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REPORT ON TROPICAL PODZOLS

by

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PREFACE

The literature on tropical soils has substantially increased in recent years. Most articles, however, are concerned with agricultural soils or other soils which are widely distributed throughout the tropical belt, such as laterite, lateritic soils and latosols. However, rather little is known about the so-called "white sands" which in some tropical regions cover large areas, but which have little or no agricultural potential. In 1941, Richards suggested the name "lowland tropical podzols" for these soils which, due to their low agricultural value, have attracted relatively little attention of pedologists.

The author, a member of the Max-Planck-Institut für Limnologie, Plön/Holstein, Federal Republic of Germany, was entrusted with a study of these soils by UNESCO in agreement with the Executive Director of the Institute.

This report has originally been prepared as a basic working paper for a Symposium on Tropical Podzols which, due to certain circumstances, has not been held. Subsequent to the submission of the report to UNESCO (October 1965), the author continued his study of world literature on this subject and added about 150 references to the original text.

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INTRODUCTION

The term podzol (podsol) meaning "ashy soil" or "soil under ash" has been introduced into scientific literature by Russian pedologists (Glinka 1914, Sibirtzew 1897, Muir 1961), and is applied to soils the essential features of which consist in translocation of sesquioxides and humus, separately or collectively, from the topsoil into the subsoil (Jenny 1941). The processes acting in podzol formation are termed podzolization.

I. BACKGROUND DEFINITION AND SCOPE OF THE TERM

The amount of information available and the limited space available for the report on tropical podzols restrict treatment in this chapter to a general outline of both podzol characteristics and podzolization.

1. GENERAL SPECIFICATION OF PODZOLS

Podzols are acid soils with pronounced profil development (Kubiena 1953, Stephens 1949). They develop on base deficient and highly siliceous parent materials, under humid climates. The most typical profiles are found on sandy or somewhat gravelly rocks poor in clayey material (Mückenhausen 1962 a, Scheffer and Schachtschabel 1960). Podzols develop also on acid volcanic rocks (Bramao and Dudal 1959), sandstone, granite, shists, and other acid hard rocks.

The very acid raw humus (mor, duff) layer on top of the soil is sharply separated from the mineral soil beyond. Usually, raw humus has a wide C/N ratio (mostly > 25, Fiedler and Reissig 1964).

In humid climates where downward percolation of rainwater is persistent sufficient moisture is present to promote intensive leaching (removal of carbonates and base depletion) ot the soil. With progressive leaching primary minerals and, finally, clay minerals are destroyed, in the upper part of the mineral soil. Inorganic and organic soil compounds transported through the topsoil and deposited in the subsoil form there pans (Mückenhausen 1962 a)

Due to intensive leaching the topsoils of podzols have low base saturation and are poor in nutrition elements (macro and micro elements as well). Podzols, therefore, are soils of low fertility.

The above general characterization of podzols is valuable for both tropical and ectropical regions (Dudal and Moorman 1964).

Seepage from tropical podzols areas has typical brownish colour (blackwater), due to finely dispersed poszol humus.

A. The podzol profile

A podzol is a complete natural body definable in terms of all its horizons and the relationship among them (Cline 1949). The profile consists of three master soil layers (horizons, Ganssen 1961 a)

- A : Acid raw humus on top of the soil; sharply demarcated from the underlying mineral soil.
  Ash coloured bleached sand (albic horizon (Anon. 1960 a) or eluvial horizon).
- B : Humus, sesquioxide, or humus plus sesquioxide accumulation in the subsoil (spodic horizon (Anon. 1960 a, Duchaufour 1965) or illuvial horizon).
- C : Parent material.

These horizons are normally subdivided, due to differences in character and colour. The complete horizon sequence of a podzol with both humus and iron accumulation reads as follows (Kubiena 1953, Mückenhausen 1962 a, Scheffer and Ulrich 1960) :

$A_{oo} = A_L = L$	:	Litter
$A_o = A_F + A_H = F + H$	:	Raw humus
$A_1 = A_h$	:	Dark coloured mineral soil mixed up with structureless humus
$A_2 = A_e$	:	Grey, greyish or white bleached sand (eluvial, albic or bleached horizon)
$B_1 = B_h$	:	Accumulated humus (humus pan; humus ortstein or orterde)
$B_2 = B_s = B_{ir}$	:	Accumulated sesquioxides (iron pan; iron ortstein or orterde)
C_1	:	Parent material with beginning decomposition
C_2	:	Fresh parent material

Raw humus develops from organic raw material (litter), by organic decomposition, and is characterized by strongly hindered biologic activity. It contains mobile acid humus (fulvic acids plus brown huminic acids, Scheffer and Ulrich 1959, 1960). This mobile acid humus penetrates the uppermost part of the mineral soil and destroys the minerals which it compose, except quartz. Thus the mobile organic compounds of the F + H and A_1 horizons bleach the mineral soil which appears as bleached sand A_2, composed by residual quartz (relative accumulation after D'Hoore 1955). Both organic and inorganic decomposition products of the upper soil layers migrate through the eluvial horizon and accumulate in the B horizon (absolute accumulation, D'Hoore 1955). Due to the degree of induration, ortstein or orterde (less indurated than the former one) develops. Ortstein is often referred to as 'coffee-rock', by Australian authors (Blackburn and Baker 1958, Leeper 1964, and others).

B horizons in which merely organic matter is deposited are B_h horizons. If predominantly free iron and aluminium oxides are accumulated the illuvial horizon is called B_s. Transitional illuvial horizons between B_h and Bs are B_{hs} horizons. With special regard to the tropics, it is worthwhile to distinguish very clearly between the iron podzol B horizon and the ironstone layer which is a result of laterization.

Chemically, macromorphologically, and micromorphologically, these different B horizons are very well distinguishable (Kubiena 1938, 1953, Osmond 1958).

Compared with other soil layers the B horizon may be richer in clay mineral (Muir 1961). But clay accumulation is not essential in the podzols (Hallsworth et al. 1953, Stobbe and Wright 1959) After Jenny (1941) clay particles migrate in podzols, but additionally, and are subjected to profound chemical alteration. Some clay in the B horizon may be of new formation.

The term ortstein excludes formations which have been formed by other than more or less vertical translocation of matter (Schlichting 1963), within the process of podzolization.

B. Podzol definition

In the Multilingual Vocabulary of Soil Science (Anon. 1960 b) the definition of podzols reads as follows :

> "Soil with acid-humus horizon overlying B horizon of iron-oxide or iron-oxide and humus accumulation (U.K.)
>
> or
>
> soil with acid-humus surface horizon, bleached A_2 and illuvial B horizons with accumulations of iron-oxide or of iron-oxide and humus (Can.)."

For a more detailed definition reference is made to Anon. (1964 a) :

"Soils with ABC profile. The A_1 horizon is of variable thickness and the organic matter is in the form of mor. In virgin soils an A_0 horizon, composed of raw organic matter is present. The A_1 horizon overlies a strongly bleached A_2 horizon the thickness of which varies widely. Sometimes this horizon is very thin and masked by organic matter - for example in the brown podzolic soils - and sometimes it has a thickness of several meters as in the case of so-called giant podzols. The B horizon has a very low base saturation, and accumulation of iron, organic matter or both, and varies in thickness from 20 to 40 cm. Podzols develop from highly siliceous parent materials under a wide range of climates.", and to Dudal et al. (1967) :

"Podsolized soils have an ABC profile. The B horizon presents accumulation of iron and/or humus. Under natural vegetation, the organic matter is in the form of raw humus (moder). There is a considerable difference between the SiO_2/R_2O_3 ratios of the clay fractions of the A and B horizons.

The delimitation of the soils included in this unit is ample due to the variation of climatic and drainage conditions under which the elimination and subsequent deposition of humus and iron may occur. This group embraces well drained soils (podzols) and bad drained ones (gley podzols). The thickness of the A horizon is variable; this horizon may be completely absent or weakly developed as in the case of the brown podzolic soils. The B horizon may consist of grains coated or cemented by humus (humus podzol), by iron (iron podzol), or, more frequently, the coating consists of a mixture of humic and iron compounds (iron humus podzol). The B horizon may be diffuse or comprised of various subhorizons; it may be soft or hard. If the A_1 horizon is peaty, the A_2 horizon is transformed into gley and the B horizon may be in the form of a thin ferruginous pan." (Translation by the author).

In the wide range of climates referred to above by Anon. (1964 a), the tropics are included.

C. Nomenclature

Soils in which podzolization is operative have been called podzolized (Tavernier 1962) or podzolic soils (Anon. 1964 a), and have been subdivided into cryptopodzolic, slightly, medium and strongly podzolic or podzolized soils, and (true) podzols (Duchaufour 1956, Muir 1961, Nogina 1962, Stebutt 1930, Glinka 1914). In the latter the podzolization processes appear in a relatively pure form (Nogina 1962). The subdivision is based upon the degree of leaching (Wilde 1958) and podzolization (Hallsworth et al. 1953) which are expressed as thickness of the bleached horizon (Muir 1961).

Different meaning, however, has been given to the adjectival forms podzolic and podzolized (Anon. 1966, Dudal 1964, Stephens 1949). In the widest sense they are applied to all soils showing bleached horizons, like podzols, grey-brown podzolic soils, sod (derno) podzols (Kundler 1959), and red-yellow podzolic soils (Bennema 1963, Bramao and Dudal 1959, Kellogg 1950, Mc Caleb 1959, Schroo 1963 a, Thorp and Smith 1949, Zonn and Karpachevsky 1964), and correspondingly podzolization is used to designate collectively the processes that tend to develop ashy A_2 horizons (Buckman and Brady 1960). Red-yellow podzolic soils are more properly included with the podzolic soils, especially because of the relatively low permeability of their B horizon and their relatively low degree of stable aggregation (Kellogg 1949). Greene (1945) discussing the classification of tropical soils deplored "the gradual stretching of the word podsolic until at last it is applied to tropical soils which are astonishing different from the podsols of the cold northern regions."

