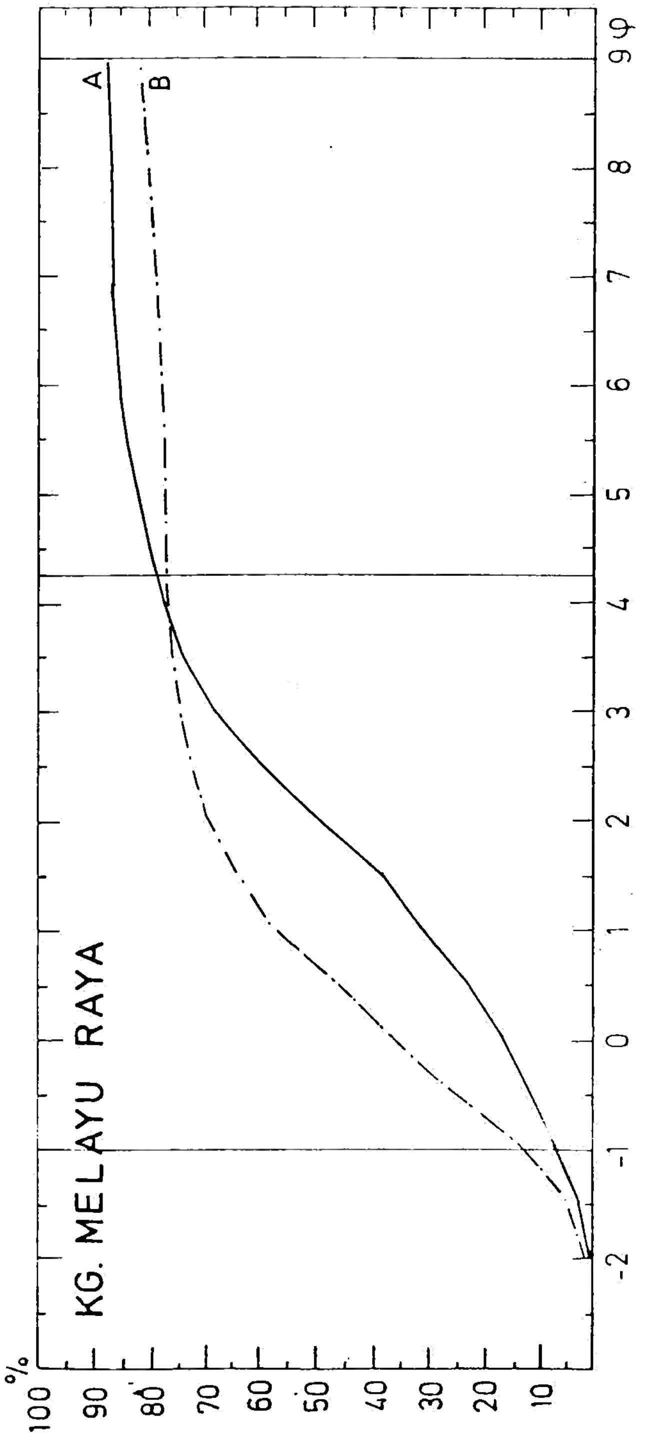

Fig. 66. — Particle size distribution curves referring to figure 65.

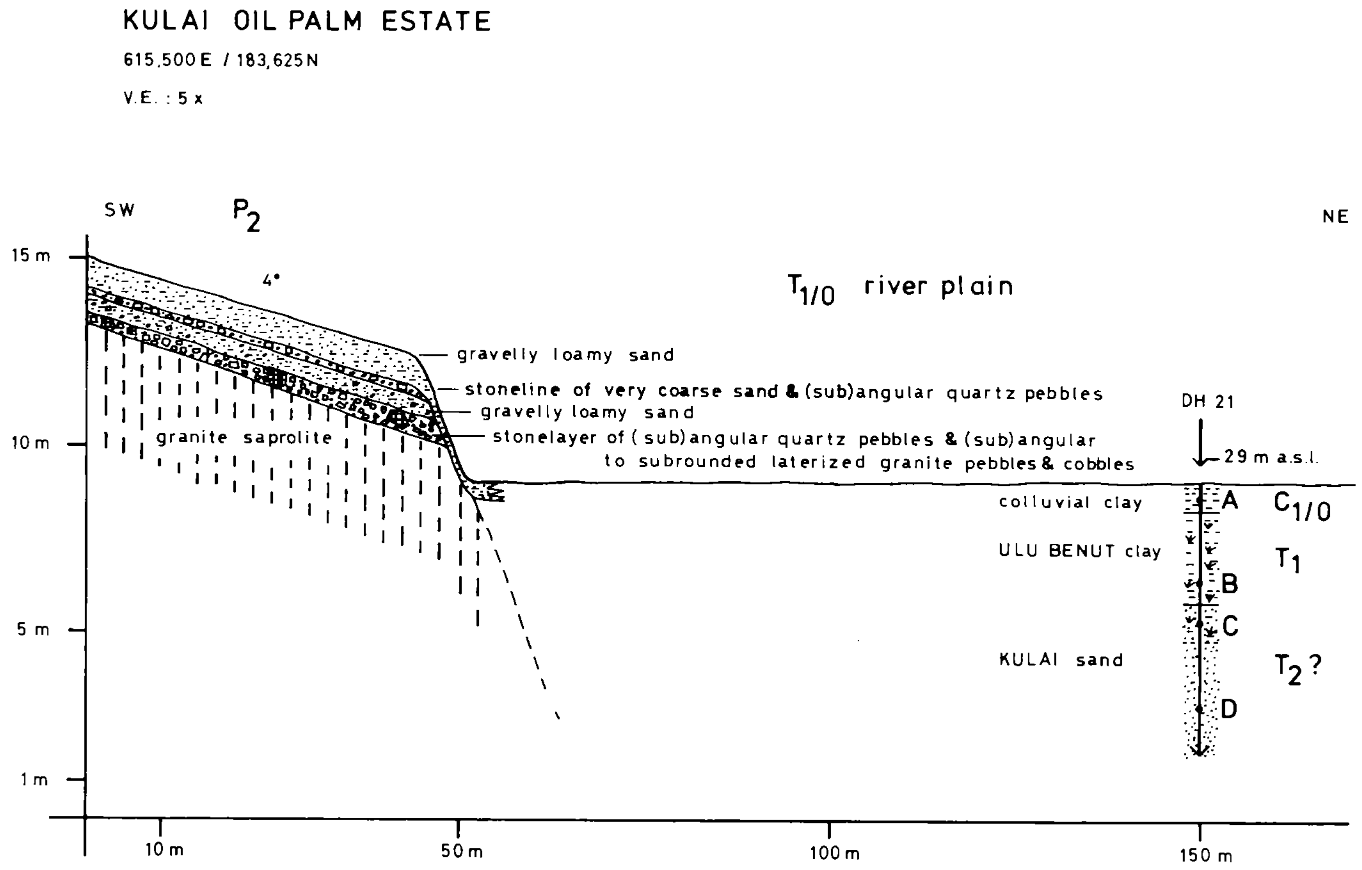

Fig. 67. — Section in the Kulai Oil Palm Estate (Johor Bahru). A, B, C and D refer to the particle size distribution curves on figure 68.

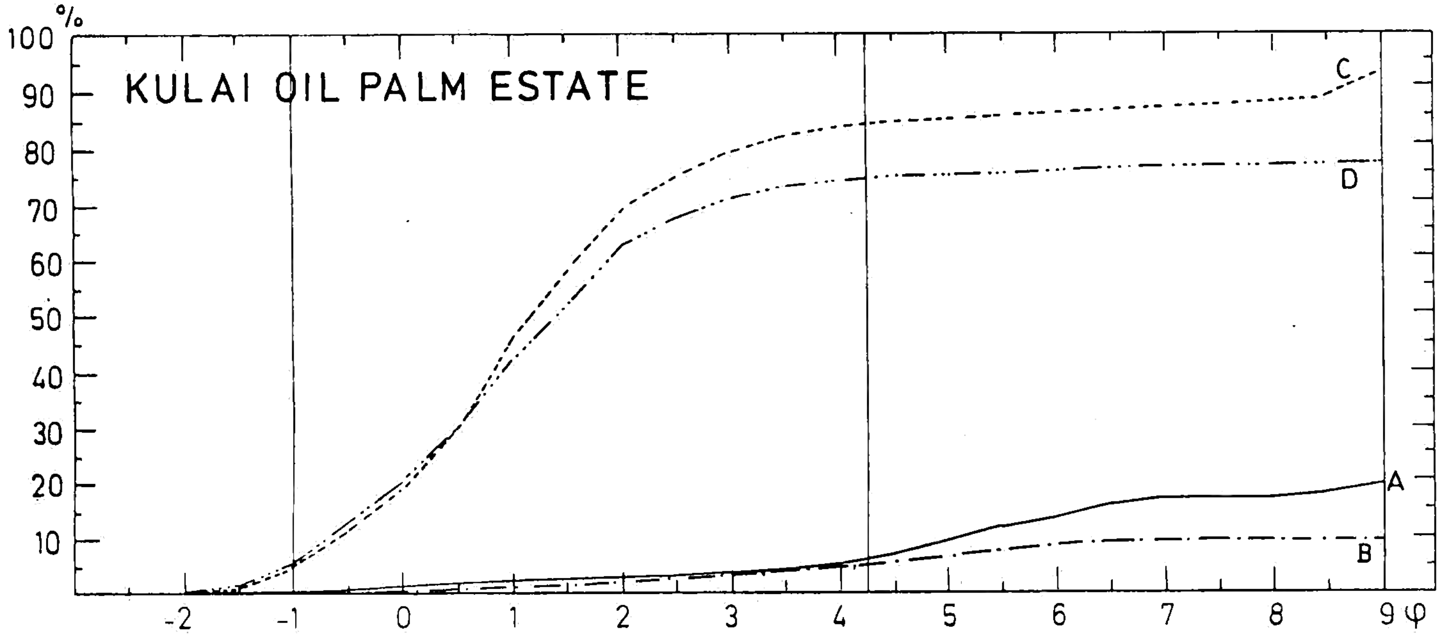

Fig. 68. — Particle size distribution curves referring to figure 67.

