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Lateritic soils of Peninsular Malaysia

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Abstract: The term 'laterite' was first introduced by Buchanan in 1807 to describe a variegated material which occurred in South India. This material when exposed hardens irreversibly. However, the terms 'laterite' and 'laterite soils', to-day have very varied definitions. In fact any red coloured material rich in iron-oxides has been described as 'laterite', resulting in a lot of confusion in the literature. In order to overcome this, new terms such as plinthite, petroplithite, pallid zone and iron-coated materials are defined as used by Soil Scientists.

Two types of 'lateritic soils' are found in Malaysia. Iron coated materials are formed by the intense weathering, leaching and accumulation of iron further down the weathering profile. Such ferruginous materials are often red coloured and retain their original rock structure at least in part. The second type of 'lateritic soils' found in Peninsular Malaysia consists of sub-rounded and rounded ferruginous gravels overlying the weathered saprolite often unconformably. These types of soils often form cappings on hills. The erosion of these materials and dissection of the landscape results in two distinct catenal relationships between the materials and erosion products. There is some disagreement among soil scientists as to the processes which gave rise to the resultant landscapes.

It is believed that, intensive tropical weathering during the Tertiary resulted in the formation of the reddish coloured soils with their iron-coated materials and their underlying plinthite (or laterite as defined by Buchanan). Subsequent dissection and erosion of the iron-coated materials gave rise to three geomorphic surfaces. These surfaces are probably related to the changes in sea-levels during the Pleistocene.

INTRODUCTION

Laterite and lateritic soils have been studied by both soil scientists and geologists. The soil scientists have been interested in the genesis of laterites and lateritic soils and their suitability for agriculture. The geologists on the other hand are interested in these because some laterites are closely related materials have economic values as ores of iron, aluminium and nickel. The different objectives of these studies on laterites and lateritic soils resulted in a wide variety of materials being called laterite and lateritic soils.

The term "laterite" was first introduced by Buchanan (1807) a geologist, as a name for a soft ferruginous material that was quarried in sothern India for building blocks. According to Buchanan, the rock hardened quickly to form material superior to good bricks in both strength and impermeability to water. A wide variety of materials have since been called 'laterite' and 'laterite soils' by many workers in many countries resulting in a great deal of disagreement about the range of materials to be covered by these terms with respect to composition, mode of formation and position in the landscape.

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It is generally agreed by most workers that laterite is a highly weathered material rich in secondary oxides of iron, aluminium or both. It is nearly devoid of bases and primary silicates, but it may contain large amounts of quartz and kaolinite. Although the original term 'laterite' of Buchanan was applied to the soft material which hardens on exposure, Harrison (1910) broadened the definition of laterite to include earthy, iron- and aluminium-rich materials that do not harden. To-day the term is also used to describe the hardened ironstone, concretions and gravels. Many published works on laterites exist. Prescott and Pendleton (1952), Sivasajasingham *et al.* (1962) and Alexander and Cady (1962) have reviewed the general principles, occurrences and the processes of formation. The mode of formation of laterite has been the subject of as many disagreements as its nature and composition. This is due to the diverse types of materials included under the term "laterite".

The objectives of this paper is to examine the types of "laterites" found in Peninsular Malaysia and to discuss their possible modes of formation.

DEFINITIONS

Like in many other countries, the terms "laterite" and "lateritic soils" have also been used rather loosely in Malaysia. This has resulted in a lot of confusion in the literature. Thus, before any discussion on the types of "laterites" and "lateritic soils" can be made, it is first necessary to define the terminology used in this paper. The terms used here were first proposed for use in Malaysia by Paramananthan and Tharmarajan (1980) and are currently used by soil scientists in this country.