In a more specific sense soils are podzolized if they show clay migration or lessivage (Anon. 1962 d, 1966, Duchaufour 1951, Tavernier 1962), and podzolic ones if podzolization (translocation and accumulation of iron and/or humus) occurs, in Eastern Europe, while in Western Europe podzolic soils (for example grey-brown podzolic soils) are characterized by clay migration, and podzolized soils, by podzolization in the above sense. It appears that there is an inversion of meaning given to the names podzolic and podzolized in both parts of Europe (Anon. 1962 d, Tavernier 1962).

Pendleton and Sharasuvana (1942) proposed that the term podzolic should be restricted to processes that are known to be producing the true or classic podzol profile; thoroughly leached eluvial layers of laterites (lixivium horizons in the sense of Mohr (1944)), therefore, should not be called podzolized. These authors deplore the fact that many American pedologists insist upon calling bleached horizons even of a laterite podzolized.

The confusion over podzols, podzolic and podzolized soils has been discussed by Muir (1961) who chiefly considered Russian literature.

Fortunately there are several publications (Anon. 1962 a, 1962 d, 1962 e, 1963 d, 1964 a, 1966, Dudal 1964, Ehwald 1957, Stephens 1949, and others) in which the respective authors correlate the various soils and compare the use of the terms podzol, podzolized, podzolic, and podzolization, in different countries or continents.

Generally, two categories of podzols are known. In poorly drained areas where the formation of indurated B horizons of podzols is connected with groundwater fluctuations the soils are groundwater podzols (Ahn 1961 a), hydromorphic podzols, gley podzols, wet podzols, or podzols de nappe of French authors. These podzols belong to the order of intrazonal soils (Thorp and Smith 1949).

Podzols under a permanent water table are usually considered to have developed when drainage was better and the water table was below the surface mineral soil; but podzolization can also occur under permanently submerged conditions (Damman 1962). This author also discussed the confusing terminology of hydromorphic and well drained podzols, commonly used in temperate regions.

Intrazonal soils are well developed soils the morphology of which reflects the influence of some local factor of relief, parent material or age rather than of climate and vegetation (Anon. 1960 b).

In the tropics groundwater podzols seem to occur more frequently than normal podzols (Bramao and Dudal 1959, D'Hoore 1964), but tropical podzols are not limited to soils formed under groundwater influence (Dudal and Moormann 1964).

Podzols formed without any influence of groundwater (normal podzols) are said to be zonal soils, i.e. soils that have a profile which showns a dominant influence of climate and vegetation on its development (Anon. 1960 b). Like silica sand, podzols are often detectable, even from the air, by their vegetation (Fosberg 1965). There are, however, authors who consider podzols intrazonal soils, because they develop only on sands (Thorp and Smith 1949).

Intergrades between podzols and brown forest soils of temperate regions were classified as bleached brown forest soils, podzolic (podzolized) brown forest soils, or secondary podzols (Duchaufour 1965, Laatsch 1957). Kubiena (1953) grouped these intergrades into the subtype semipodzol of the podzol class. After Mückenhausen (1962 a) soils more intimately related to brown forest soils belong to a subtype of the latter (for example podzol-braunerde), and those more related to podzols are podzol subtypes (for example braunerde-podzol). Kundler (1962) put podzol-braunerde and braunerde-podzol into the brown podzolic soils.

Intergrades between podzols and other great soil groups (soil types in the German sense of the expression, Mückenhausen 1962 b, Kubiena 1953) are also known (examples are parabraunerde-podzols, podzol-lessivé, and others).

After the U.S. Americam soil classification (Anon. 1960 a), podzols fall mainly in the spodosol order. The spodosol order originates in the western European concept of podzols (Smith 1965). Spodosols are found in humid climates, but their range is from the boreal forests to the tropics. These soils do not form in clayey materials. Spodosols do not seem to form until there has been significant eluviation.

Spodosols include normal podzols, brown podzolic soils, and groundwater podzols. But not all podzols belong to this order; some are entisols. Deep white quartz sands, the "white sands" of many tropical countries, may be considered albic horizons, but the U.S. soil systematics group them quartzic psamments.

Four suborders compose the spodosol order : Aquods include groundwater podzols; aquods of tropical and subtropical regions are thermaquods. Thermaquods are actually called Tropaquods (Smith 1965). Those tropaquods having an albic horizon of more than two m. depth are grouped psamments. Humods include humus podzols. Orthods include normal podzols and brown podzolic soils. Ferrods include iron podzols.

In the opinion of Stephens (1963) the distribution of the podzols and groundwater podzols between the two orders entisols and spodosols reveals an interesting source of confusion.

Exceptionally deep podzol profiles have been referred to as giant podzols, in tropical and non-tropical regions as well (Dames 1962, Jenny 1948, Wortmann and Maas 1954, and others).

D. Environmental conditions of podzols

From the distribution of podzols in northern latitudes where the soils are exposed to temperate or cool humid climates (Duchaufour 1951, Joffe 1949, Mückenhausen 1962 a, Pagel 1964, Robinson 1937, Scheffer and Schachtschabel 1960) the main soil forming factors may be deduced :

Temperate or cool humid climates with relatively low mean annual temperatures, high percolation of rainwater, and consequently, strong leaching of soils.

Vegetation (often composed by so-called raw humus plants, Kubiena 1948) which produces a kind of litter that - due to its chemical composition, due to acidity and climatic conditions - decomposes uncompletely and thus gives rise to the formation of acid raw humus (Scheffer and Ulrich 1959). Permeable, base deficient and highly siliceous parent material.

The above soil forming factors are present in northern latitudes, and at higher elevations of southern and equatorial regions. But in tropical lowlands with warm humid climates podzols are also common. They are found on chemically very poor parent materials, and groundwater influence is often included in their development.

2. PODZOLIZATION

Ezamination of the literature shows that the term podzolization has been applied as a general collective term to describe the processes occurring in almost any soil showing visible signs of apparent sesquioxide, humus and/or clay migration as well (Buckman and Brady 1960, Papadakis 1964, Robinson 1937, Smith 1962, Stephens 1949).

In the American usage this term has been applied more and more to the processes that produce podzolic soils with textural B horizon (argillic horizon (Anon. 1960 a), clay accumulation as in grey brown podzolic and related soils) rather than to the podzols (Smith 1962).

For accuracy's sake, however, clay migration as occurring in grey brown podzolic soils should be excluded from podzolization (Kundler 1957, Mückenhausen 1962 a). Scheffer (1965), therefore, defined podzolization as follows : Unter the influence of strongly acid percolating solutions enriched with organic reducting, complex forming and chelating agencies, the soil minerals become destroyed and the weathering products are separately translocated, carbonates being totally absent at the start of podzolization.

Podzolization, the reaction chain that leads to the formation of podzols (Stobbe and Wright 1959, Swindale and Jackson 1956), includes breakdown of primary silicate and clay minerals as well, subsequent translocation of both the decomposition products (sesquioxides) and humus, and accumulation of these compounds in illuvial podzol B horizons (Friedland 1958, Mackney 1961, Reuter 1964, Werbitzki and Pantjuchin 1964).

It is suggested that destruction of clay minerals occur also in the red yellow podzolic soils (Simonson 1949). After Breburda (1965), however, a clear separation of soils with clay migration from those with clay destruction is not possible, due to the fact that both processes are often combined in a specific soil.

Both downward movement of intact clay minerals and accumulation of them in argillic horizons should be referred to as lessivage (Duchaufour 1951), lessivation (Fiedler and Reissig 1964, Mückenhausen 1962 a, Scheffer and Schachtschabel 1960, Scheffer and Ulrich 1960, Reuter 1964), or illimerization (Fridland 1959). Gerasimov and Glazovskaya (1965) include leaching and translocation of fine-clay particles in the pseudo-podzolization process. Podzolization itself is characterized, in their opinion, by advanced decomposition of the mineral soil constituents, mainly due to the action of free fulvic acids.

Podzolization and lessivation may occur simultaneously in acid soils of temperate regions (Brydon 1965, Cann and Whiteside 1955, Fridland 1958, Muir 1961). In this case a new soil type should be established (Mückenhausen 1962 a). Lessivation may subsequently be followed by podzolization (Altemüller 1962, Duchaufour 1951, Fiedler and Reissig 1964, Scheffer and Schachtschabel 1960).

Podzolization or podzol formation includes (Ahn 1961 a, Duchaufour 1956, Jenny 1941, Laatsch 1957, Stebutt 1930, Stobbe and Wright 1959, Vageler 1938, and others) :

Formation of colloidal humus (Gallagher 1942/43) or of acid raw humus as source of fulvic acids (Scheffer and Ulrich 1959, Wright and Schnitzer 1959), at the soil surface. Leaching of mineral salts (removal of calcium carbonate, if present, and other free salts), replacing of exchangeable bases of the exchange complex by hydrogen and aluminum and removal of sesquioxides originated by the breakdown of the mineral complex. Eluviation (washing out) of fine particles (organic compounds, eventually clay) and material in solution, from upper horizons. Illuviation (washing in) of soil material into lower horizons.

Duchaufour and Souchier (1965) defined podzolization as follows : production of soluble, aggresive and durable organic compounds (fulvic acids), and strong liberation of iron and aluminum.

Not only the above physico-chemical, but biological processes too are involved in podzolization (Aristovskaya 1956, 1964, Crawford 1956, 1962, Gordienko 1955, Ponomarewa 1964, Stobbe and Wright 1959, Swindale and Jackson 1956, Wilde 1958, and others), and play an important role in mobilization and deposition as well of sesquioxides (Deb 1949).