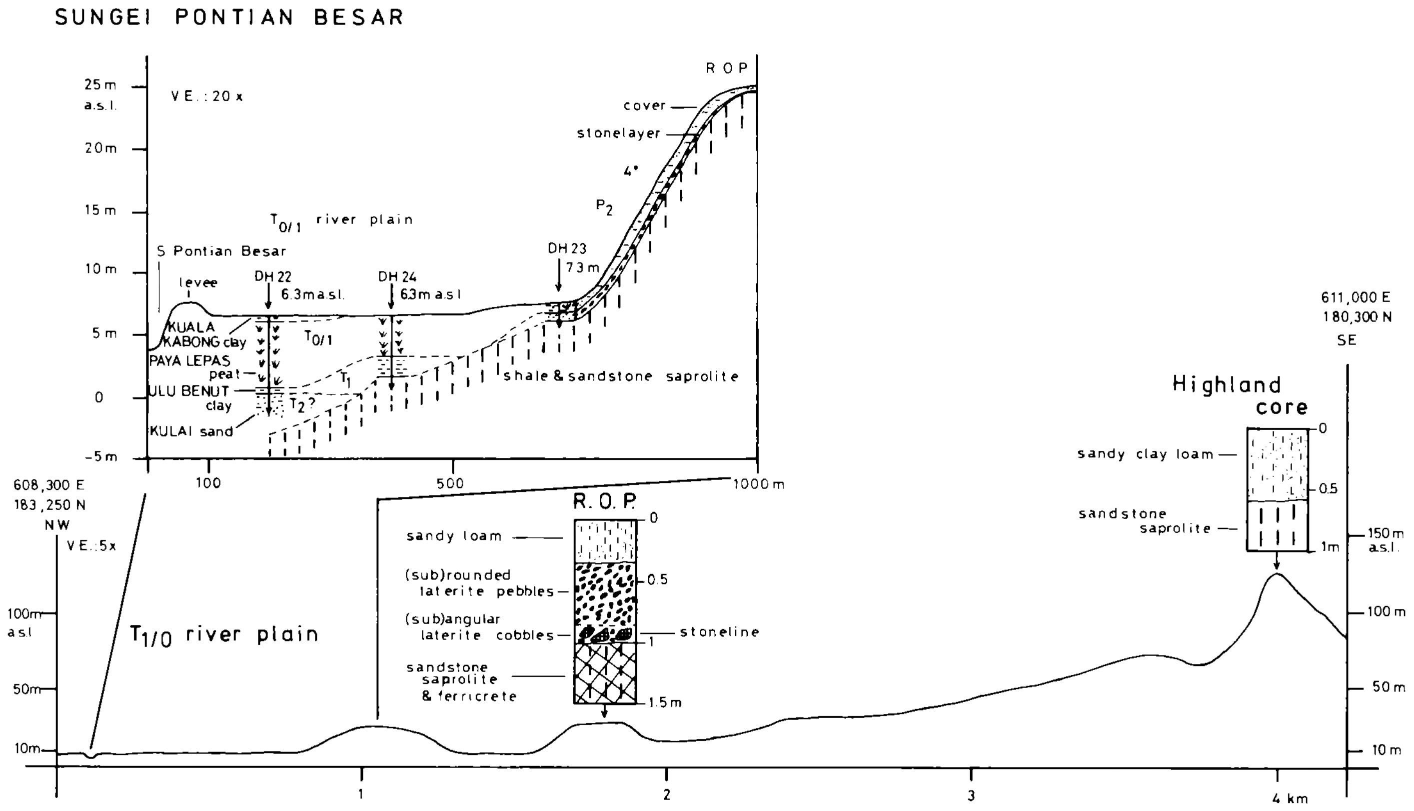

Fig. 69. — Section in the plain of the S. Pontian Besar (Johor Bahru).

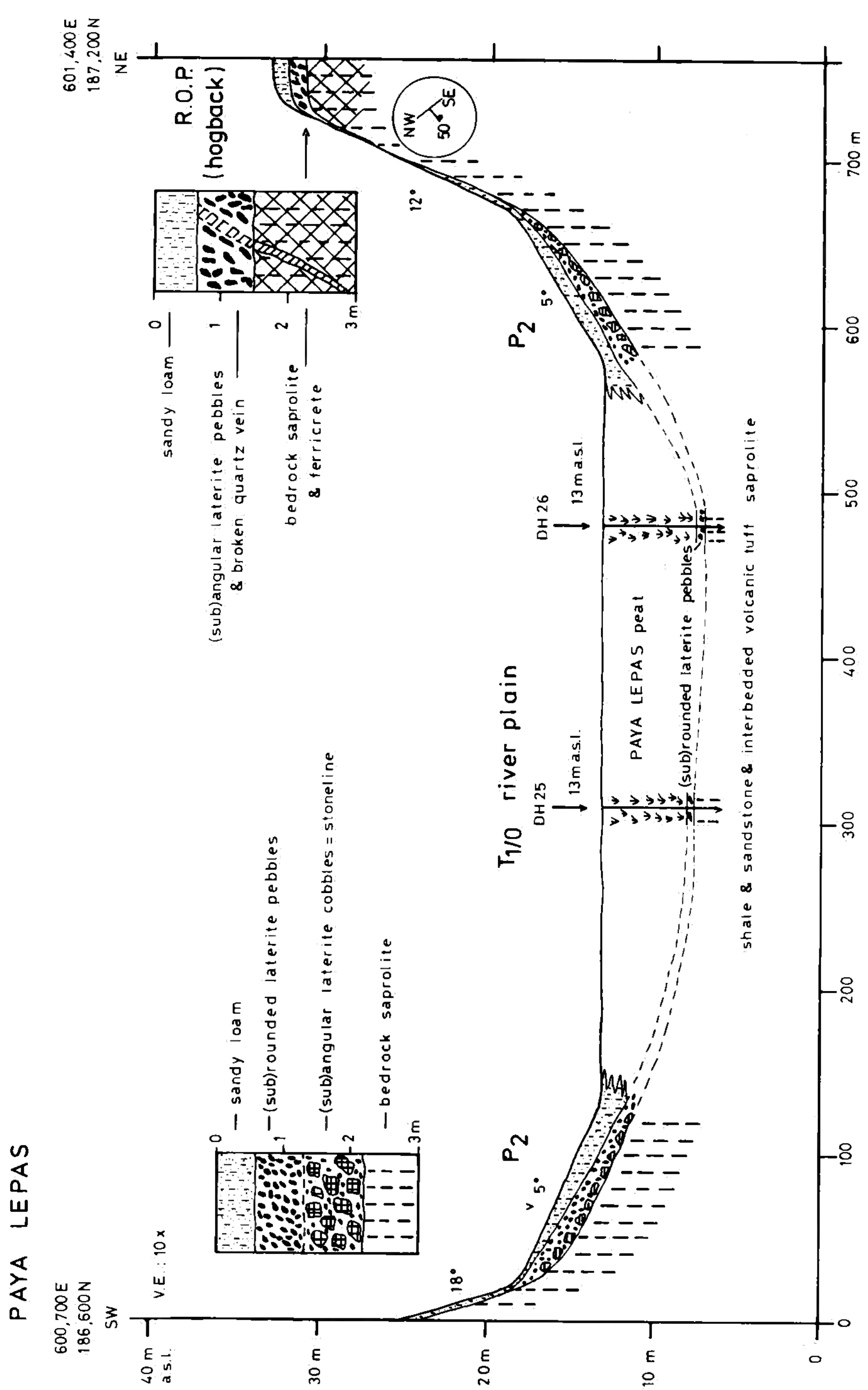

Fig. 70. — Section in the Paya Lepas area (Johor Bahru).

Close to the pediments the T_1-surface is often covered by a veneer of colluvial clay whose thickness rarely exceeds 1 m.

The T_0-channels are narrow and hardly incised (up to 20 m wide and 3 m deep). Beyond the sandy levees a thin layer (thickness up to 1.5 m but mostly below 0.5 m) of floodbasin silts and clays, the Kuala Kabong-clay member, is deposited on top of the T_1-surface. As the present-day floodplain is not a distinct geomorphic feature it is often difficult to distinguish in the field between T_0 and T_1-deposits. Therefore only those deposits related to obviously recent processes are labelled T_0. It stands for reason that the Paya Lepas-peat is a diachronous member including T_1 and T_0 (Figs. 69 and 70).

3.2.4. Correlation

3.2.4.1. T_2- and T_1-terraces

It would be premature to make a detailed correlation of river terraces and their deposits for areas spread over a distance of 5° latitude, the more so since systematic investigations on the Quaternary of Peninsular Malaysia have not been completed (SUNTHARALINGAM 1984). It must however be possible to situate them in a general framework.

During the geomorphological and soil survey the presence of Quaternary volcanic ash deposits was established in the Padang Terap- and Kuala Pilah-test areas (DEBAVEYE *et al.* 1986 ; BOUCKAERT *et al.* 1989). In the Padang Terap area the ash deposits extend over 238 ha, scattered on both sides of the Padang Terap river between 6°17' N and 6°21' N (Fig. 71). This is so far the most northerly position of the ashes observed on the Peninsula. The observed thickness of the pyroclastic material is 1.2 m to more than 2 m. The ashes are exposed in closed depressions on top of the T_2-terrace and on the transition to the lowermost pediment segments (Fig. 72). The ashes never cover the T_1-surface and near Kuala Nerang they are even locally covered by a veneer of recent alluvium without soil profile development. In the Kuala Pilah-area volcanic ashes were found in several soil pits in the Juasseh-plain (Fig. 51). The ash layer is always located on top of the T_2-terrace and has a thickness of about 0.5 m. The extension is difficult to assess as in most cases, the ash layer is covered by a veneer of recent colluvial clay (thickness up to 0.8 m). As it is the case in Padang Terap, the ashes were never found on the T_1-terrace.