(a) Iron-coated or Iron-indurated Parent Material

These are materials which have been indurated by iron. They are essentially *in-situ* and their bedding or rock structure is retained. Local movement such as soil creep may have taken place. Such materials are common over iron-rich rocks such as schists, amphibolite, basalt and andesite. On sedimentary and metamorphic rocks these materials tend to be platy while on igneous rocks they are often fine gravels. It is believed that these materials were formed by iron being released during weathering and coating the rock fragments. In the early stages of impregnation the rock texture is easily determined by breaking a piece. However, if the material is completely impregnated, then it becomes very difficult to determine the original parent rock. In deep roadcuttings however, these iron-coated materials can be traced to uncoated rocks.

(b) Pallid Zone

This is a soft pale coloured material which occurs in many soils—particularly those developed over iron-poor shales. The material is massive structured, light gray to white in colour and is impervious to water. The material can be cut by a knife and grades into rock below. The material is often low in iron but small reddish mottles may occur in the material. When squeezed between the fingers the material has a soapy or silty feel. This material is prone to landslips on roadcuts. The mineralogy is kaolinite, illite and quartz.

(c) Plinthite

The term plinthite is used to describe the variegated material which commonly occurs above the pallid zone. Plinthite is defined as an iron-rich, humus-poor mixture of clay with quartz and other diluents. It commonly occurs as dark red or red mottles which form a reticulate pattern with the light gray to white matrix. The mottles in the plinthite have sharp boundaries. Plinthite when exposed hardens irreversibly to petroplinthite. Red mottles which do not harden on exposure are not considered to be plinthite. Some criteria to separate plinthite from red mottles is shown in Table 1 (after

TABLE 1

CRITERIA FOR HELPING SEPARATE PLINTHITE FROM SIMILAR MATERIALS THAT WILL NOT IRREVERSIBLY HARDEN

Criteria	Plinthite	Red mottles or hardening bodies
Texture	Sandy loam to sandy clay; possibly clay loam	In material of any texture
Hue	7.5YR to 10Y	10YR to 10R
Consistence	Firm to very firm moist; commonly has very firm center; hard to very hard dry; has harsh dry feel when rubbed even if horizon is water saturated. Considerable resistance to penetration by sharp knife point.	Friable to firm moist soft to hard dry. Resistance to penetration by sharp knife point the same as or sightly greater than adjacent bodies.
Streaking	Leaves only a slight stain when rubbed even when moist.	Colour will streak and stain fingers when moist.
Shape and size	Discrete bodies either with platy or irregular or spherical nodular shapes; plates are 1.5 cm thick and up to 10 cm long; nodules are < 1.5 cm long but > 2 mm	Any shape and size
Color contacts and purity	Red bodies are sharply defined without diffuse edges; edge many cut across a coarse sand grain-plates and nodules are dense, uniformly colored bodies with few pores.	Red bodies have irregular and poorly defined edges; adjacent grays and yellows are intermixed with red colors; under a hand lens appear to be iron impregnated clays commonly with clay flows and interpenetrating brown, yellow and gray colors.
Consistence on a weathered road cut	Remain extremely firm to very firm when moistened and very hard to extremely hard when dry.	Pieces of red and brown soil soften to friable to firm when moistened; hard to slightly hard dry; moist pieces can be broken by rolling between thumb and forefinger.
Resistance to handling	Will withstand rolling under moderate pressure between thumb and forefinger	Will disintegrate when rolled under moderate pressure between thumb and forefinger.
Resistance to slaking in water	Moist or dry samples will not slake within 2 hours even when periodically gently agitated.	Moist or dry samples will slake quickly. Clay samples may be exceptions.

Daniels *et al.*, 1978). Plinthite is probably formed in a horizon that is saturated with water at some season followed by a dry period. This wetting and drying is essential for iron to segregate. Plinthite is common therefore at the footslopes where iron-rich solutions seep out of the hills. The deep fluctuating groundwater table common in sub-recent alluvium in Peninsular Malaysia is also conducive for the formation of plinthite. Plinthite may occur in various amounts and may be continuous or form a horizon of varying thickness. The term 'plinthite' as used here is probably describes the material originally described as 'laterite' by Buchanan (1807).