As shown by Bloomfiled (1953, 1954a, 1954 b, 1954 c, 1955, 1956) and others leachates of litter play an important part in both mobilization and immobilization of sesquioxides in podzols.

It should be mentioned that the concept of podzolization is based upon studies realized in the ectropics, and that further careful investigations are required before the genesis of podzols will be completely understood.

In the following chapters soils which are classified podzols will be considered by the various authors and which fit the above described modern concepts of podzol and of podzolization. It is obvious, however, that with special regard to the older literature, the authors classified by them described soils podzols which in modern pedology will not be included in this group. These referance are also included here, in order to give a more complete picture.

3. GEOGRAPHICAL DISTRIBUTION OF PODZOLS

For the purposes of this report tropical podzols include those occurring within the true tropics and adjacent areas like Florida, southeastern Australia, and the North Island of New Zealand. Podzols occurring elsewhere are ectropical podzols.

The line at an altitude of 1,000 m may for conveniences' sake be regarded as an arbitrary borderline between lowlands and uplands (Andreae 1965, Jin-Bee 1960, Schroo 1963 a, Smythies 1965).

The distinction between soils occurring in plains and those developed in uplands is justified from the cartographic point of view, but not from the soil systematics point of view (Ehwald 1957). This report, however, intends to describe podzols of the tropics, and is not directed to soil systematics.

A. Ectropics

The great extension of extropical podzols may be seen from the data of table 1, published by Gracanin (1951). After Gerasimov (1963), however, typical podzols are not so widespread as assumed before. Further information on the distribution of extropical podzols are given by Blanck (1939), Ganssen (1957, 1961 b), Glinka (1914), Kubiena (1953), Mückenhausen (1962 a), Nogina (1962), Papadakis (1964), Robinson (1937), Stebutt (1930), Stemme (1932), and others.

Table 1. Soils of the world (in 10^6 hectares)

Soils	Eurasia	Africa	North America	South America	Australia	Antarctica
Podzols and moor	827	-	548	-	-	-
Mountain podzols	648	-	160	35	9	-
Other soils	3,850	2,984	1,724	1,772	888	1,400

B. Tropics

a. Delimitation of the tropics

Strictly, the tropics are limited by the tropics of Capricorn and Cancer. Soils occurring within that region are distinctly tropical soils ore, more precisely, inter-tropical soils. But these tropical parallels are not boundaries of soils, climates, nor vegetation, and similar soils, climates, and vegetation may be found on either side of them.

In a very general meaning, the tropics include regions that are continually warm, or essentially free of frost. The climate may be wet (humid tropics) or dry (arid tropics).

As podzolization demands sufficient amounts of water to produce leaching of the soil mass podzols can be found only in humid tropical regions.

Many attempts have been made to define exactly the arid and humid tropics (Fosberg et al. 1961, Knoch 1929, Köppen 1918 a, 1918 b, Troll 1956, Thornthwaite and Hare 1956, and others). Using either vegetation or climatic criteria the resulting tropical areas disagree, especially with regard to their bordering regions (Fosberg et al. 1961).

For the purposes of this report the tropics include the regions covered by the climatic zone V of the map of seasonal climates of the Earth, by Troll (1964). Florida, southeastern Australia, and the North Island of New Zealand (though belonging to Troll's climatic region 7 of the warm-temperate subtropical zone IV) are included in the tropics, in this report, due to the fact that podzols occur in great extent in these areas the rainfall of which is comparable with that of Troll's tropical zone.

b. Subdivision of the tropics

The climatic zone V is subdivided in five climatic regions which are tabulated as follows :

V 1 : Tropical rainy climates with or without short interruptions of the rainy season. 12 - 9 1/2 humid months. Evergreen tropical rain forest and half deciduous transition woods.

V 2 : Tropical humid-summer climates. 9 1/2 - 7 humid and 2 1/2 - 5 arid months. Rain-green humid forest and humid grass-savannah.

V 2a : Tropical winter-humid climates. 7 - 4 1/2 humid and 5 - 7 1/2 arid months. Half deciduous transition woods.

V 3 : Wet and dry tropical climates with 7 - 4 1/2 humid and 5 - 7 1/2 arid months. Raingreen dry wood and dry savannah.

V 4 : Tropical dry climates with 4 1/2 - 2 humid and 7 1/2 - 10 arid months. Tropical thorn succulent wood and savannah.

V 4a : Tropical dry climates with humid months in winter.

V 5 : Tropical semi-desert and desert climates with less than 2 humid and more than 10 arid months. Tropical semi-deserts and deserts.

The tropical zone of Troll corresponds more or less to the tropical zone of planation surface formation (Büdel 1961, 1963), and includes the rain forest formations, as shown by Richards (1957).

c. Some historical notes on tropical podzols

When some sixty years ago knowledge of tropical soils was limited (Ramann 1911) the existence of tropical podzols was not known. Ramann noticed that in tropical America where blackwater rivers are frequent iron is dissolved in the neighbouring soils, and kaolin is formed. This may be regarded as the first vague information on the occurrence of podzols in the tropics.

Originally, it was believed that under tropical environmental conditions accumulation of humus could not develop, and, therefore, raw humus formation was not expected to occur in the tropics.

Even in modern soil literature the opinion is expressed that tropical soils in general are poor in humus. But this opinion seems to be more repeated than proved (Greenland and Nye 1959, Jenny 1950, Jenny et al. 1949, Laudelout 1961, Nye 1961, Smith et al. 1951, and others).

Because of the supposed lack of humus accumulation in the tropics podzols were believed to be absent there (Stremme 1930). Only at high elevations within the tropical belt where climatic conditions are similar to those of ectropical lowlands podzols - following the vertical soil zonation (Stebutt 1930) - were supposed to develop, on suitable parent material (Mohr 1944, Senstius 1930 a, 1930 b). Mohr (1933, 1944) established podzol characteristics of certain soils of Indonesia, by their gross morphological features. Giesecke (1930) discussing the occurrence of tropical peat formations dedicated a small chapter to tropical bleached sands; he pointed out that everywhere in the tropics blackwater rivers are genetically related to bleached (= podzolized) sands (Lemée 1960). Harrassowitz (1930) calling upon Vageler reported on raw humus and corresponding podzol profiles widely distributed under tropical jungle. Robinson (1937) also citing Vageler regretted the lack of descriptions of tropical podzols.

There are also authors, unfamiliar with tropical soils, of the opinion that podzol formation is one of the most general soil forming processes in the tropics (Dietrich 1941, Schucht 1943). These writers have contributed to the softening of the original meaning of the terms podzol and podzolization, because they confounded podzolization with acid leaching and bleaching as well (Vageler 1938).

Even in recently published pedologic literature podzols and related raw humus soils of the tropics are not sufficiently considered (Aubert 1960, Finck 1963, Fiedler and Reissig 1964, Ganssen 1957, Ganssen and Hädrich 1965, Kellogg 1950, Krause 1958, Pagel 1964, Papadakis 1964, Wilde 1962). Most of the literature considered by these authors has been already cited by Mohr and van Baren (1959), and Richards (1959) who have dealt with tropical podzols in the most detailed manner. According to Richards (1964) most textbooks and soil classifications hardly mention tropical podzols. Duchaufour (1965) believed that podzols are rare in the tropics. Gerasimov and Glazovskaya (1965) mentioned podzolic lateritic soils or podzolic laterites occurring in the tropical regions of America, Africa, Asia and Australia.

The formation of podzols and/or laterites depends upon the intensity of leaching as the major soil forming process, in the humid tropics (Puri 1965).

The main reason why tropical podzols have been neglected so long is no doubt their low agricultural value (Richards 1941, 1964).

In recent years literature on tropical podzols has increased. The bibliography on these soils (Anon. 1962 b) necessarily had to be revised three years later (Anon. 1965 a). The progress of research on tropical podzols has been accounted for by Klinge (1966 c). After this author (Klinge 1966 e) who also published data on the acreage of lowland tropical podzols of the various continents, these soils occupy around 7 millions of hectares.

d. Uplands

According to Richards (1941) there was nothing surprising in the observation of tropical podzols at high elevations, because, except for the small seasonal range of temperature, the climate at high altitude in the tropics may be very like that of cool temperate lowlands.

e. Lowlands

Podzols occurring in the tropics from sea level up to 1,000 m elevation are considered as lowland tropical podzols, in this report. Lowlands may be subdivided in hot lowlands (0-200 m altitude), and hill lands (200-1,000 m altitude) (Mohr 1944, Senstius 1930 a).

The term lowland tropical podzol is induced from the title of a paper by Hardon (1937), and was first used by Richards (1941). The main task of this report is to deal with lowland tropical podzols to be distinguished from the podzols of tropical mountains and temperate regions (Richards 1941). Lowland tropical podzols occurring down to sea level are not found sporadically, but have a wide distribution in the tropical rain forest region of both hemispheres. Their natural vegetation has marked characteristics of its own and may be regarded as an edaphic climax (Richards 1941).

In the opinion of Bramao and Dudal (1959), and Richards (1957), the presence of podzols in tropical lowlands, where climatically they seem out of place, evidently depends more on the nature of the soil forming material than on the soil forming processes themselves.

Lowland tropical podzols may develop with or without influence of groundwater table. If they do so, they are called lowland tropical groundwater podzols, lowland tropical hydromorphic podzols, or gley podzols, thermaquods being a synonym proposed by the U.S. soil classification system (Anon. 1960 a).

II. GLOBAL DISTRIBUTION OF LOWLAND TROPICAL PODZOLS

1. CENTRAL AMERICA, CARIBBEAN ISLANDS, AND FLORIDA

The countries of the Central American isthmus and the Antilles may be treated together, on account of the ecological unit of the Caribbean region to which they belong (Beltrán 1958).