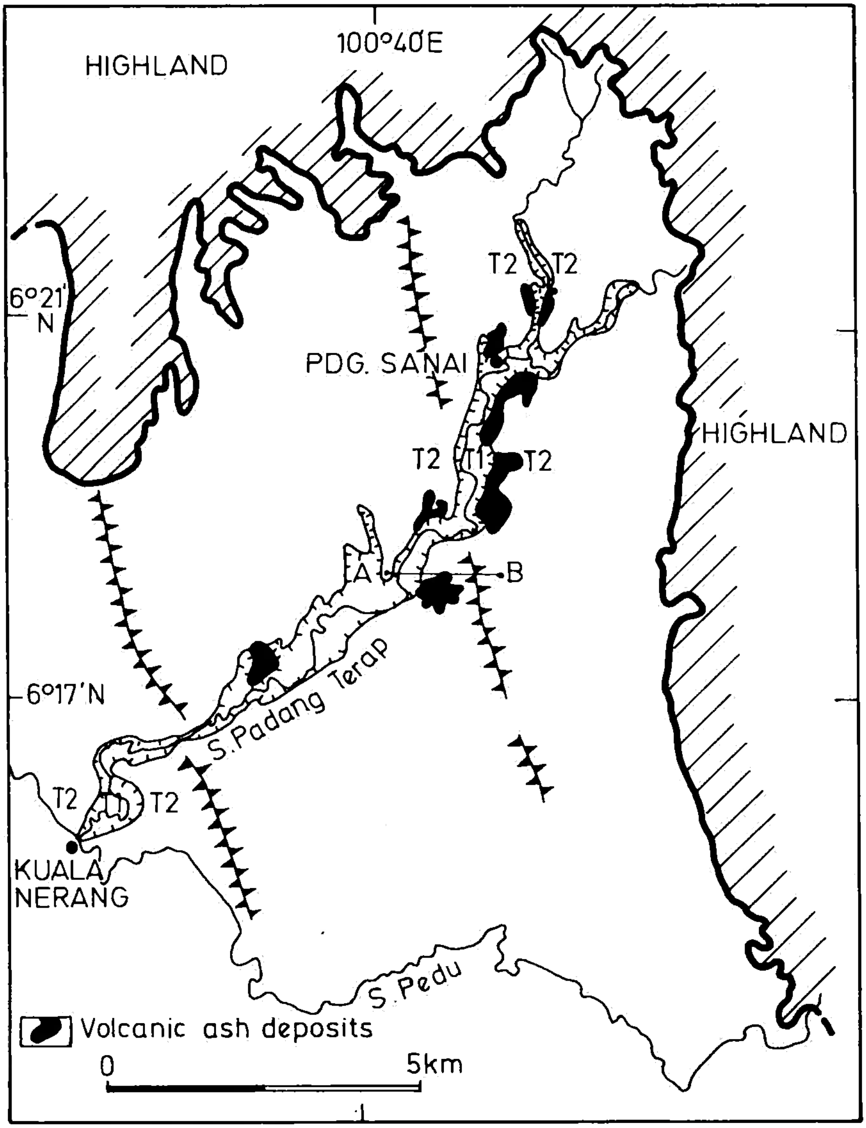

Fig. 71. — Location of volcanic ash deposits in the Padang Terap-test area.

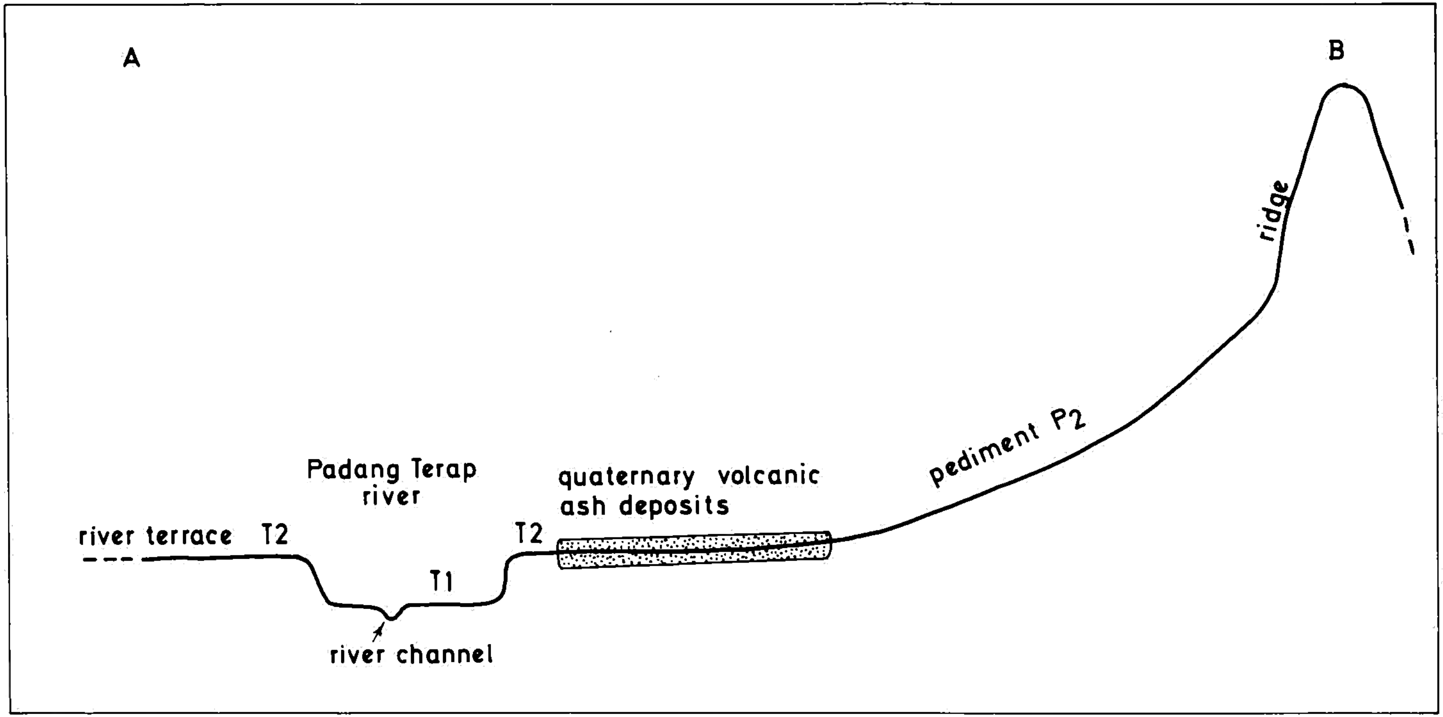

Fig. 72. — Geomorphological position of the volcanic ash deposits in the Padang Terap-test area.

Electronprobe X-ray microanalyses on glass shards proved that the ashes in both areas are identical and that they originate from an explosion of the Toba volcanoe in N-Sumatra. For those reasons they may serve as an important marker horizon.

Similar Quaternary ash deposits have been reported for several other areas in Peninsular Malaysia. The ashes were observed in Perak (SCRIVENOR 1930, WILBOURN 1938, STAUFFER 1970), West Pahang (RICHARDSON 1939, ALEXANDER 1968) and Selangor (STAUFFER 1971, 1973b, STAUFFER & BATCHELOR 1978). For all these areas it was postulated that the pyroclastics originated from the Toba and were mingled with local detrital material prior to final deposition.

The T_1-deposits of the Padang Terap- and Johor Bahru-areas may be correlated, as in both cases they gradually connect with the coastal plain deposits.

The geomorphic position of the terraces in the three test areas, the correlation of the T_2-surfaces in the Padang Terap- and Kuala Pilah-areas by the presence of volcanic ashes and the correlation of the T_1-surfaces in the Padang Terap- and Johor Bahru-areas, make it plausible that fot all test areas T_2 and T_1 are equivalent and belong to the same geomorphic generation.

The T_2- and T_1-deposits may be equivalent to the Kinta valley "Old Alluvium" and "Young Alluvium" of Walker (1955) respectively.

The T_2- and T_1-deposits in the Johor Bahru-area are part of BURTON'S (1973) "Recent and Sub-Recent Alluvium". Burton recognizes a sandy and a clayey facies and states that the bulk of the sand is quite coarse and angular and thas been derived from granite. The sandy facies in general lacks stratification, being well-bedded in only a few places. The sandy alluvium in Johor is aggraded to a maximum elevation very slithtly above the 50-foot contour level. This corresponds to the observations on the position of the Melayu Raya-sand member (Fig. 65).

For the Johor Bahru-area a correlation may also be made with the stratigraphy of the coastal plain deposits of Taiping and Beruas in Perak (SUNTHARALINGAM & TEOH 1977, SUNTHARALINGAM 1985). The Melayu Raya- and probably the Kulai-sand members are very similar to the Lower sand member of the Simpang Formation. The Ulu Benut-clay, Jeram Batu-clay, Kuala Kabong-clay and Paya Lepas-peat members are similar to the Beruas Formation consisting of fluviatile-estuarine-lacustrine deposits overlying the Simpang Formation. The Pontian Kechil-clay member is equivalent to the Gula Formation that covers the nearly continuous stretch of marine sediments that are present in the coastal plain of Peninsular Malaysia.

3.2.4.2. Pediments and river terraces

In all three test areas a gradual transition from the lower segments of the pediments in the T_2-surface was observed. The stonelayer, the bulk of which is composed of laterite gravel, gradually interfingers with coarse alluvial deposits almost exclusively composed of quartz (e.g. Kg. Kuala Tekai, Fig. 43). The fact that practically no laterite gravel is found in the alluvium, corroborates the local origin of the stonelayer material that was only transported over short distances.

For Johor, Swan (1970a) recognizes three types of pediments, all of which were observed in the Johor Bahru-test area. Undissected pediments occur on the northwest flank of Gunong Pulai, where they gradually merge with the T_2-surface. A convex slope break or toe separates the pediment from the clay plain or T_1-surface (Fig. 21). Pediments that enter directly in contact with the T_1-surface are commonly dissected by abrupt gullies, 1 m to 8 m in depth and up to 30 m in width, that have eroded headwards from the toe of the pediment. In some cases the pediment is partially buried as a result of aggradation by alluvio-organic or beach material (e.g. Paya Lepas, Fig. 70).

From the above sketched picture it can be concluded that the pediments are older than the T_1-surface and that at least their lower segments fit with the T_2-surface in one single landform generation ; therefore they are labelled P_2.