(d) Petroplinthite

When plinthite is exposed it hardens irreversibly to petroplinthite. The term 'petroplinthite' refers therefore to materials which are iron-rich and hard. The petroplinthite may be vesicular or nodular. The vesicular petroplinthite is common at the 'knick point' or break in the slope where the plinthite has hardened in place to form petroplinthite. The nodular petroplinthite comes in various shapes and sizes. They may be angular and about 2 cm in diameter or psisform with a diameter of only a few millimetres. The angular pieces are believed to be formed by the breakdown of the vesicular petroplinthite. The nodular petroplinthite is probably a result of reworking of the angular pieces. These nodular petroplinthites may also be formed by the plinthite being eroded and moved before hardening is complete. The bulk density, the degree of rounding increase and the size decreases from the angular to nodular petroplinthite. The nodular ones invariably are darker and more polished and often occur more commonly in the upper layers of the soil while the angular ones increase with depth. In some cases, the petroplinthite may be recemented by iron to form large blocks. The term 'laterite' as used by the layman often refers to 'petroplinthite' as defined here.

(e) Typical 'Lateritic' Profile

The similarity of lateritic profiles from many parts of the world has tempted many workers to define a 'typical lateritic profile'. This is shown in Figure 1. The profile can be divided into five parts. Such profiles can only be seen in deep roadcuts.

A surface soil cover may sometimes be present. Where present, this cover consists of a red, or strong brown, friable, iron-rich clay which is free-draining. This soil cover is of varying thickness and ranges from 10 cm to over 3 metres. In places this soil cover is eroded exposing the ferruginous crust below.

The ferruginous crust is often made up of three types of petroplinthite embedded in a matrix similar to the surface soil cover. The types of petroplinthite which form the crust are:-

(i) iron-coated parent materials
(ii) angular fragments and blocks of vesicular petroplinthite
(iii) nodular petroplinthite.

There appears to be some sorting of the materials as the fine, black pisiform gravels of higher bulk density occur higher up the profile, while the iron-coated parent materials and blocks at the base of the crust. In some cases, the whole ferruginous crust