Generally, the knowledge of the soils of the area is limited (Blanck 1939, Maiwald 1939, Pendleton 1945, Stremme 1932). Sapper (1899, 1905) published soil maps of Central America in which podzols are not indicated.

Wright and Bennema (1965) reported on groundwater podzols of the southern Caribbean lowland plain of Central America.

Matthews et al. (1960) described imperfectly drained weakly developed groundwater podzols of the Duablo series (see profile description No 1) developed on old alluvial terraces (probably late Pleistocene to early Recent) which are built up by sandy out-wash material from areas of igneous rocks. The podzols are associated with the Achona soils also subjected to podzolization, but presently of incipient development.

The original vegetation of tropical moist-dry to semi-xerophytic forest with grasses is now cleared. The dominant tree is <u>Curatella americana</u>.

The soils are used for the production of rice, peanuts, and tobacco.

The Duablo series occurs in the Alanje district of southwestern Chiriquí, Republic of Panamá. Possibly they occur elsewhere on the Pacific slope of Panamá, Costa Rica, and other countries.

<u>Profile description No 1</u>

Lowland tropical podzol : Duablo groundwater podzol (After Matthews et al. 1960).

A_1 14 cm Black (10YR 2/1, moist) or dark greyish-brown (10YR 4/2, dry) fine sand with a single grain structure; soft when dry, loose to very friable when moist; neutral; moderate to rather high organic matter content; rapidly to very rapidly permeable when undisturbed; roots pleintiful. 5 to 20 cm thick, with the average near the lower figure; clear smooth lower boundary.

A_2 14 cm Dark grey (10YR 3/1, moist) or light greyish-brown (10YR 6/2, dry) partially leached fine sand with no apparent structure; loose when dry or moist; moderately acid; low organic matter content; very rapidly permeable; roots rather few. 10 to 24 cm thick with the average near the higher figure; abrupt smooth to wavy lower boundary.

B_1 8 cm Very dark greyish-brown (10YR 3/2, moist) or greyish-brown (10YR 5/2, dry) fine sand, structureless to very weakly cemented; slightly hard when dry and slightly firm when moist, with occasional slight streaks of darker or lighter greyish-brown; moderately acid; low organic matter content; rapidly to very rapidly permeable; roots very few. 4 to 10 cm thick (sometimes absent); clear smooth to wavy lower boundary.

B_2 24 cm Very dark greyish-brown (2.5Y 6/2, dry) weakly cemented fine sand with numerous streaks and spots of rusty brown, olive, and bluish-grey; low organic matter content, but somewhat higher in organic matter than horizons A_2 and B_1; moderately to rather rapidly permeable; practically no roots. 12 to 25 cm thick; clear wavy to irregular lower boundary.

C 40 cm plus. Dark grey (10YR 4/1, moist) or grey (10YR 5/1, dry) loose incoherent sand to coarse sand. Individual sand grains (usually partly decomposed rhyolite) may be light or dark grey, pink, brown, blue, etc., but with the greys predominating to give the overall effects indicated above. Slightly acid; very rapidly permeable. Very thick, but thickness undetermined.

Some soils occurring in savannah areas of the southeastern coast of Santo Domingo show podzol characteristics (Balzarotti 1930).

0.4 per cent of the total area of Puerto Rico are occupied by groundwater podzols, under swamp forest (Bonnet 1949, Hardy 1949). Weyl (1966) mentioned very poor quartz sand (glass sand) occurring upon Puerto Rico.

Hardy (1949) mentioned soils of Jamaica resembling the groundwater podzols of Puerto Rico.

The Valencia sand of Trinidad is probably a podzol (Hardy 1940, Richards 1957, Richardson 1963). In the Aripo savannah upon this island similar soils with iron or clay pans occur (Beard 1945, Richards 1957). Groundwater podzols and bleached soils as well have been reported by Hardy (1949), and Hardy et al. (1936). Milne (1940), on a trip to the West Indies and America, saw tropical podzols and groundwater podzols of this island, and the "white sand" soils of British Guiana as well.

Carapite forests (Amanoa caribaea consociations) of Dominica (Beard 1944) are found in waterlogged places. The soils have a very thick surface unit of raw humus, an iron pan in the subsoil, and may be regarded as lowland tropical gley podzols.

According to the opinion of Richards (1941) the blackwater rivers of the tropics are associated with podzols, if there are no peat or swamp formations in the area, tropical lowland podzols may be more widespread in the lowlands of eastern Central America than actually known. For blackwater rivers have been reported by Helbig (1959) occurring in the Miskito savannah of Honduras and Nicaragua (Gierloff-Emden 1963, Parsons 1955, Taylor 1963), where extent sand beds occur (Sapper 1937). Bleached grey-white sandy Pine Ridge soils have been reported by Hardy et al. (1935).

From what is said above it may be concluded that actually little is known on lowland tropical podzols of the region. Some additional information may be included in the botanical literature on the area, recently discussed by Knapp (1965).

In Florida partially belonging to the Caribbean vegetation area groundwater podzols (Leon, Immokallee, and St. Johns fine sands) are widespread (Anon. 1960 a, Beckenbach and Hammett 1962, Davies 1943, Gammon et al. 1955, Henderson 1939, Joffe and Conybeare 1943, Leighty 1961, Leighty et al. 1957). These soils are developed on marine deposits of non-calcareous sands. They are associated with pine flatwoods and dry prairies.

The Immokallee fine sands show light grey to medium grey fine sand 6-8 in. deep underlain by very light grey to white splotched fine sand. At 26-46 in. depth an organic stained layer 4-6 in. thick, not a hardpan, follows. Below this B horizon there are brownish or yellowish fine sands grading into white sand. The Leon fine sands have a more definite hardpan usually much nearer the surface. The organic cemented B horizon enriched in aluminum is thinner than that of the Immokallee soil (Richardson 1930). The depth at which the hardpan occurs appears to be controlled by the groundwater surface (Vernon 1943).

In the vegetation growing on groundwater podzols of Florida Serenoa repens (saw palmetto), Aristida stricta (wire grass), heath shrubs, and Sabal palmetto (cabbage palm) are common plants. The flatwood pinelands and saw palmetto prairies are both edaphic and fire sub-climaxes (Davies 1943).

The groundwater podzols are associated with blackwater rivers, half bog soils, and bog soils (Beck 1953, 1958, Henderson 1939).

2. SOUTH AMERICA

Before Ganssen (1957) quoted a very limited number of publications on lowland tropical podzols of South America, little was known of these soils (Blanck 1939, Matthei 1935 a, 1935 b, 1936/7, Stremme 1932). Hardy (1942, 1945) referred to podzols occurring in nearly the whole Amazon basin where they are associated with groundwater laterites.

In the last years soil investigations in South America have remarkably progressed (Anon. 1962 a, 1964 a, Bennema et al. 1962, Bramao and Lemos 1961, Wright et al. 1964). A modern soil map of South America shows podzols in the Guiana highlands and lowlands as well (Bramao 1966). The detailed legend for the third draft of the soil map of South America (Anon. 1965 b) mentions podzols of humid tropical lowlands, mainly occurring in the Guianas, Brazil, Colombia and Venezuela.

A. Coastal regions

Jenny (1948) described a podzol under forest developed on an alluvial Tertiary ridge, near Buenaventura, Colombia. After Wright and Bennema (1965) podzols occur on coastal terraces of the Pacific coastal lowlands of Colombia.

On the Atlantic coast of Brazil, typical podzols under secondary forest were observed by Vageler (1939/40). They occur on litoral sediments of the Archeano. Kegel (personal communication to H. Sioli, 1963) observed raw humus on top of bleached sand overlying humus pans developed from sandstones of the Formaçao Barreiras in the Zona Verde of Pernambuco and Paraiba. Kegel (1966) referred to podzols both with raw humus and ortstein occurring on elevated surfaces suilt up by the Tertiary Barreiras beds (so-called "chãs"), along the rainy coast of the "Polígono das sêcas". Hueck (1966) mentioned ortstein layers actually being eroded by the ocean, at Cabo Frio, and heath soils with pans under restinga, in the nearby dunes. Intergrades between dystrophic red-yellow podzolic soils to quartz regosols and podzols of the coastal region of southern Brazil have been reported by Wright and Bennema (1965).

It may be added that ectropical podzols occur in southern South America (delta of the Rio Paraná (Bonfils 1962), Tierra del Fuego, Patagonia (Wright and Bennema 1965)).

B. Orinoco basin

Little information on the soils of the Orinoco basin are available (Vareschi 1956). In the soil map of Venezuela (Anon. 1947) no podzols are mapped. Rowles (1966) also does not refer to podzols in Venezuela. The soil map of Hardy (1962) shows an extent area of bleached earths, in the llanos of Venezuela and Colombia. Bonazzi (1957), in his book on the soils of the Venezuelan llanos, did not touch the proble, of podzolization under tropical environmental conditions. Kiener (1954) concluded from his investigations of some representative soils of the upper Orinoco region that they are poor in nutrition elements and have low agricultural value. Van der Voorde (1962) reported on peaty soils of the Isla Macareo, Orinoco delta, but did not refer to podzols.

Due to the presence of blackwater rivers in the upper Orinoco region and in Venezuelan Guiana (de Civrieux and Lichy 1950, Hueck 1961 a, Mägdefrau 1958, 1960, Mägdefrau and Wutz 1961, and others) lowland tropical podzols are supposed to occur there, as already suggested by Chaves (1963). Wright and Bennema (1965) reported on leached, acid, white sands of very low fertility, some of which are podzols occurring on low river terraces of the region.