The shallow depressions in the interridge-compartments of the Padang Terap-area form the extension of the T_2-surface and are therefore labelled D_2. The fact however that parts of P_2 may be surrounded at all sides and isolated by D_2 (Fig. 48) shows that the depressions were active forms even after the formation of the T_2-P_2-complex. Their irregular dambo-like planform and the presence of a stoneline of laterite gravel suggest that lateral and headwards widening were the main processes of evolution.

3.3. Low hills

The pediments are developed at the foot of highland cores or at the foot of low hills that are in relation to the highland cores (Fig. 20).

In most cases the low hills show a topflat, almost circular in planform and with a restricted diameter of some 200 m in average. The topflats grade over a narrow crest-slope into a gently curving to rectilinear mid-slope with slope inclinations between 15° and 25° (e.g. Bukit Kanni, Fig. 76). A nick marks the transition of the mid-slope to the pediment.

In the Kuala Pilah- and Johor Bahru-test areas, the low hills form a dense complex (Figs. 15 and 18). The hilltops are interconnected by rather unpronounced windgaps. The altitudes of adjacent tops are remarkably similar and fit in surfaces very gently sloping from highland cores towards the main riverplains (Figs. 69, 73, 75, 76). In

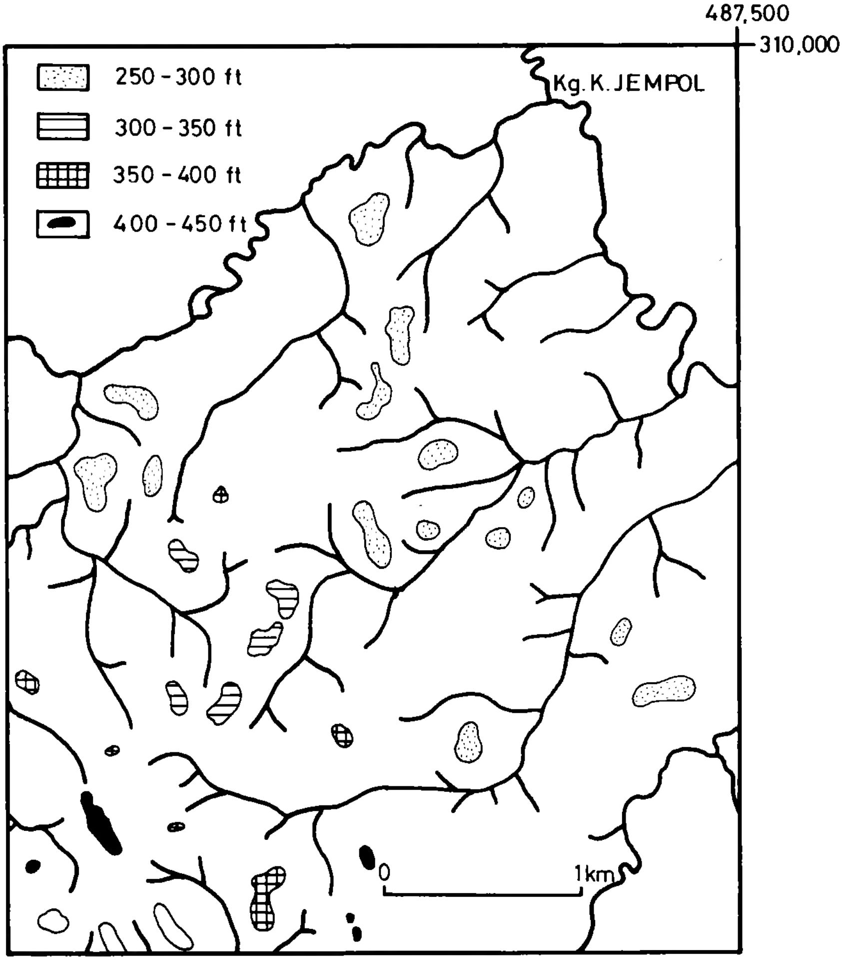

Fig. 73. — Distribution of the low hills in a representative area of the Kuala Pilah-test area (as derived from contours with 50 feet interval on the 1/63,360 topographic map).

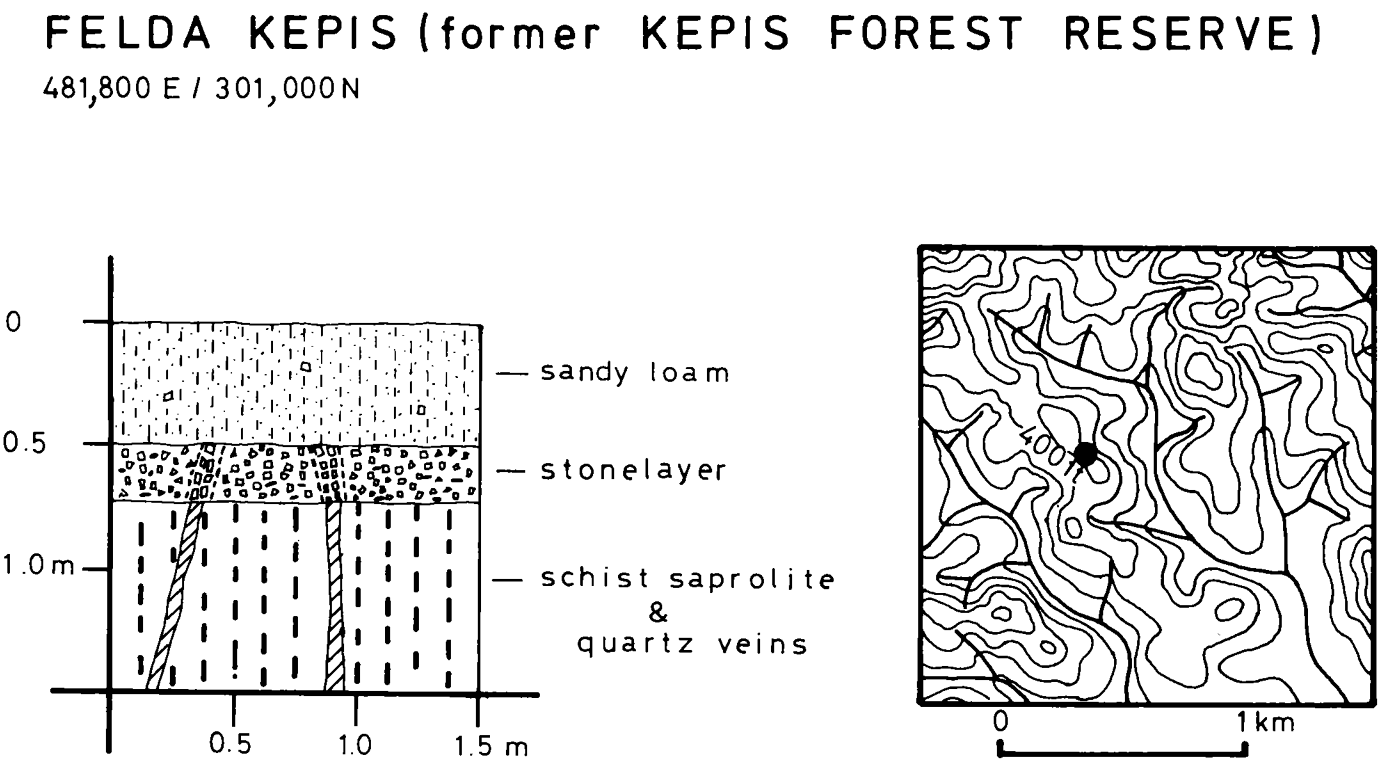

Fig. 74. — Section of a low hill topflat in FELDA Kepis (Kuala Pilah).

the Padang Terap-area the number of low hills is rather low ; they commonly occur in the central parts of the interridge-compartment (Fig. 12).

Observations in soil pits show that the build-up of the superficial layers on the topflats is very similar to the one on the pediments. The cover material shows a very close relationship to the underlying saprolite and the bulk of the stone-layer is composed of laterite gravel. In some cases the cover is very thin and patches of stone-layer material are exposed at the surface. Indications for an allochthonous as well as for an autochthonous origin are present : stone-lines (e.g. Sungei Pontian Besar, Fig. 69) and rock features continuing into the stone-layer (e.g. Felda Kepis, Fig. 74) were observed. In the Kuala Pilah-area (Sungei Sabaling Estate, E of Bahau) orientation dependent stone-layer undulations were observed in long sections ; they possibly testify to slope pedimentation (Fig. 75). In the same sections thin sandstone

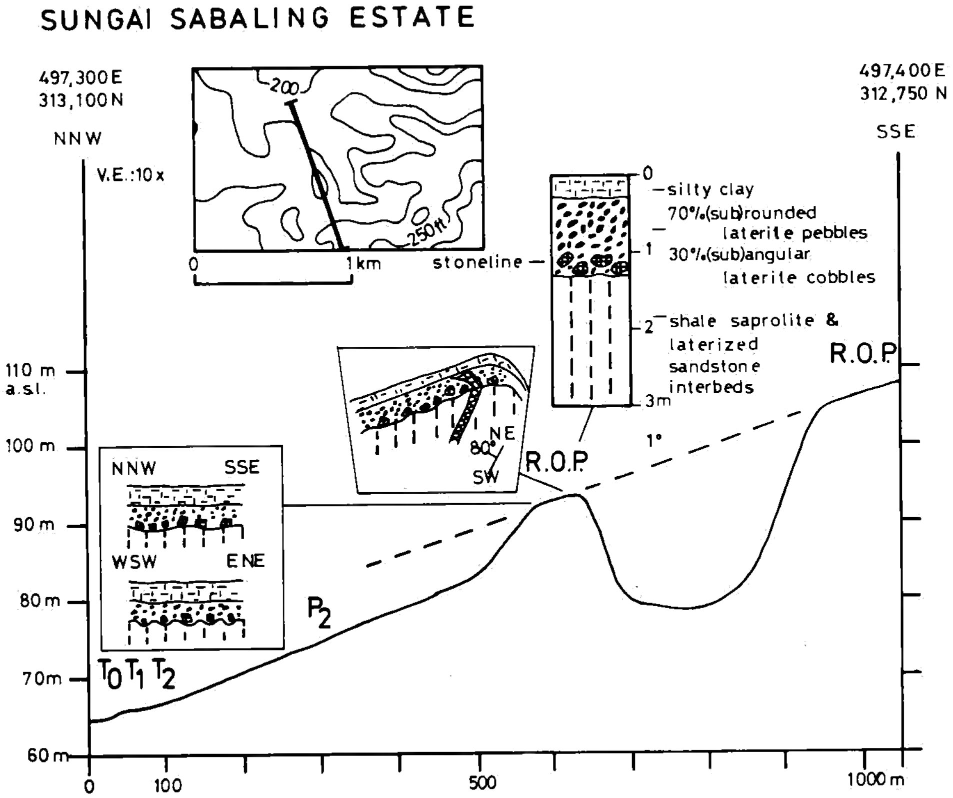

Fig. 75. — Section of low hills in the Sungei Sabaling Estate (Kuala Pilah).