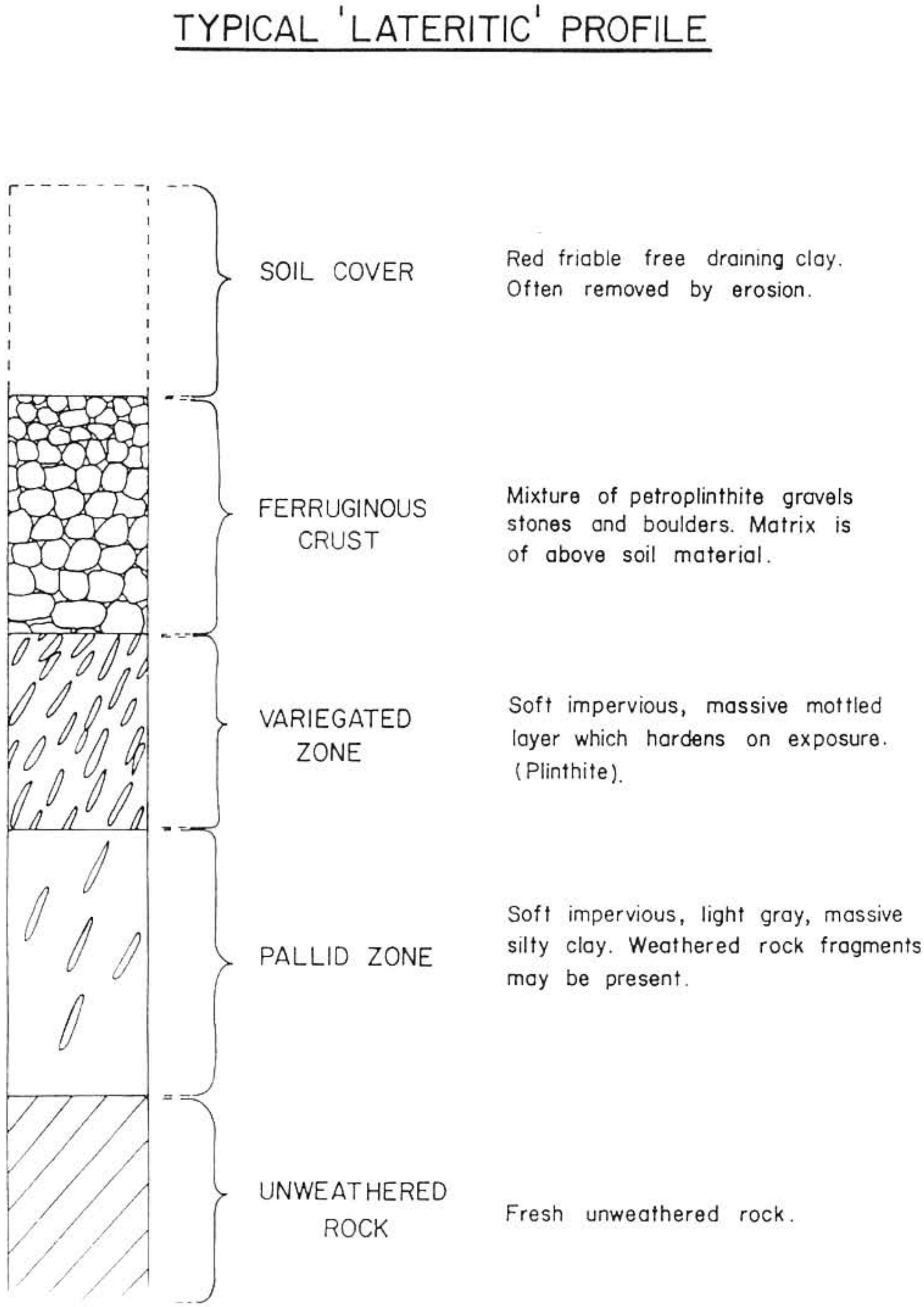

Fig. 1. Typical 'lateritic' profile.

is dominated by iron-coated materials. The ferruginous crust varies in thickness from about 5 cm to over 5 metres. In Malaysia, by convention, unless the petroplinthite and/or iron-coated layers exceed 25 cm in thickness, the soil is not considered to be a 'lateritic' or petroplinthic soil.

The base of the ferruginous crust changes rather sharply to a highly variegated, massive, impervious layer of plinthite. The plinthite has many reddish and whitish streaks forming a honeycomb structure.

The fourth zone in the 'laterite profile' is a pale coloured massive weathered saprolitic pallid zone. The colours are light gray to white with only a few fine reddish spots which harden on exposure. This material is massive structured and has a soapy or silty feel indicating high silt contents and the presence of illite is common. Faint bedding planes of the shale may be discerned in the material if it is developed over sedimentary rocks.

The fifth and lowest layer is the rock layer where the original bedding is still intact. Where the profile is developed over shales often this layer is soft and can be dug with a spade.

TYPES OF 'LATERITIC SOILS' IN PENINSULAR MALAYSIA

Two main groups of 'lateritic soils' have been identified by soil scientists in Peninsular Malaysia. These are:-

(i) soils with iron-coated parent materials

(ii) soils with petroplinthite gravels.

The main distinction between these two groups of soils is that the soils with iron-coated parent materials are considered to be essentially *in situ* while those with petroplinthite gravels are considered to be reworked. The petroplinthite gravels are considered to lie unconformably over an eroded plinthite layer.

Soils with Iron-Coated parent materials

Rocks rich in iron weather to release iron which is then leached through the soil and eventually coats the rock or saprolite underneath. The iron-coated materials therefore, often retain the original rock structure. However, if the impregnation or induration by iron has reached an advanced stage, it may be difficult to determine the original rock. Soils with iron coated parent materials are common over rocks rich in iron such as basalts, andesites, schists and ferruginous shales.