C. Guianas

Bleached sands, white sand soils, or podzols are widely distributed in the Guiana peneplains (Hardy 1942, Wright and Bennema 1965). The soils bear highly characteristic types of evergreen tropical forest like Wallaba forest (Eperua), Dimorphandra conjugata forest with thick peaty humus on top of the podzol soils (Richards 1945), muri bush (Myers 1936), or even savannah vegetation (Beard 1953, Hoock 1965, Lindemann and Moolenaar 1959). Blackwater rivers rise always in podzol areas. Richards has variously reported on the association of blackwater rivers, podzols, and specific vegetation (Richards 1936, 1941, 1945, 1956, 1957, 1958, Davies and Richards 1933, 1934).

Wallaba forests occur too in the other Guianas, in Venezuela, Colombia, and in some parts of the Brazilian Amazon region; they are always associated with acid white sands (Aitken 1930, Davies 1929, Ducke 1940, Lemée 1961, Lindeman and Moolenaar 1959, Richards 1945, Smith 1945).

After Davies and Richards (1933) the coloration of blackwater rivers is locally considered to be derived from the dead leaves of the Wallaba tree.

a. British Guiana

The white sands of British Guiana were formerly believed to have arisen by the decomposition of granite in situ; recent evidences, however, show that they are more probably Tertiary alluvial deposits formed in a shallow sea, though ultimately derived from granite (Brown 1919, Richards 1957). Rutherford (1964) believes that the white sands of the southern savannah region are deposits of the older higher level rivers and sand banks which under the influence of humic illuviation are degraded in times when rain forest was growing on these sediments. After Bleackley (1964) the White Sand of Berbice Formation is a continental deltaic deposit of Plio-Pleistocene age. Prior to its deposition the land surface was capped with laterite or bauxite portions of which were removed in a pre-Berbice erosional phase (van Kersen 1955). After Bracewell (1956) the white sand belt of British Guiana appears to occupy the valleys of an old river system.

The stratigraphic position of the Berbice Formation is shown in table 2.

Table 2. Stratigraphical subdivision of the Corentyne Series
(After Bleackley 1957, 1964, Bleackley and Dujardin 1959)

Geomorphic unit	Stratigraphic subdivision	Nature of sediments	Age
Young coastal plain	Superficial deposits	Shell beaches, sand ridges, old leves	Holocene
	Demerara clay formation	Soft marine fossiliferous clays	
Old coastal plain	Coropina formation	Marine and brackish silts and clays, clay often mottled	Pleistocene to late Tertiary
White sand "plateau"	Berbice (White Sand) formation	Unconsolidated sands resting on sandy clays, clays and lignits	
		Bauxite	
	Rose Hall formation		Early Tertiary to Mesozoic
	Basement		Precambrian

In order to obtain exact data on the age of the various deposits which are characterized by scarcity or even absence of good marine fossils, palynological studies were realized (van der Hammen 1961 a, 1961 b, 1963, van der Hammen and Wijmstra 1964).

The White sand formation which forms a zone of distinctive topography between the crystallines and the coastal plains (Bleackley 1956) is of specific interest, with regard to lowland tropical podzols.

In the White sand formation podzols with humic pans over 30 cm thick are found below bleached sands, at a depth varying from 6 to 12 m, and overlying reddish sandy loam (Bleackley and Khan 1961, 1963). In other profiles irregular humus iron pans occur at about the level of the watertable, and fall with the latter towards the valleys. White sand can also form the bleaching of residual sands of different ages (McConnel and Dixon 1961, Bateson and Allderidge 1961).

Humic B horizons of podzols (Tiwiwid series) have been encountered by Stark et al. (1959). Giant podzols and groundwater podzols as well are mentioned by Sourdat and Marious (1964).

Bleackley and Khan (1961, 1963) described one white sand body which is of importance for the understanding of the genesis of lowland tropical podzols: "Further, it was observed that the 'muris' could occur in juxtaposition to latosols or red loams, e.g. at Warabaru mine, Ituni, where a white sand body about 50 m wide extends downwards from the surface to the bauxite bed about 12 m below. On the flanks a zone 5-6 m wide occurs with a mottled aspect due to the presence of patches and 'pipes' of white sand set in yellowish sandy loam, each area of white sand surrounded by a boundary crust of dark material. With progressive increase in colour, the mottled zone passes into red sandy loam. Within the white sand body, towards the base, several large patches of red sandy loam are present which show signs of partial bleaching. Samples of the centre of the body, from the intermediate zone, and from the flanking red sandy loam show almost identical size distribution, which would be improbable if more than one phase of sedimentation were involved. However, the most conclusive evidence that these sediments were laid down at the same time was provided by the occurrence of a horizontal layer of gravel, at about 6 m below the ground-level, passing from the white sand through the mottled intermediate zone into the red sandy loam in which it was traced for several metres". The juxtaposition of white sand to red and brown soils has been already observed by Davies and Richards (1933).

From the above description results that the podzols of the white sand body have not developed from a sediment of pure lithological character, but from a latosol or red loam which after the authors, are associated with the podzols.

A description of the samples taken from a podzol profile exposed in the Maria Elizabeth mine at Mackenzie, is given below (see profile description No 2), and the results of mechanical and chemical analyses are reported in table 3.

<u>Profile description No 2</u>

Lowland tropical podzol (after Bleackley and Khan 1963)

	40 cm	Spoil
A_{11}	15 cm	Sandy clay, 5YR 3/1, very dark grey. Sample 1.
A_{12}	15 cm	Sand, 5 YR 3/1, very dark grey. Sample 2.
A_{21}	35 cm	Bleached white sand. Sample 3.
A_{22}	20 cm	Bleached white sand. Sample 4.
A_{23}	15 cm	Transitional into humic layer. Sample 5.
B_{11}	25 cm	Black humic loamy sand. Sample 6.
B_{12}	15 cm	Transitional loamy sand, very hard but moist. Sample 7.
B/G	20 cm	Gleyed sandy loam resting on iron pan 1 cm thick. Sample 8.
	30 cm	Light red sandy loam, 2.5YR 6/8. Sample 9.

Table 3. Data on the above described lowland tropical podzol

Sample No	% Sand	% Silt	% Clay	pH	% C	ppm Fe_2O_3	ppm Al_2O_3	ppm P_2O_5
1	51	2	41	5.2	3.8	13,600	900	6
2	82	3	8	5.4	3.4	5,000	500	7
3	92	1	7	5.6	0.2	nil	nil	9
4	87	2	10	5.8	0.1	nil	nil	9
5	88	1	8	5.3	2.0	500	100	13
6	83	2	9	5.1	3.2	1,400	500	17
7	80	1	12	4.9	3.8	300	1,000	17
8	78	4	16	5.1	1.3	600	1,000	20
9	79	2	18	5.1	0.3	2,900	600	14

Bleackley and Khan concluded from their observations in British Guiana that the progressive transformation of latosols to lowland tropical podzols is accompanied by simultaneous degradation of the original forest cover.

Furthermore, they pointed out that in white sand areas the surface and groundwater as well are characteristically brown in colour. Blackwater rivers of British Guiana are also reported by Carter (1934), Giesecke (1930), and others.

b. Dutch Guiana (Suriname)

The soils of Suriname were first described in 1795 (Dost 1963). In 1963, the first approximation of the reconnaissance soil map of the country at a scale 1:2,000,000 was finished (Anon. 1963 a). A glance on this map shows that groundwater podzols occur the main areas being both the coastal region and the river valleys which mostly run from North to South. After Dost (personal communication, 1963) the oldest groundwater podzols are on Tertiary terrace, remnants of Tertiary depositional plains and pediplains, all of very coarse sandy texture. The bleached zone reaches as deep as 10 m, more often 3 to 5 m. Sometimes several alternating white sand and ortstein (mostly humic sedimentation) layers occur. Very young fully developed groundwater podzols are known, 300 to 400 years old. Frequently, downward movement of percolation water is laterial (Dost 1964). Next to groundwater podzols normal podzols may occur.

Along the northern slopes of the Guianese shield the pre-Cambrian rocks of both British and Dutch Guiana disappear beneath a complex of very young, mostly unconsolidated sediments bordering the Atlantic coast (Brouwer 1953). After van der Eijk (1954, 1957), these young sediments of northern Suriname belong to three geological formations (Table 4).

The Demerara formation, of Holocene age, consists of sea and river deposits. The Coropina formation is of probably young Pleistocene age. The Zandery formation is not older than Miocene, the origin of the material being still uncertain. The supposition of being probably fluviatile deposits (van der Eijk 1957) is supported by the fact of cross-bedding observed in the White sand series of British Guiana which is identical with the Zandery formation of Suriname.

The name White sand formation might give the false impression of being composed by bleached sands only. In Suriname less than 17 per cent of the soils of the Zandery formation are formed by bleached sands, whereas by far the greater part is made up by red sandy clay or even clay (Schulz 1960).

The three Formations are ranged parallel to the Atlantic coast the Demerara formation being the nearest to the sea. It is followed by the Coropina sediments which appear in isolated 'islands'. Farther inland, the deposits of the Zandery formation occur (Schols and Cohen 1953).