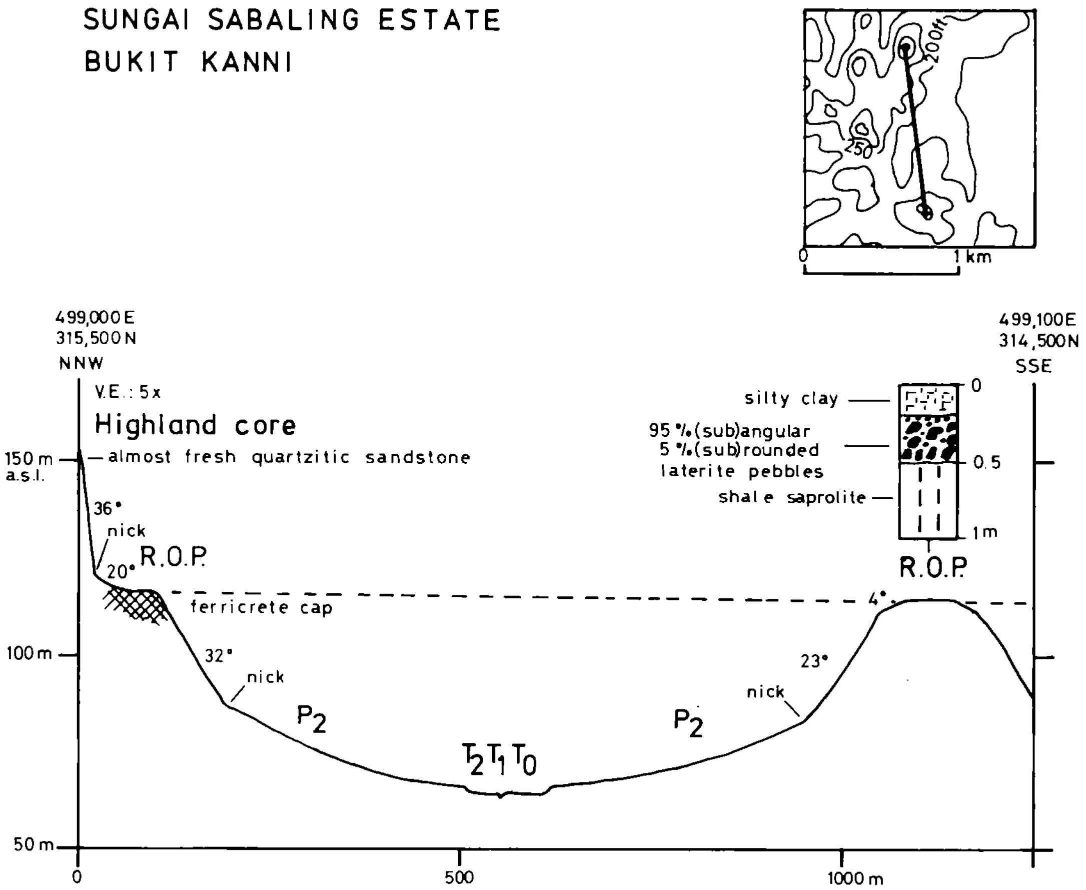

Fig. 76. — Section of low hills developed at the foot of Bukit Kanni (Kuala Pilah).

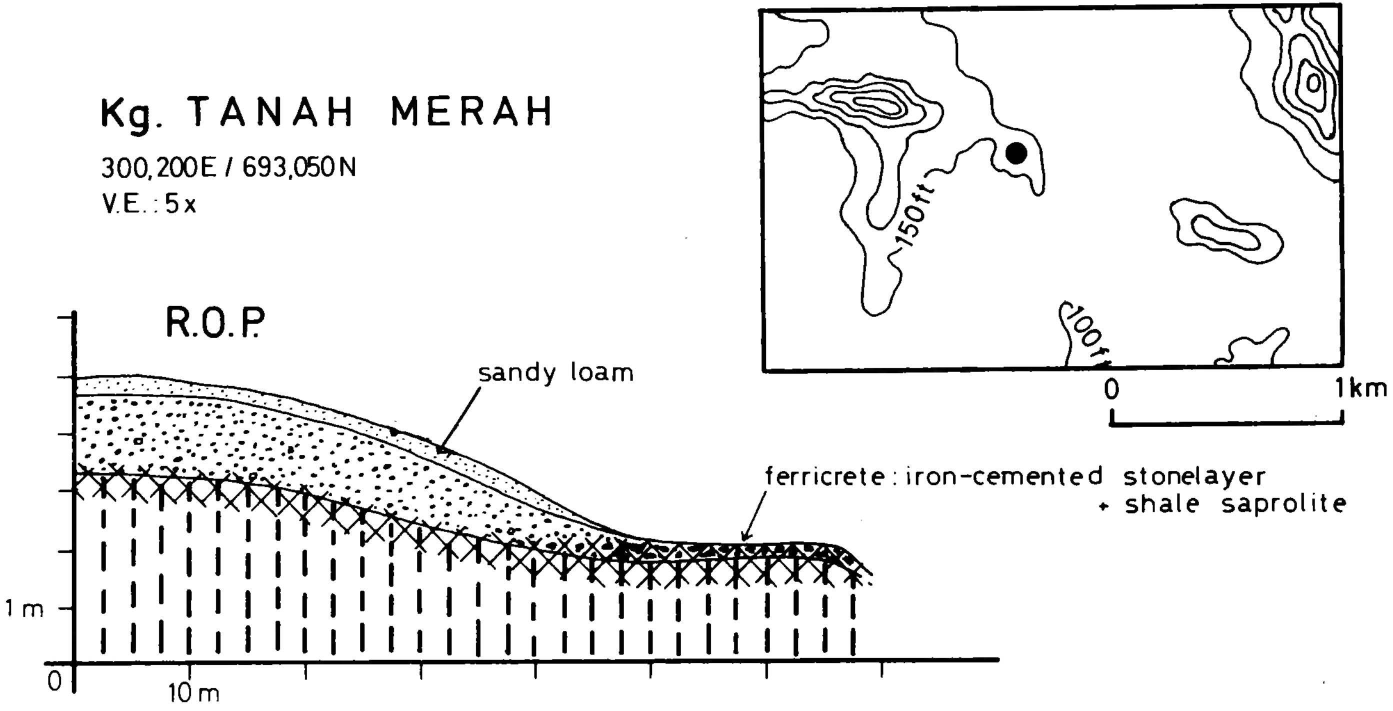

Fig. 77. — Section of a low hill near Kg. Tanah Merah (Padang Terap).

beds at the rim of the topflat were found to bend in a direction towards the riverplain and opposite to their own dip and to the adjacent mid-slope. Such feature can only be explained by soil creep on long continuous slopes. It shows that the low hills most probably were part of a single surface developed at the foot of the highland cores and sloping towards the main drainage lines. On Bukit Kanni (Fig. 76) the nick that marks the contact between the low hill-surface and the highland core was conserved by the development of a ferricrete cap.

In the Padang Terap-area most of the low hills show ferricrete caps developed at their rim (e.g. Kg. Tanah Merah, Fig. 77). Those low hills most probably are the remnants of the lower segments of pediments developed at the foot of the ridges. After incision (D_2), the older pediments were consumed by development of the younger pediments (P_2) and only the lowermost central parts of the interridge-compartment, with maximum sesquioxide accumulation, were conserved (Fig. 78). A detailed study of the laterite gravel in the low hill's

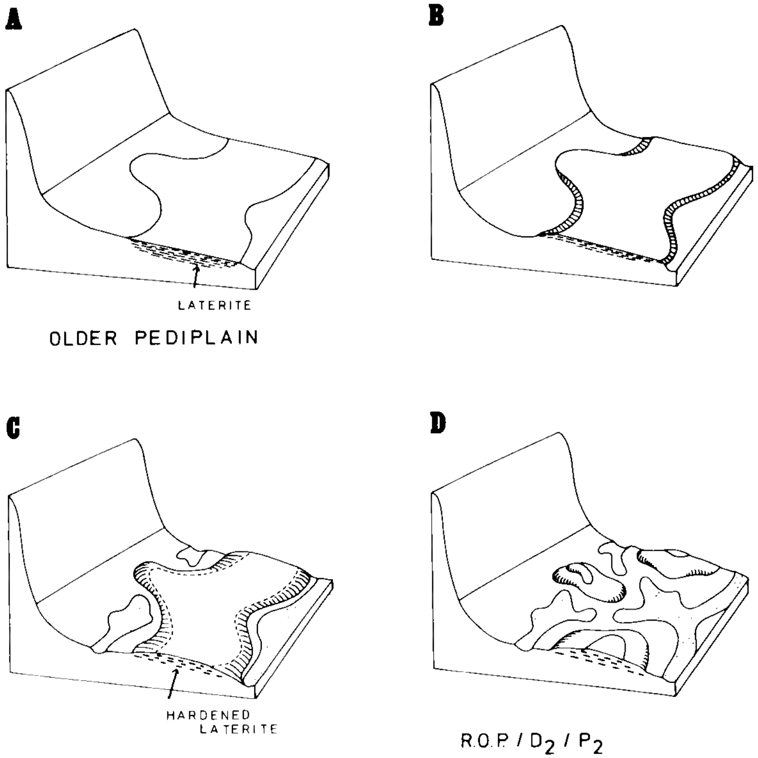

Fig. 78. – Geomorphological evolution of an Older Pediplain in the Padang Terap-test area (after De Dapper & Debaveye 1985).

stone-layer provided indications for at least two generations of low hills in the Padang Terap-area (DE DAPPER & DEBAVEYE 1984, DEBAVEYE & DE DAPPER 1987).