Basalts and andesites weather very rapidly because the rock contains many weatherable minerals. Consequently, the iron-coated parent materials seldom show any original rock structure. The gravels in these soils often are sub-rounded and few. The amount of gravels is less than 50 % by volume and these gravels are embedded in a reddish or brownish clay which is similar to the soil above. Below the gravel layer more soil rather than plinthite is encountered. These soils over intermediate and basic rocks are rich in goethite, kaolinite and gibbsite and are free draining. The roadcuts on these materials are stable and the material can be readily used as a source of fill materials for roads etc.

In the case of shales and schists, the iron-coated parent materials retain their bedding or schistosity. The iron-coated gravels in this case tend to be elongated and vein quartz may be found transversing the iron-coated materials. These platy materials may be continuous or occur as fragments ranging in length from a few centimetres to over 10 cms. These materials often make up more than 70% by volume of the soil horizons and have very little fine earth (<2 mm) fraction. Underlying these platy iron-coated materials may be a weathered friable plinthite or these iron-coated materials may grade into fresh rock. In deep roadcuts the bedding or elongation of these iron-coated materials may be traced into the underlying rock.

Soils with iron-coated parent materials occur in rolling to hilly terrain (22–40% slopes). The terrain is dissected with narrow valleys and the areas are being actively eroded by the present-day river systems. Sometimes, these iron-coated materials occur deep in the soil (2–3 m below the surface) and are only exposed at the 'knick-points' where erosion has removed the soil cover. In some cases, the soil cover has been removed and the iron-coated materials occur close to or at the surface giving the appearance of the materials forming caps on hills.

Soils with Petroplinthite Gravels

Soils with petroplinthite gravels occur extensively in some parts of Peninsular Malaysia. These soils are separated from those with iron-coated parent materials by the dominance of petroplinthite gravels. These soils also seem to have been reworked as indicated by the gravels lying unconformably over the plinthite layer. There is some disagreement amongst soil surveyors as to the amount of transportation these petroplinthite gravels have been subjected to. It is however, agreed that three levels or geomorphic surfaces are present in Peninsular Malaysia. These geomorphic levels are termed P, P_3 and P_2 surfaces with P being the oldest and P_2 being the youngest. For a long time, especially during the reconnaissance soil survey of Peninsular Malaysia (1955–1968) only two surfaces were recognized. However, Paramananthan and Lim (1978) proposed that there were in fact three recognizable levels with the possibility of an even older Pre-Tertiary peneplain. Subsequent detailed surveys have confirmed that these three geomorphic surfaces do in fact exist. The soils in the oldest surface P, have many angular petroplinthite fragments and only a few rounded petroplinthitic gravels. On this surface, large blocks and iron-coated materials may also be present. The P_3 surface on the other hand occur on a lower elevation and the rounded gravels became more common although minor amounts of angular fragments are still present. In the soils on the P_2 or youngest surface which is generally level, only the rounded gravels are present and these lie directly over fresh petroplinthite. The gravels within each soil profile on each of the surfaces appears to be sorted with the finer gravels nearer the surface. The degree of rounding and the particle density of the gravels increases from the older P surface to the younger P_2 surface. The soils with reworked petroplinthite gravels are similar to those found in Africa where the French pedologists have used the term 'soil remanie' to describe such soils. Some criteria to distinguish the soils on the different geomorphic surfaces have been proposed by Debaveye (Personal communication, 1981) and are given in Table 2.