Table 4. Geology, belts, landscapes, and soil associations of Northern Surinam
(After J.J. van der Eijk 1957)

Broad Geological Grouping	Geological Formations	Belts	Landscapes		Soil Associations
Young sediments	Demerara	Northern belt, with young soils from sedimentary parent materials	Young coastal plain	Young sea clay landscape	Swamp soils, mangrove-and foreland soils
				River levee landscape	River levee soils
				"Rits" landscape	Coarse sandy "rits" soils Fine sandy "rits" soils Inter-"rits" swamp soils
	Coropina	Middle belt, with mainly old soils from sedimentary parent materials	Old coastal plain	Old offshore bar landscape	"Wal" soils Fen soils Gully swamp soils
				Old sea clay landscape	"Schol" soils Gully swamp soils
			River terrace landscape		River terrace soils
			Sedimentary rest hills		"Sedimentary" laterite soils
	Zandery		"Dek" landscape		Bleached "dek" soils, non-bleached "dek" soils, creek valley soils
Younger intrusives			Dolerite dikes		Dolerite laterite soils
Crystalline basement	Orapu — Rosebel	Southern belt, with mainly soils from residual parent materials	Granite landscapes		Granite yellow earths Granite laterite soils
	Orapu — Maäbo		Schist landscape	Subgraywacke landscape	
				Schist hill landscape	Schist laterite soils, foot plain soils, creek valley soils
	Balling			Schist mountain landscape	

After Schols (1956) the most conspicuous features of the young continental deposits are large areas of white quartz sands on which savannah vegetation is found; the occurrence of savannah, however, should not be taken as a definite indication of this formation.

In the young coastal plain podzols occur on 'ritsen' (= ridges, Geijskes 1952), in badly drained sites (van der Voorde 1955, 1957). Podzolization is less pronounced if the soils are well drained. The vegetation is classified as evergreen seasonal forest.

The 'wal' soils of the old coastal plain form a hydrosequence. 'Wal' soils of high plateaux have a 20 to 40 cm thick humic pan, almost at a depth Of 90-150 cm. On low lying plateaux the bleached sand horizon reaches 40-90 cm down. Below, a thin B horizon appears. The vegetation is evergreen seasonal forest. On high summits, Wallaba forests occur (Lindemann 1953).

The soils of the old coastal plain are described by van der Eijk and Hendriks (1953). Groundwater podzols of both the Rysdyk and Pallisade series occur in this landscape (van der Voorde 1957).

In the 'dek' landscape widely different soils have developed, from the original parent material :

Bleached 'dek' soils, completely white bleached owing to a very strong podzolization, and
non-bleached 'dek' soils.

Different clay contents of the original sediments are probably responsible for the development of these two soil associations.

On bleached 'dek' soils (see profile description No 3), four vegetation types are observed :

Profile description No 3

Lowland tropical podzol (Zandery series)
(After J.J. van der Eijk 1957)

A_{11} 2 cm White, loose, moderately coarse sand.

A_{12} 28 cm Greyish brown, loose, moderately coarse sand, in which the white grains of quartz are conspicuous.

A_{13} 25 cm Light brownish grey, loose, moderately coarse sand, gradually merging in

A_2 230 cm White, loose, moderately coarse sand.

B_{h1} 20 cm Very dark brown, moderately coarse sand, cemented into a hardpan by organic matter.

B_{h2} 5 cm Very dark brown, moderately coarse sand with rounded gravel, constituting the lower part of the hardpan.

D 310 cm+ Greyish brown, non-sticky, plastic clay, rich in very fine mica plates. Weathered schist.

Poor vegetation of mainly grasses and Cyperaceae, or open savannah of the Zandery type. Well drained podzols occur of which the humus ortstein 15 to 30 cm thick occurs in 2 to 3 m depth. In some places different B layers are found, one above the other, which are described too by Bakker et al. (1953).

More or less dense scrub vegetation of mainly Humiria and Clusia of the Cassipora savannah type.

Savannah woodland with dark red matted or fibrous raw humus, and thin humic pans in the subsoil, often in 60-90 cm depth. Evergreen seasonal forest in which Wallaba dominates in the canopy.

The creek valley soils of the 'dek' landscape are often built up by completely bleached sediments which on the surface are dark coloured by humus. If they are waterlogged during the year, peat formation takes place.

Badly drained foot plain soils of the schist hill landscape are highly podzolized. In 40 to 90 cm depth illuviation of organic matter and/or iron compounds is observed (see profile description No 4).

Profile description No 4

Lowland tropical podzol (Bosland series)
(After J.J. van der Eijk 1957)

A_1	30 cm	Greyish brown, very friable fine sandy loam.
A_{21}	15 cm	White, very friable, fine sandy loam.
A_{22}	20 cm	White, fine sandy loam of very close packing. This 'fragipan' has a compact consistence, but, once dug out, the material is of very friable consistence.
B_{2h}	20 cm	Dark reddish brown hardpan, consisting of sericite containing 'silt loam', cemented by iron oxides. Many brown and grey mottles.
D	95 cm+	Mottled white and brown, kaolin-like 'silt loam', rich in sericite; feels greasy and displays a silky gloss. Some very coarse sand in the upper part.

The typical profile of groundwater podzols with bleached eluvial horizon and dark coloured hardpan is not fully developed in all cases where bleaching of sandy soils is observed (van der Voorde 1956).

The agricultural value of the bleached soils is very low, on account of their low nutrient content and poor permeability of the illuvial layer. If the agricultural area of the old coastal plain is to be extended, it would be desirable not to use the bleached sands.

Important contributions to the knowledge of lowland tropical podzols in Suriname have been made by investigators who studied the relations existing between vegetation and soils, especially between savannah vegetation and soils (Beard 1953, van Donselaar 1965, van der Eijk 1957, Lanjouw 1936 a, 1936 b, 1954, Lindemann 1953, 1965, Stahel 1945, and others). Cohen and van der Eijk (1953) recognized ten savannah types corresponding with the landscapes (van der Eijk 1954) or soil associations to which they belong. Van der Voorde and Hooijsma (1956) reported on soil and water conditions in a savannah area with groundwater podzols of the Zandery formation.

Schulz (1960) studied vegetation and soils of both Mapane and Upper Coesewijne regions. He found that the boundaries of open savannah and savannah forest, and of bleached sands coincide exactly, whereas rain forest is found on red coloured soils containing at least 5 per cent clay. Creeks rising in bleached sand regions of the Zandery formation are typical black-water rivers. In the Mapane region very seldom only a hardpan is found in the bleached soils. Schulz put forward the hypothesis that the formation of the bleached sands being lowland tropical podzols is strongly accelerated by repeated burning of the vegetation, practised by the natives. Bakker (1951, 1954) attributed the savannah belt to both edaphic and anthropogenic factors.

Heyligers (1963), in his study on the savannah vegetation of Suriname, dealt broadly with the white sandy soils. He described various bleached soil profiles, some with a hardpan in the subsoil, and others without. Heyligers observed that on the border line with the white sandy soils the red sands show features which point to a translocation of humic sesquioxidic substances as well, and that the white sandy soils are developed from these latosols. The author reached the conclusion that under present day conditions the bleaching of the sandy deposits gives no rise to permanent illuvial layers, and that the white sandy soils are neither podzols sensu strictu nor groundwater podzols, but merely leached sands.

Bakker (without year) reported on snow-white bleached sand which is due to extremely acid leaf extract and litter, e.g. of Dimorphandra conjugata.

c. French Guiana

The White sand series (Berbice formation) of British Guiana being identical with the Zandery formation of Dutch Guiana, has its equivalents in the "sables blancs" of French Guiana (Cruys 1959, Boyé and Cruys 1961, Schols and Cohen 1953). The vegetation of French Guiana is closely related to that of Suriname (Aubert de la Rue 1958, Beard 1953, Heyligers 1963, Lanjouw 1936).

After Boyé and Cruys (1961) the coastal sedimentary formation of French Guiana forms a smaller belt along the coast that it does in the other Guianas. Below the grey-white sand, often podzolized, of the Coropina - Coeswijne series, there occurs a humic hardpan few inches thick which may represent a buried soil. The upper continental white sands usually are considered to represent the middle or the lower Pleistocene. There are three main types of continental white sands, in French Guiana :

Eluvium from metamorphic rocks, leached in situ.

Transported sediments, sorted by stream action, and

Pluvial washed-out sands.

Colmet-Daage (1953) mentioned strongly lessiviated and often podzolized soils with B_T and B_h horizons, respectively, which have developed from continental sediments of the coastal plain.

D. Amazon basin

This region bordered by the Guianese shield, Andes, Central Brazilian shield, and the Atlantic Ocean is made up by the eastern lowlands of Colombia, Ecuador, Peru, Bolivia, and the Brazilian portion of Amazonia.

Early information on lowland tropical podzols of Amazonia is given by von Humboldt (1958), and Spruce (1908). Some occurrences of the so-called Pará sandstone (Katzer 1903) possibly are iron ortstein layers of podzols.

In the geographical and ecological literature concerned with the region reference is made to the association of podzols, specific vegetation covers, and blackwater rivers (Bluntschli 1921, Braun-Blanquet 1964, Beard 1953, de Castro Soares 1956, Fochler-Hauke 1963, Fosberg 1950, Hackemann 1962, Hueck 1957, 1961 b, 1966, Huber 1910, Klinge 1966 b, 1966 c, 1966 d, Klinge and Ohle 1964, Koegel 1914, 1930, Muntz and Marcano 1888, Schimithüsen 1959, Sioli 1966, Sioli and Klinge 1961, 1962, 1965, Walter 1960, 1962, and others). Special reference is made here to the work of Richards who in various occasions discussed the mutual relationships between vegetation, blackwater rivers, and lowland tropical podzols (Richards 1941, 1945, 1956, 1957, 1964, Davies and Richards 1933, 1934).

Limnological studies on rivers of Amazonia are associated with the names of Braun (1952), Gessner (1955, 1958 a, 1958 b, 1959, 1960 a, 1960 b, 1964), and Sioli (1951, 1954 a, 1956 b, 1964). Sioli (1954 b) studying blackwater rivers of the Upper Rio Negro region concluded that these rivers flow from podzol areas.

Pedological literature on Amazonian podzols is scarce. Giesecke (1930), de Castro Soares (1956), Camargo (1958), and Mohr and van Baren (1959) did not mention podzols. None of twelve publications on Amazonian soils of "Amazonia. Bibliografía 1614 - 1962" (Anon. 1963 c) deals with podzols.