From the observations sketched above, the conclusion can be drawn that the low hills are remnants of (an) older peneplain(s): R.O.P. That peneplain was most probably a pediplain developed at the foot of highland cores.

3.4. Discussion

It is now generally accepted that most of the landforms of the tropics just as those from high-latitude regions, are relict landscapes altered by the impact of younger land formation processes.

The concept of alternating stable and unstable morphogenic phases was already established by ERHART in 1955. During unstable phases, or phases of rhexistasy, landforms are shaped and erosion and deposition is the predominant process. During stable phases, or phases of biostasy, weathering and soil formation are predominant.

Several factors may cause morphogenic unstability and lead to changes in the balance of erosion and deposition of a drainage basin (BUTZER 1976):

1. Available relief may change through slow but protracted tectonic deformation.
2. More rapid but no less effective are the changes in available relief that can affect the terminus of a stream: in most cases fluctuation in the sealevel. The resulting readjustments of the stream channel mainly affect the lower floodplain but are gradually transmitted upstream.
3. Changes in climate and vegetation cover affect interfluves, hillslopes and rivers and lead to changes of slope erodibility and rainfall erosivity resulting in changes of amount, rate or annual distribution of surface runoff and stream discharge.

It is very likely that tectonic deformations are only expressed on a regional scale since no major tectonic events took place in the Cenozoic of Peninsular Malaysia.

For ROHDENBURG (1970) in the course of the Quaternary, all climatic zones of the world were marked by an alternation of periods of morphodynamic activity with extensive slope erosion and periods of morphodynamic stability with soil formation. The Holocene is a period of morphodynamic stability owing to overdense vegetation in areas of abundant rainfall and insufficient or too evenly distributed rainfall in areas with reduced vegetation. The conditions of activity prevailing in tropical areas during the Pleistocene are due to changes in rainfall distribution since only this can explain both a less dense vegetation and a substantially increased ratio of surface runoff. Following Rohdenburg the question as to whether changes in rainfall distribution also involved a change in the absolute rainfall amount, is only of secondary importance. Therefore it is better to replace the classical pluvial-interpluvial concept for the tropics by an activity-stability concept.

Most geomorphologists working in Peninsular Malaysia do not accept that Quaternary climatic changes have affected the Peninsula. For DOUGLAS (1969), West-Malaysia belongs to the inner core of the humid tropics. The particular geomorphological interest of that area is that it is one of the few morphoclimatic zones where the present landforms are believed to result from the action of geomorphological processes of similar nature and intensity to those found at the present day, without forms inherited from different climates in the past. SWAN (1972) states that Johor is a region "where evergreen rainforest has been the climax vegetation since late Mesozoic times" (p. 161). For MORGAN (1973) "it seems probable that the slope and soil features of the study areas (in Selangor and Negeri Sembilan) reflect the present processes operative in the landscape and that the landforms (...) are uncomplicated by the presence of dissected surface remnants » (p. 143).

VERSTAPPEN (1974, 1980) postulates however that climatic variations of great magnitude have occurred in SE Asia during the Quaternary when Glacial and Interglacial periods alternated at higher latitudes. Three factors have exerted a great influence on the climatic conditions of the past in SE Asia. Since most of the precipitation in SE Asia is associated with the Inter-Tropical Convergence Zone, marked changes in the distributional pattern of the rainfall must have occurred, when during the Glacials, the anticyclones over Asia and Australia were more strongly developed than at present. The worldwide drop in air and sea water temperature is a second factor, which caused a lowering of the snowline and the forest-line and affected the altitudinal zoning of vegetation in the area. That postulate is corroborated, amongst others, by FLENLEY (1979). A third factor is the emergence of both the Sunda and the Sahul shelves during the Glacials due to the lowering in sea level (Fig. 79). The increased continentality

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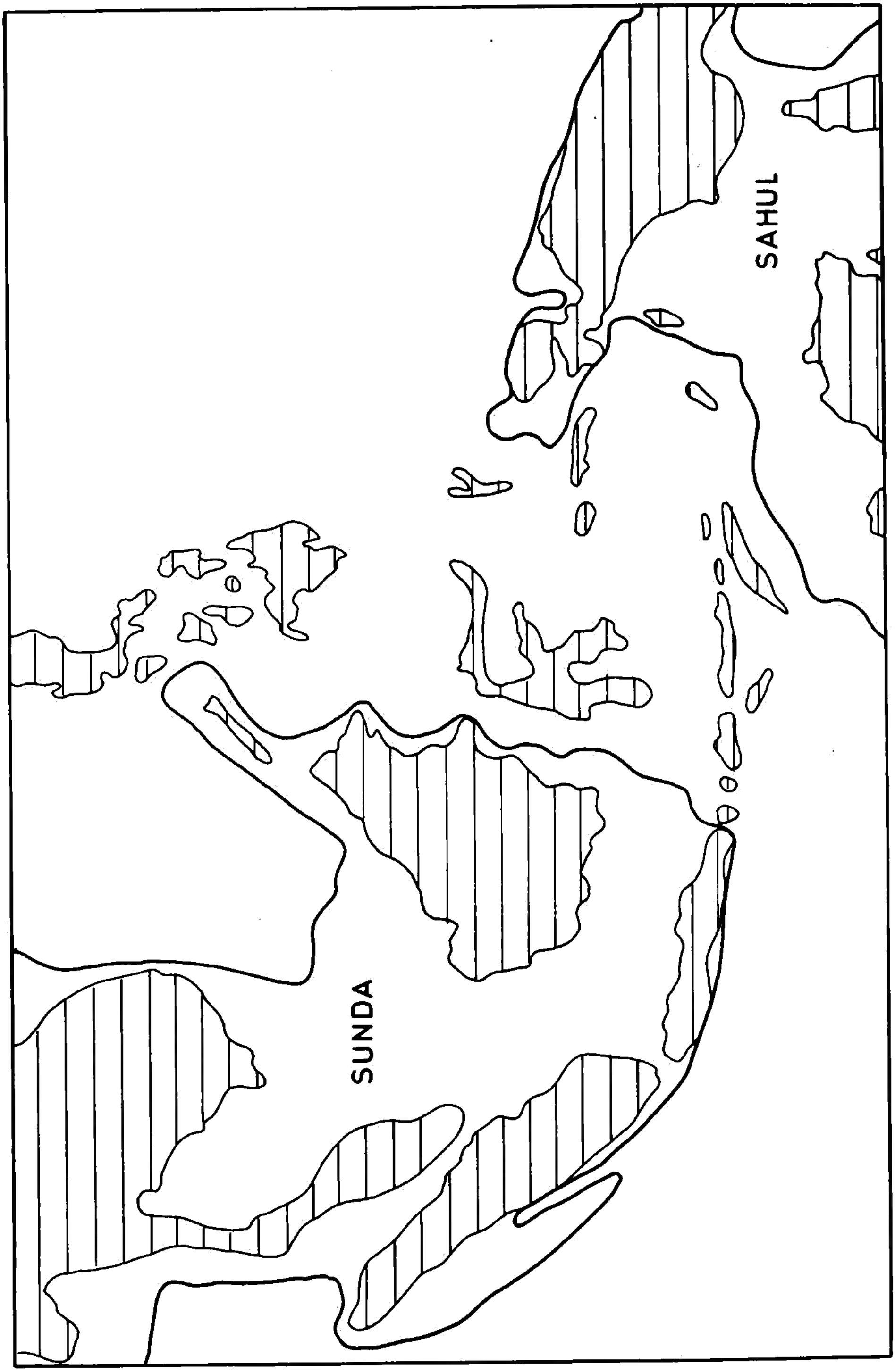
Fig. 79. - Map of the extension of the Sunda and Sahul shelves (after VERSTAPPEN 1974).


SUNDA
SAHUL

may have caused increased dryness, particularly in lowland areas. As a result of those changes drier conditions with lower precipitation values and a longer dry season prevailed in Malesia (Malaysia and Indonesia) during the Glacials.

It stands for reason that the slope pedimentation process that was operating on the footslopes, could not take place under the dense forest cover that prevails at present-day. Slope pedimentation issuing from gullies requires a sparse vegetation cover but combined with a considerable surface runoff. Such a slope environment may point to a climatic shift marked by a longer and pronounced dry season and concentration of the precipitation. The question as to whether the annual amount of rainfall was lower (cf. VERSTAPPEN) is indeed of minor relevance to the matter (cf. ROHDENBURG). The transition from a dense forest cover to a more open vegetation will lead to morphogenic unstability because both landscape and vegetation are not adapted to the processes operating. As a result phases of morphodynamic activity (*sensu* ROHDENBURG 1970) or rhexistasy (*sensu* ERHART 1955) will be ushered in. It is very probable that the unstable phases were much shorter than the stable phases as they only represent an adapting response to a disturbance of the latter balanced ones.

Such an environment with less protected slopes could also account for the marked presence of coarse grained lithostratigraphic members in the T_2-alluvia of these areas where the bedrock provides coarse saprolites. This is the case for the Kuala Pilah and Johor Bahru-test areas where important parts of the drainage basins are underlain by granitic rocks.

The clayey nature of the bulk of the T_1-deposits and of the local colluvium deposited at the foot of the pediments could point to a restauration of the dense forest cover, leading to well protected slopes whereon lateral clay eluviation is the predominant process. The coarse sandy and fine gravelly members at the base of the T_1-alluvium can be partly explained by reworking of the T_2-deposits after incision of the T_1-bed. Part of it can also be explained by extension of the T_1-incision into slopes still under an open vegetation cover.

For the Kuala Pilah-area the presence of the Chachar-clay member, intercalated between the sandy Jempol and Tebat members, may testify to the existence of at least two phases marked by sparse vegetation and separated by a dense forest phase during the aggradation of the T_2-floodplain. Inferring climate from alluvium on such a local scale is hazardous however since river deposition is often strongly time-transgressive and may depend upon local geomorphic tresholds.