TABLE 2

SOME CRITERIA FOR THE SEPARATION OF THE LATERITIC PENEPLAIN SOILS*

Characteristic	Peneplain Level		
	P	P_3	P_2
1. Terrain Class	C_3	C_2–C_3	C_2
2. Height Above Valleys (Approximate)	7–8 m	4–5 m	1 m
3. Gravel Layer			
a. Depth	All stonelines occur at shallow or moderate depths. Soils with a deep gravel layers are rather exceptions. The moderately deep soils occur at somewhat lower slope position, surrounding the shallow groups.		
b. Thickness	30–40 cm	40–70 cm (Shallow soils) 20–30 cm (Moderately deep soils)	10–40 cm
c. Gravel Content % Volume/Volume	30–35	40–60	35–45
d. Composition of Gravels			
i. Rounded Laterite Gravels	0.2–0.5 cm in diameter	0.2–1.5 cm in diameter	0.2 to 0.5 cm in diameter
ii. Laterised Parent Material	Many	Common to few 2–5 cm in diameter	Very few to none 2–3 cm
iii. Manganese Gravels		Occur in moderately deep soils at the edges of the plantation surface	
4. Horizon Symbol of Gravel Layer	B_2t B_2ox	B_2t (B_2ox)	BC (B_3t)
5. Nature of Horizon Underlying Gravel Layer	2.5YR 5/6 or 5YR 5/6 Clay to heavy clay; no gley; fresh shale fragments.	7.5YR or 5YR Clay to silty clay with few, fine 10YR 7/8 and many coarse sharp 2.5 YR 4/8 mottles (Rarely few spots of 10YR 7/2) Material crumbles easily between fingers.	10YR 8/1 or 8/0 gley colours; common coarse sharp 10R 4/6 or 10R 3/6 clay to silty clay. Material is massive and impervious.
6. Nature of Horizon Overlying Gravel Layer	2.5YR, 5YR or 7.5YR clay to heavy	7.5YR 6/8 and 5YR 5/8 with few mottles. Sandy clay to clay	10YR 7/2 Gley, 10YR 6/8, 7.5YR 5/8 and 5YR 5/8 with mottles. Loamy to clayey.
7. Drainage Class	8	7 and 6	6, 5, 4, 3
8. Other Features	Recementation of gravels to form larger blocks common. Ferricrete at break of slope		

*Debaveye, J. Belgian Expert, Dept. Agric. Kuala Lumpur, personal communication 1981.

GENESIS OF 'LATERITIC SOILS' OF PENINSULAR MALAYSIA

Although lateritic soils have been mapped for a long time, very little of the genesis and occurrence of these soils has been clearly understood. In recent years however, the staff of the Natinal Soil Survey, Department of Agriculture have been attempting to understand the genesis of these soils.

For a long time, all the 'lateritic soils' mapped in Peninsular Malaysia have been treated as soils developed *in-situ*. Thus, for example, Law and Leamy (1966) and Wan Daud (1975) both considered that the lateritic Malacca Series formed a toposequence with the non-lateritic Durian and Batu Anam Series. They believed that the Malacca Series was formed over iron-rich shales while the Durian and Batu Anam Series were on iron-poor shales. Similarly, Joseph (1965) considered that both the Pokok Sena and Chungloon Series to be developed over shales although both these soils had rounded lateritic gravels and occurred on relatively flat terrain.

If one looks closely at the lateritic materials which occur in the soil, two main types can be recognised. These two types, the iron-coated materials and the petroplinthite gravels have been defined earlier. Thus, any theory on the genesis of 'lateritic soils' must explain the origin of these two types of lateritic materials. It must also explain the three geomorphic surfaces (P. P_3 and P_2). The proposed theory must also explain the types of toposequences described by Law and Leamy (1966) and Wan Daud (1977).

Paramananthan and Lim (1978) first introduced the concept of the reworked nature of soils with petroplinthite in Peninsular Malaysia. They suggested that there was an old peneplain which was formed probably during Pre-Tertiary times. This peneplain was then eroded to give rise to three geomorphic levels where lateritic soils occurred. This concept was evaluated by J. Debaveye, Belgian Soil Surveyor attached to the National Soil Survey, who worked in the Padang Terap area of Kedah. Subsequent to this, M. De Dapper, a geomorphologist also visited the area and summarised his findings in a report De Dapper (1981).

The ideas presented in this paper represents the current thinking of the staff of the National Soil Survey and that of the authors who have also carried out additional work in the State of Pahang and Malacca.

The formation of "lateritic soils" in Peninsular Malaysia was probably initiated during the Tertiary. It is believed that tropical climates prevailed in this part of the world resulting in an intensive tropical weathering. This weathering resulted in the formation of deep friable soils with iron-coated materials at depths. Plinthite also formed below the iron-indurated materials. A Tertiary age is postulated for this first stage because the lacustrine deposits of the Tertiary have some petroplinthite gravels mixed with the rounded quartzite pebbles (eg. Perlis).