There is considerable doubt whether the exact chemical process occurring in Amazonian soils is laterization or tropical podzolization (McGrath et al. 1953).

The soil map of South America (Hardy 1942, 1945) shows both podzols and groundwater podzols associated with groundwater laterites, in the whole Amazon region. Snow white porous quartz sand called product of tropical podzolization, by some people, is mentioned by Sakamoto (1959).

The most modern and most comprehensive study on Amazon soils has been published by Sombroek (1966) who referred to stripe-like patches of groundwater humus podzol on Pleistocene terraces, white sandy regosols and shallow Pará podzols, without cementation in the B_h horizon.

According to this author, the thickness of the A_2 of the groundwater podzols varies from 20 to 200 cm and more. No data on extention of these soils are given in Sombroek's study, in which reference is also made to Bog soils, Half Bog soils and Humic Gley soils, intergrade to groundwater podzols.

Colombia and Ecuador : The soils of the eastern portions of both countries are acid and poor (Hubach 1955). No exact information on lowland tropical podzols is available (see Grubb and Whitmore (1966) who wrote that podzolization may go on at any altitude within the tropics provided that physical conditions are suitable and that plants occur with leaf-leachates able to mobilize iron in the soil; but they did not find podzols in the forest area studied by them). In the Llanos Orientales of Colombia, no podzols were found (Anon. 1964 c). After Grubb et al. (1963) the soils of eastern Ecuador show aspects which remember brown forest soils, podzols, or both, of temperate regions.

Peru : Little is known about the soils of the vast Peruvian Amazon plain (Anon. 1963 b, 1964 b). The most extensive soils are highly acid latosols (Drosdoff et al. 1961). Ellenberg (1959) met woth 2 to 3 m deep 'pockets' of humus orterde of strongly bleached lowland tropical podzols, near Iquitos where blackwater rivers occur (Uhle 1907 a). These podzols are said to have developed from dune sands (Ellenberg 1964 a).

Bolivia : The soils of the humid tropical portion of northern Bolivia are scarcely yet explored (Anon. 1964 b, Wright 1964, Storie 1953). Herzog (1910) described dwarf forests growing on white sand. Wright (1964) described a soil (El Palmar loamy sand) which is regarded as a mature soil trending towards a subtropical gley podzol, and other soils characterized by clay eluviation.

It is suggested that in the above mentioned four countries lowland tropical podzols occur in greater extent than actually known.

Rio Negro basin : In this river basin white or bleached sands occur under evergreen forests which are called caatinga (catinga) to be distinguished from caatingas of the arid Northeast of Brazil (Cole 1960). Caatingas of the Rio Negro type (or caatinga amazonica) are very abundant in the granite area of the Upper Rio Negro and Upper Orinoco where the rock is covered with barren white sand (Mägdefrau 1960, Rice 1921, Spruce 1908), and blackwater rivers occur, the Rio Negro being the biggest of all (Hueck 1961 a, 1966, Ule 1907 a, Vareschi 1963). Both the kind of water and vegetation nourished by it depends entirely on the nature of the soil (Spruce 1908). Sombroek (1966) refers to caatinga amazonica occurring in the carchment area of the upper and middle Rio Negro and also in the upper Amazon region near São Paulo de Olivença.

In the Rio Negro caatingas some species of the genus Eperua are frequent (Ducke 1940). These forests resemble the Wallaba forest of the Guianas (Davies and Richards 1934, Richards 1961), with regard to both floristic composition and soils. Physiological data for plant species frequent in these caatingas were published by Ferri (1959, 1960, 1961) who expressed the opinion that caatingas seem to be conditioned by soil deficiencies. Phytosociological studies of caatingas were performed by Ducke and Black (1954), and Rodriguez (1961). Aubréville (1958, 1961) proposed the term "fourrés et forêts basses amazoniens sur sable blanc", for caatingas and similar forest types which, on his judgement, are the finest examples for the importance of soils, from the ecological standpoint.

Soil investigations in caatingas were carried out by Vieira and Filho (1962). The highly sandy caatinga soils are low in organic matter, exchangeable cations, and phosphorus as well, but have a rather narrow C/N ratio varying between 9.4 and 13.6. Exchangeable hydrogen and aluminum are high. These authors classified the soils as regosol on sandy fluviatic sediments, over buried soils of granitic origin. In the opinion of Sombroek (1966) these soils have developed on Pleistocene terraces of the area.

Klinge (1962) published data on both humus and nitrogen contents of lowland tropical podzols from caatingas of the Upper Rio Negro. In the same paper, data are given for a podzol near Manáus, Lower Rio Negro.

In the Manáus area low forests are frequent which are similar to the Rio Negro caatingas (Richards 1941, 1945, Sombroek 1966) with Eperua species (Ducke and Black 1954, Takeuchi 1960 a, 1961, Ule 1907 a, 1907 b), or carrasco (Aubréville 1961), these local names being applied without agreement between the various authors (Takeuchi 1962). These low forests are also known by the local name of campina (Ducke and Black 1954, Sombroek 1966); Lecointe (1907) found they occur in the area between the lower course of the Rio Negro and the Trombetas.

Klinge (1965) described soil catenas developed on probably fluviatic deposits ('brown sand') laid down in small valleys with blackwater rivers, in the surroundings of Manáus (Sombroek 1966). The lowest lying members of these catenas are lowland tropical podzols. These podzols have gradational contact with flanking brown soils (braunlehm sensu Kubiena 1953). In some cases the podzols are waterlogged or even flooded by high water, in others there is no groundwater influence (see profile descriptions No 5 and 6). From Klinge's field observations and micromorphological studies on the soils of the catenas (Altemüller and Klinge 1964) it is concluded that, if the soils on 'brown sand' are on slopes, apparent lessivation takes place which is accompanied by downward movement of organic matter leading to the formation of a bleached white sand layer A_2, over an illuvial horizon in which clay and organic matter have accumulated. When lessivation has become stronger, podzolization starts leading to the formation of a podzol B horizon. In profiles directly flanking the podzols are two B horizons : the upper one is due to podzolization and continues to the B horizon of podzols at the valley bottom. The lower one is due to lessivation and continues to the humic argillic horizon of the textural brown soils on the upper slopes which have been tentatively named eluviated braunlehm.

Profile description No 5

Lowland tropical podzol : groundwater podzol. Rio Cuieiras, State of Amazonas. (After Klinge 1965, cf. fig. 3)

A_{oo}	1 cm	Loose litter
A_{11}	3 cm	Brownish grey sandy loam, well rooted.
A_{12}	3 cm	Humic grey sandy loam, weakly rooted.
A_2	25 cm	Light grey loamy sand, rooted. Some darker patches.
B_{h1}/G	90 cm	Light brown loamy sand with fine gravel. Some rotten sandstone fragments.
B_{h2}/G	4 cm	Brownish black sandy loam. Orterde cemented by humic substances. Organic matter surrounds well rounded sandstone fragments of children's head size. Groundwater level in november 1962 at 124 cm depth, during rainy season much higher.
D	126 cm+	Clayey sandstone, bleached.

Profile description No 6

Lowland tropical podzol : giant podzol. Near Manáus (After Klinge 1965, cf. fig. 4).

A_o	20 cm	Raw humus plus spoil.
	10 cm	Raw humus rich in bleached quartz grains.
A_h	100 cm	Dirty grey humic sand, well rooted. Merging in
A_e/B_h	240 cm	Dirty grey quartz sand with numerous fine humic stripes parallel to the surface. The lower boundary of this horizon is very irregular. In some places bleached sand 'pipes' surrounded by a small zone of humic cemented sand penetrate the B layers.
B_h	5 cm	Blackish brown humic cemented orterde
B_s	15 cm	Reddish brown loam, weakly endurated. Merging in
B_t	370 cm+	Pale yellow loam of braunlehm character.

With two B horizons are braunlehm podzols. Soils under high tropical rain forest developed on Barreiras deposits and occuring on flat 'terra firme' (non-flooded land, de Oliveira 1956) plateaux show weak lessivation. This fact is mentioned also by Sombroek (1966). In these soils there is generally no bleached horizon, but small patches of bleached sand, at the upper boundary of the mineral soil.

Putzer (personal communocation, 1965) holds the opinion that the soils on 'brown sand' are geologically younger than those on the Tertiary terra firme. The deposition of the 'brown sand' is suggested to have occurred during a Pleistocene pluvial phase.

There is no doubt that the podzols develop from eluviated braunlehm as parent soil. This result resembles much those obtained in the Guianas by Bleackley and Khan (1961, 1963), Heyligers (1963), and Schulz (1960), in Sarawak by Wood and Beckett (1961), and in Central Africa, by Sys (1956).

White sandy soils of some metres depth occur in the Rio Branco (Takeuchi 1960 b) and Rio Negro area as well. These soils may have developed from giant podzols which by progressive leaching lost the B horizon, or theu are regosols developed from white sandy parent material. Sombroek (1966) states that groundwater laterite soils, low phase, may also have a bleached top sandy which can lead to confusion with the white sandy regosols described by this author and by others.

Middle and Lower Amazon : Recent soil studies revealed that lowland tropical podzols associated with blackwater rivers occur too in these portions of the Amazon region (Wright and Bennema 1965). After these authors quartz regosols and sandy podzols are found on ridges parallel to the coast.

Patches of white sand were encountered by Heinsdijk (1958 a, 1958 b, 1958 c), at various places south of the Amazon river. The vegetation consisted in caatinga forest, scrub vegetation, and grass shrub. Often these white sandy soils were found to occur along the rivers, on river deposits.