The geomorphic evidence for a dry climatic shift is conflicting with the work of Swan and Morgan. For SWAN (1970a) the piedmont slopes in Johor are the humid tropical equivalent of the pediments of drier environments. The pediments evolved under an undisturbed dense forest cover and originated from inward weathering and backwearing of steep slopes. The piedmont slope itself is lowered by evacuation of silty and clayey material of sheet wash erosion and lateral physical and chemical eluviation. MORGAN (1973) explains the shaping of piedmont slopes in Selangor and Negeri Sembilan by similar processes operating under undisturbed dense forest. The evacuation of fine material takes place largely by subsurface wash and throughflow. For Morgan however slope evolution occurs by slope replacement which takes place mainly by downwearing of the basal and piedmont slopes rather than by inward weathering of the maximum slope segment.

The observations in the Kuala Pilah- and Johor Bahru-areas show however that at least part of the pediment evolution took place under a less dense vegetation cover. The fact that the piedmont slopes are partly inherited from a drier climatic phase, invalidates the application of the monocyclic concept of humid tropical pedimentation for Peninsular Malaysia.

Possible retorts to the objections are the fact that Morgan limited his study to soil samples at 30-45 cm depth and overlooked the importance of the stone-layer and the fact that Swan did most of his field investigations on slopes developed in granite where it is difficult to differentiate between stone-layer and saprolite. A survey study at Kg. Kangkar Pulai, at the SE fringe of Gunong Pulai and situated just outside the Johor Bahru-test area, showed however that thin stone-layers are present in granite and may be recognized by the somewhat more rounded aspect of the angular grus (DE DAPPER 1984).

It is obvious that landform development also continues under a dense forest cover. In this respect Rohdenburg's model is too strict. Phases of morphodynamic activity are rather short periods during which soil development cannot cope with the accelerated stripping of the superficial layers, so that soil profiles are truncated. During phases of morphodynamic stability geomorphic slope processes are not halted but slowed down to a level whereby soil development keeps pace with the changes of the landform surface so that soil profiles are preserved.

However, the role of slope pedimentation in shaping pediments in Peninsular Malaysia ought not to be overemphasized. The process only lowers the pediment surface (cf. Morgan) and the partly autochthonous stone-layer on the upper middle segments proves that even the lowering is restricted in a saprolite with laterite development. If however the low hills are remnants of an older surface, than at least 10 m of material has to be stripped in order to reach the younger pediment level (e.g. Sungei Sabaling Estate, Fig. 75). The restricted thickness of the stone-layer, the fact that stone-layer material was hardly evacuated from the slopes and the limited activity of slope pedimentation on duricrusted saprolite, lead to the conclusion that the bulk of the stripped material was almost devoid of ironstone. In the case of fine-textured saprolites, e.g. those derived from shale, the material could be removed by the eluviation processes described by Swan and Morgan but by the slope pedimentation process *a fortiori*.

The presence of R.O.P. implies a major dissection of the landscape ; the presence of river terraces also testifies to repeated incision and aggradation of the river channels.

VERSTAPPEN (1974, 1980) postulates that a eustatic lowering in sea level did not result in incision of the river courses in Malaysia. As an objection against incision, he formulates the fact that the glacial extension of the lower river courses in the shelf areas had an extremely gentle gradient. Verstappen is rather inclined to generally link the incision, in areas that remained emerged, to the interglacial conditions marked by a dense forest cover. It is however difficult to explain the dissection of a major graded surface such as the Older Peneplain (Pediplain) without intervening lowering of the final base level. It is very reasonable that on the newly shaped hillslopes a sparse vegetation cover will promote denudation or a general surface erosion by sheetwash and rill and gully development, whereas a dense forest cover favours dissection.

Part of the terrace development may be explained by the dynamics of the rivers themselves. The fact, however, that the terraces can be correlated over the whole Peninsula, leads to the assumption that sea level changes also played an important role. In the lower valleys, sea level changes will have a direct effect on dissection and aggradation of alluvium as they are graded to the ultimate base level. The effect of 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 may be expected ; it can eventually be countered by a new sea level rise.

CHAPTER 4

GEOMORPHOCHRONOLOGY

Near Kg. Kangkar Pulai, just outside the Johor Bahru-test area, R.O.P. were found to be developed at the foot of highland cores, reaching elevations of 114 m and covered by unconsolidated boulderly deposits, described by BURTON (1973) as the Boulder Beds (a1) of the Older Alluvium Formation (DE DAPPER 1984). Consequently in that area the Older peneplain (Pediplain) is younger than the Older Alluvium deposits that are dominantly of early to middle pleistocene age (STAUFFER 1973).

As was already mentioned above, the volcanic ashes found in the Padang Terap- and Kuala Pilah-test areas originate from the Toba volcanoe in N-Sumatra. Here, according to NINKOVICH *et al.* (1978), NINKOVICH *et al.* (1978) and NINKOVICH (1979), a most spectacular eruption took place some 75,000 years ago and resulted in the so-called Toba Tuffs. According to these authors the deposits of that eruption are exposed not only in the northwesternmost part of Sumatra but they are also found in piston cores from the Bay of Bengal and on Peninsular Malaysia. STAUFFER *et al.* (1980) disagree with the hypothesis that the eruption of Toba, about 75,000 years ago, was a solitary event and present radiometric dating evidence for four or five great eruptions in the last 1.9 million years. They suggest an age of about 30,000 years for the most catastrophic eruption and show that the ash deposits found on the Peninsula may have been formed at that time. Recently ALDISS & GHAZALI (1984) gave geological evidence that the 30,000-year-old ashfall tuff erupted from a centre just north of the Toba depression and called it the Sibuatan Tuff.

Several radiocarbon determinations have been made of wood and peat from the Old Alluvium with which the T_2-deposits may be correlated. Those in Kinta (SIVAM 1968) proved to be beyond the range of the method (ages given as >39,900 years BP). Of three determinations of material from Sungei Besi in Selangor (AYOB 1970), two were similarly beyond the range of the method (ages given as >41,200 and >41,500 years BP, but a third sample yielded an age of 36,420 years BP. This sample was of woody stems, some apparently in upright growth position, from a level about 13 m a.s.l., within the upper half and probably the upper third of the alluvial section present. This dating would make the age at that point late pleistocene (STAUFFER 1973).

The effect of sealevel changes on the shorelines in West-Malaysia is well-documented (HAILE 1971, TJIA *et al.* 1972, TJIA 1975, TJIA *et al.* 1975, TJIA *et al.* 1976, TJIA *et al.* 1977). In a study of sealevel changes during the late Pleistocene and Holocene in the Strait of Malacca, GEYH *et al.* (1979) and STREIF (1979) provide C-14 dates from *in situ* roots and peat which indicate that the sealevel was lowered eustaticly to at least 40-60 m below the present level between 36,000 and 10,000 years BP. The sealevel rose from − 13 m to about + 5 m from 8,000 to 4,000 years BP and then approached its present level.

For the Johor Bahru-test area a palynological study of a shallow peat near Pekan Nanas, was done by HASELDONCKX (1977). The peat is part of the informal Paya Lepas-Peat member. The profile, 58 cm thick, starts on fluviatile sandy sediments, most probably the Kulai-sand member, and shows a succession from an open swamp vegetation with mangrove influence to a marginal peat swamp facies with river bank vegetation. A radiocarbon dating on the deepest peat sample yielded an age of 4,896 years BP. This date shows a good time correlation with the results of Streif.

The position of the volcanic ashes on top of the T_2-surface in the Padang Terap- and Kuala Pilah-test areas permits to situate the P_2-T_2 complex in a late pleistocene environment that was drier than the present-day one. In the Padang Terap-area the ashes are found in small closed depressions on T_2 and even on the lowermost parts of the P_2-pediments ; in the Kuala Pilah-area the ashes are covered by a veneer of local clayey colluvium. From these observations it may be assumed that at the time of deposition of the ashes the T_2-floodplain and the P_2-pediment were fully developed geomorphic surfaces but that the dense forest cover was most probably not yet restored.

The fact that the volcanic ashes are never found on top of the T_1-surface proves that the incision of the T_1-bed was contemporaneous or posterior to their deposition. The incision of the T_1-bed, leading to the conversion of the T_2-floodplain into a T_2-terrace, may be linked with the retarded effect of the low sealevel between 36,000 and 10,000 years BP. The effect of a restored dense forest cover could eventually add to the incision. The aggradation of the T_1-floodplain may be linked with the sealevel rise up to + 5 m from 8,000 to 4,000 years BP, whereas the elaboration of the T_1-terrace corresponds with the lowering of the sealevel to its present position.

In a palaeoecological study of Tasek Bera (Fig. 5), a huge inland swamp in southern Pahang, MORLEY (1981) states that the present configuration of the area is of fairly recent origin. The study, based on palynological investigations and radiocarbon datings shows a transition from a forested valley to a swamp that took place only 4,500 years ago. However, the stratigraphic studies at Tasek Bera were not sufficient to rule out the possibility of there being older sediments and it is also possible that the date may be underestimated by root contamination. According to Morley, the transition to swamp conditions was rapid and was caused by a reduction in gradient of the stream resulting from minor tilting of the area by tectonic movement. The capture of the Pahang headwaters by the Muar system that took place after formation of the T_2-surface in the Kuala Pilah-area may eventually be linked with the tilting. The fact however that the terminus of the Muar is closer to the shelf margin than it is the case for the terminus of the Pahang, may also offer a partial explanation for the more rapid headward extension of the Muar.

Apart from VERSTAPPEN'S (1974, 1980) postulates, relatively little is known about the Quaternary palaeoclimate and evolution of Malesia. More work has been done for the adjacent regions.

In a study on late quaternary environments in north-central India, WILLIAMS & CLARKE (1984) show a change from sparse vegetation and high sediment yields at glacial maximum (25,000 to ~ 17,000 years BP), to dense vegetation and low sediment yields during the warm and wet postglacial.

Based on geomorphological and pedological evidence, SPÄTH (1981) and GARDNER (1981) come to the conclusion that arid conditions prevailed around 20,000 – 25,000 years BP in the perhumid and semihumid parts of Sri Lanka and South India.

For northeastern Australia, WILLIAMS (1985) reports that rainfall was drastically reduced in the interval between about 80,000 and 20,000 BP. This long interval of aridity in tropical northeast Queensland probably reflects the impact of generally lower sealevels, leading to increased continentality, throughout the 60,000 or so years preceding the last glacial maximum.