The next phase in the development was the dissection of this Tertiary landscape of highly weathered materials with iron-coated parent materials followed by local transport and deposition giving rise to a peneplain surface (P). The erosion products do not appear to be transported for long distances but have been deposited over an erosion surface of plinthite. The lack of horizontal transport is indicated by the stones and boulders marking the early depositional phase. The finer petroplinthite gravels which occur closer to the surface of soils on this plantation surface (P) could be a result of plinthite which hardened during transport.

This newly formed geomorphic surface (P) was probably subjected to another cycle of erosion and deposition. This would result in the older P surface being left as cappings on hills due to an inversion of relief while the detrital materials which are now more rounded forming a new planation surface (P_3). In some cases, where erosion was very active this would expose the plinthite and pallid zones underlying the cappings on the older P surface and soil formation over these layers could have proceeded to give a landscape as described by Law and Leamy (1966) and Wan Daud (1977).

The petroplinthite layer of the new P_3 surface was subjected to another cycle of erosion and deposition. This reworking of the petroplinthite and subsequent deposition over the eroded plinthite surface gave rise to a new geomorphic surface (P_2). Soil formation on the plinthite and pallid zones of the older surfaces probably continued.

TABLE 3

PROBABLE GEOMORPHIC PROCESSES FORMING LATERITIC SOILS

Geologic Age	Geomorphic Process	Result
Tertiary	Intensive chemical weathering under tropical conditions.	Reddish coloured ferruginous soils with iron coated materials and formation of plinthite. *Soils*: Padang Besar, Batu Lapan, Seremban.
Pleistocene	i) Physical weathering and transport or micropedimentation.	Inversion of relief and hardening of plinthite to petroplinthite during erosion and transport forming peneplain (P) *Soils*: Malacca, Gajah Mati, Tavy and Tandak
	ii) Dissection of petroplinthite 'cap' and either micropedimentation or transport and removal of laterite exposing plinthite 'cap' and either micropedimentation or transport and removal of laterite exposing plinthite and/or pallid zone.	Erosion and transport forming P_3 geomorphic surface. *Soils*: Pedu, Terap. *In areas where erosion is dominant:* Soil formation on pallid and/or plinthite. *Soils*: Durian, Asahan, Batu Anam, Lokyang
	iii) Further dissection and transport of older geomorphic surfaces.	Erosion and transport forming P_2 geomorphic surface. *Soils*: Pokok Sena, Chungloon Further soil formation on plinthite and/or pallid zone. *Soils*: Durian, Asahan, Batu Anam, Lok yang

It can be expected that with each reworking, the petroplinthite gravels become more rounded and smaller. Thus, while the petroplinthite gravels on the P surface are angular and larger, those on the P_2 surface finer and better rounded. This would therefore explain to some extent the different types of petroplinthite observed. With each reworking, the terrain becomes more level. The formation of each new geomorphic surface would require a change in base-level of erosion. These changes in base levels could be related to the changes in sea levels during the Quaternary. In Africa, where similar geomorphic surfaces occur, they have been related to changes in sea levels during the Quaternary. A summary of the probable age and geomorphic processes forming the lateritic soils of Peninsular Malaysia is given in Table 3. It must be pointed out that the geologic ages suggested for the different surfaces is tentative and more detailed study is necessary before these can be confirmed.

Need for further work

The genesis of lateritic soils presented here is based on the work carried out in specific areas of Peninsular Malaysia. It is currently difficult and dangerous to extrapolate these ideas to other areas where lateritic soils occur. More detailed surveys in other areas with lateritic soils is necessary before this laterite problem can be understood. Detailed studies on the differences of the soils on each geomorphic surface needs to be carried out to confirm some of the ideas, presented in the paper. Such work is currently being carried out by staff of Universiti Pertanian Malaysia with the help and cooperation of the National Soil Survey.

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