As BOWEN (1985) states, inter-regional correlation of quaternary development histories is always difficult and it is especially the case for the low-latitudes where the general framework is still very fragmentary. Bowen also warns for force-fitting the pieces of the local jig-saw into preconceived pigeon-holed classifications.

Taking Bowen's remarks into account, one can nevertheless notice that the geomorphic evidence for drier climatic conditions during the late Pleistocene in Peninsular Malaysia, frames in the accumulating evidence of severe aridity throughout most of the tropical savanna and forest zones during the late Pleistocene (THOMAS 1978, STREET 1981 ; STREET & HARRISON 1984). WILLIAMS (1985) argues that glacial maxima during the Quaternary were reflected in cooler, drier and windier climates throughout much of the intertropical zone and proposes the term "intertropical ice-age aridity".

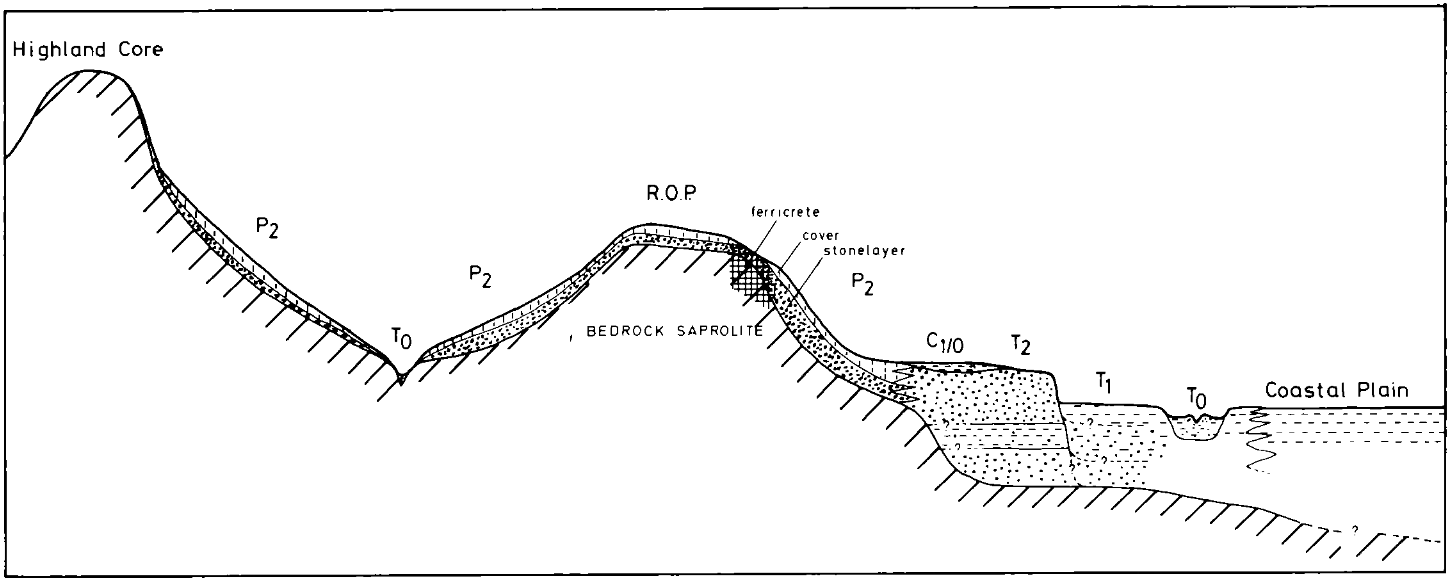


Fig. 80. — Chronosequence of landforms in the testareas.

PROCESSES		MORPHOGENIC PHASE	VEGETATION COVER	CLIMATIC PHASE	CONSERVED LANDFORMS & SUPERFICIAL LAYERS				CORRELATION & CHRONOLOGY	
INTERFLUVES & HILLSLOPES	RIVER VALLEYS & PLAINS				INTERFLUVES & HILLSLOPES	RIVER VALLEYS & PLAINS				
						PADANG TERAP	KUALA PILAH	JOHOR BAHRU		
Deep chemical weathering & soil development on Oldest Surface		STABLE	↓	↓	saprolite; granite grus				?	
Development of Older Peneplain(s) - Pediplain(s)		UNSTABLE (several phases ?)	DENSE OPEN	VERY WET DRIER	remnants of Oldest Surface = highland cores low hills-topflat-surface & pedisediments (stonelayer & cover)				MIDDLE	post-"Older Alluvium" (J.B.) Early to middle Pleistocene (Stauffer, 1973)
Deep chemical weathering & soil development on Older Peneplain(s) - Pediplain(s); laterite development on lower slopes		STABLE	↓	↓						
Dissection of Older Peneplain(s) - Pediplain(s)			↓	↓	low hills = R.O.P. ferricrete on crest-slopes	lay-out of drainage network grain			LATE PLEISTOCENE	
Slope pedimentation	Aggradation of T_2-surface	UNSTABLE	DENSE	VERY WET	younger pediments = P_2 & pedisediments (stonelayer & cover)	T_2-alluvium	T_2 - Jempol-sand - Chachar-clay (?) - Tebat-sand	T_2 - Melayu Raya-sand - Kulai-sand (?)		
Deep chemical weathering & soil development on P_2	↓ Soil development on T_2-surface	STABLE	OPEN ↓	DRIER ↓		T_2-surface				volcanic ash (P.T. & K.P.) 30,000 y BP (Stauffer et al. 1980) (Aldiss and Ghazali 1984)
	Incision of T_2-surface		↓	↓		T_2-terrace & T_1-channels				sealevel drop -40 m to -60 m between 36,000 y - 10,000 y BP (Geyh et al. 1979)
	Aggradation of T_1-surface		↓	↓	local clayey colluvium	T_1-alluvium	T_1-alluvium	T_1 - Kulai-sand - Ulu Benut/Jeram Batu/Pontian Kechil-clay	HOLOCENE	sealevel rise -13 m to + 5m between 8,000 y - 4,000 y BP (Geyh et al. 1979)
	↓		↓	↓			capturing of Pahang by Muar			Tasek Bera formation by minor tectonic tilting (K.P.) 4,500 y BP or somewhat older (Morley 1981)
	Soil development on T_1-surface		↓	↓				- Paya Lepas-peat		Pekan Nanas marginal peat swamp 4,896 y BP (Haseldonckx 1977)
	Incision of T_1-surface		DENSE	VERY WET		T_1-terrace & T_o-channel		T_o-Paya Lepas-peat -Kuala Kabong-clay		sealevel drop to present level (Geyh et al. 1979)

Table 5. — Tentative chronosequence of landforms related to geomorphic events and environmental changes.

CONCLUSIONS

In conclusion, following common chronosequence of landforms and morphogenic processes may be established, in decreasing order of age, for the three test areas (Table 5, Fig. 80):

1. Low hills, whose rims are often sustained by ferricrete caps, are remnants of an Older Peneplain (R.O.P.). The Older Peneplain was most probably a Pediplain, developed out of the Oldest Surface whose remnants are present in the landscape as cores of highland. For the Padang Terap-test area there is evidence that the Older Peneplain (Pediplain) groups at least two generations of geomorphic surfaces. In the Johor Bahru-testarea the Older Peneplain (Pediplain) is probably of middle pleistocene age.
2. A complex geomorphic surface comprises:
   - a rock-cut river terrace level (T_2),
   - younger pediments (P_2), developed at the feet of highland cores and R.O.P., and grading into T_2.

The superficial layers of the P_2 testify to extensive slope pedimentation under a fairly open vegetation. In granite terrains (Kuala Pilah- and Johor Bahru-test areas), the bulk of the T_2-alluvium is strikingly coarse and probably reflects a rather unprotected slope environment. In the Kuala Pilah-test area, the presence of the Chachar-clay member in the Juasseh-plain may testify to a wet climatic shift during the T_2-aggradation. Volcanic ashes found at the top of T_2 in the Padang Terap and Kuala Pilah-test areas, permit to situate the development of the complex in a late pleistocene environment that was most probably markedly drier than the one prevailing today.

3. Holocene T_1-terraces are cut-and-filled in or cover T_2. In the Padang Terap- and Johor Bahru-test areas, they grade into the coastal plain. For the Kuala Pilah-test area, part of the Pahang headwaters were captured by those of the Muar, probably during the T_1-aggradation. The incision of the T_2-surface may be linked to an important sealevel drop between 36,000 − 10,000 years BP. The

aggradation of the T_1-surface may be attributed to a sealevel rise between 8,000 y – 4,000 years BP. During the Holocene the dense forest cover was restored. The well-protected slope environment is reflected by the clayey nature of the bulk of the T_1-alluvia and of local colluvium (C1/0).

4. The present riversystem (T_0) is rock-cut or cut-and-filled in T_1 and exhibits an active morphology of riverbanks, levees and bakswamps. The T_0-incision may be linked to the drop of the sea to its present level since 4,000 years BP.

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APPENDIX

Particle size analysis

The texture of most of the samples was determined on the field and classified according to the U.S.D.A. texture triangle (FAO, 1977). If important, the presence of gravel (particle size >2 mm) was indicated in the description by a proper adjective.

As a control, representative samples were examined in the laboratory.

The elementary particles were dissociated according to the following procedure :

a) destruction of ligands due to sesquioxides with sodium dithionite ;
b) oxidation of the organic matter by hydrogen peroxide ;
c) dispersion with sodium hexametaphosphate.

The fractions larger than 50 µm were separated by sieving using a 0.5 phi interval up to -2 phi (4 mm).

The silt and clay fractions were analysed with a Micromeritics Sedigraph 5 000 ET. The method is based on the transmission properties of low energy X-rays in a suspension.

For some samples the organic carbon content (OC %) was determined as a measure for the amount of organic matter present. The organic matter is oxidized with $K_2Cr_2O_7$ in a solution of H_2SO_4. At the end of the oxidation, the excess $K_2Cr_2O_7$ is back titrated with a $Fe\ SO_4$ solution, during which the excess of $K_2Cr_2O_7$ is reduced into Cr^{+2} by Fe^{+2}.

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