In the Brazilian State of Pará, the soils developed on Pleistocene deposits (Ackermann 1964). The soil map of the Zona Bragantina (Anon. 1954/60) shows some small patches of hydromorphic regosols and podzols (Egler 1961). Falesi (1964) mentioned deep podzols with both iron and humus ortstein occurring near creeks.

Lowland tropical podzols (groundwater podzols and normal podzols) have been studied by Klinge (unpublished, 1962), south of Vigia, Pará, and were mapped by Filho et al. (1963) (Sombroek 1966) as regosol-groundwater podzols. These soils are found under grass (campo), and dwarf forest (campina baiza), and are characterized by low content of organic matter and lack of a raw humus unit, at the soil surface. Hydromorphic podzols on Quaternary sand southeast of Breves, Pará, are described by Vieira and Santos (1962), who published some analytical data for these soils, and a soil map of the region.

Day (1961) reported on groundwater podzols developed on Quaternary sediments often associated with bogs, half bogs, and sandy regosols. Profile description No 7 is quoted from Day's report.

<u>Profile description No 7</u>

Lowland tropical podzol : groundwater podzol (After Day 1961)

A_1	30 cm	Dark brown (7.5YR 3/2) organic loamy sand. Has a pepper and salt appearance due to light coloured sand grains mixed with dark organic matter. pH 4 or lower.
A_2	20 cm	Light grey (10YR 7/2) loose structureless sand. pH 4 or lower.
AB	20 cm	Brown (7.5YR 4/4) loamy sand.
B_{21}	10 cm	Dark reddish brown (5YR 3/4) organic iron cemented pan (ortstein). pH 4 or lower.
B_{22}	10 cm	Dark reddish brown (5YR 3/4) loamy sand.
C	50 cm	Brown (10YR 5/3) loamy sand. pH 4 - 4.5

He found considerable variation in the state of induration in the B horizon which ranges from being almost undetectable in compaction with an auger to being penetrable only with difficulty. These groundwater podzols occur in small drainageways, and are probably widespread throughout the Lower Amazon. They are of very limited extent in any individual unit, and its total area is relatively small.

Groundwater humus podzols near São Miguel do Guamá are described by Sombroek (1966) who also gave analytical data on one profile (profile description No 8, table 5). In the Guamá-Imperatriz area surveyed by the same author, patches of groundwater podzols were found, likely to have developed on the sandy Corda beds.

Profile description No 8

Lowland tropical podzol : Groundwater humus podzol (After Sombroek 1966, p. 154).

A_1 10 cm Dark brown (7.5YR 3/2) sand, spotty by presence of very many white sand grains. Single grains. Moist, loose. Not sticky when wet. Soft when dry. Many roots. Many pores. Transition clear and spotty.

A_2 35 cm Light grey (10YR 6/1) sand. Single grains. Moist, loose. Not sticky and not plastic when wet. Soft when dry. Many pores. Many roots. Transition gradual and smooth.

B_{1h} 15 cm Dark grey (10YR 4/1) sand. Weak, medium to fine subangular blocky structure. Moist, friable. Not sticky and not plastic when wet. Slightly hard when dry. Many pores. Many roots. Transition abrupt and irregular. Krotovinas of B_{1h} penetrating into underlaying horizon.

B_{21hm} 20 cm Ortstein: brown to dark brown (7.5YR 4/2) loamy sand. Massive, indurated. Moist, extremely firm. Extremely hard when dry. Not sticky and not plastic when wet. No pores. No roots. Transition abrupt and broken.

B_{22hm} 30 cm Ortstein: brown to dark brown (7.5YR 4/4) loamy sand. Massive, strongly cemented. Moist, very firm. Very hard when dry. Not sticky and not plastic when wet. No pores. No roots. Transition gradual and irregular.

B_3 40 cm Light olive brown (2.5Y 5/4) sand. Single grains to weak, medium to fine subangular blocky structure. Moist, very friable. Not sticky and not plastic when wet. No pores. No roots.

Day reported also on well drained podzols (see profile description No 9), of extremely limited extent, occurring in close association with sandy yellow latosols, and well drained white sand regosols.

Profile description No 9

Lowland tropical podzol : Pará-podzol (After Day 1961)

A_1 15 cm Finely mixed black and light grey (40 + 60 %) loose structureless organic sand. pH 3.8. Boundary clear and wavy to the A_2.

A_2 30 cm Pinkish grey (7.5YR 7/2) very loose structureless sand. pH 4.0. Boundary to B_{2h} abrupt and intermittent to wavy.

B_{2h} 15 cm Dark brown (7.5YR 3/2) massive very friable loamy sand. Some compaction. pH 4.2. Lower boundary gradual and wavy.

B_{22} 20 cm Dark brown (7.5YR 4/4) massive very friable loamy sand. pH 4.6. Boundary gradual and wavy.

B_{23} 30 cm Dark yellowish brown (10YR 4/4) massive very friable loamy sand. Diffuse and smooth boundary to A_{1b}.

A_{1b} 30 cm Dark brown massive very friable loamy sand. Several carbon fragments. pH 5.2. Diffuse and smooth boundary to the B_{2b}.

B_{2b} 100 cm Light yellowish brown, massive, very friable sand. pH 5.0. Boundary to C diffuse and smooth.

C 240 cm+ Yellow (2.5Y 7/6), loose structureless sand. Water table at 250 cm.

Table 5. Analytical data for lowland tropical podzol (groundwater humus podzol) of eastern Amazonia (After Sombroek 1966)

Horizon	A_1	A_2	B_{1h}	B_{21hm}	B_{22hm}	B_3
Depth (cm)	0-10	10-45	45-60	60-80	80-110	110-150
Coarse gravel %	0	0	0	0	0	0
Fine gravel %	0	0	0	0	0	0.7
Coarse sand %	61.1	59.0	58.4	57.5	55.0	56.1
Fine sand %	36.3	39.2	35.6	33.7	36.3	37.8
Silt %	2.2	1.2	1.8	2.1	1.5	1.8
Clay %	0.4	0.6	4.2	6.7	7.2	4.3
"Natural clay" %	0	0.2	1.4	1.3	1.5	1.8
Index of structure	100	67	67	81	79	57
Fine earth attacked by H_2SO_4 conc.						
SiO_2 %	0.70	0.52	1.97	2.19	2.23	1.42
Al_2O_3 %	0.51	0.41	1.64	3.38	3.54	1.76
Fe_2O_3 %	0.10	0.20	0.30	0.32	0.32	0.20
TiO_2 %	0.10	0.08	0.31	0.32	0.26	0.18
P_2O_5 %	0.02	0.02	0.02	0.03	0.03	0.03
$\frac{SiO_2}{Al_2O_3}$	2.34	2.18	2.04	1.10	1.07	1.37
$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$	2.09	1.64	1.82	1.04	1.01	1.27
C %	0.60	0.10	0.40	1.89	1.81	0.60
N %	0.05	0.01	0.04	0.13	0.12	0.04
C/N	12.0	10.0	10.0	14.5	15.3	15.0
pH(KCl)	4.2	3.8	3.7	4.2	4.5	4.8
Moisture equivalent g/100 g	3.0	2.1	4.8	10.4	9.9	5.5
P_2O_5 mg/100 g						
Truog	0.7	0.5				
Bray	1.9	0.6	1.9	0.7	0.4	1.9
Exchangeable Cations						
Ca^{++} + Mg^{++}	0.84	0.30	0.30	0.23	0.27	0.26
K^+	0.05	0.03	0.03	0.06	0.07	0.08
Na^+	0.02	0.02	0.02	0.02	0.02	0.03
S value	0.91	0.35	0.35	0.31	0.36	0.37
$(Al)^+$	0.12	0.16	0.80	1.94	0.97	0.24
H^+	1.28	0.44	2.21	10.34	10.18	3.01
T value	2.31	0.95	3.36	13.59	11.51	3.62
V value	39.4	36.8	10.4	2.3	3.1	10.2
Textural ratio				5.0		

The podzols were found on Pleistocene deposits near Belém, Pará, and also on parts of the Tertiary plain of Amapá. They resemble the soils studied by Blackley and Khan (1961, 1963), in British Guiana. In the opinion of Day the podzols are more in a stage of development rather than associated with a particular geologic deposit (Boyé and Cruys 1961).

With regard to the State of Pará, Day (1959), Sombroek (1966), and Heinsdijk (1957, 1958 a, 1958 b, 1958 c, 1960) referred to groundwater podzols and white sand regosols as well occurring mostly in small patches or in narrow bands along the rivers.

For the well drained lowland tropical podzols Day proposed the name Pará (from the name of the Brazilian State of Pará) podzols. This name seems not to be well chosen, because it may be confounded with para-podzols (Mihalic 1963), a denomination like para-braunerde, para-rendsina, and others in which the prefix 'para' refers to a soil forming process (as in the case of para-braunerde), or soil parent material (as in the case of para-rendsina) deviating from the 'norm' (braunerde, rendsina) (Ganssen 1961 a).

It is remarkable that in the Amazon basin lowland tropical podzols and associated white sandy soils as well occur mostly in creek valleys. This fact is explained to some extent by Demangeot's (1959) reconstruction of the geological evolution of Central Amazonia (Table 6), or by Vann (1963) who explained white sand beds in valleys of Amapá as remnants of an old laterite crust which is removed by erosion.

Table 6. Geological evolution of Central Amazonia (After Demangeot 1959)

Phase	Events
5	Filling up of great river beds. Flandrien ?
4	Renewing of erosion. Formation of large and deep river beds.
3	Formation of drainage system which attains its maturity. Sedimentation of white sands (D_1)
2	Warm humid and arid climates. Deposition os strata B, C and D
1	Sedimentation of the Barreiras beds. Lateral support from erosion surfaces. Pliocene ?

In summarizing up what is said about the Amazon podzols, from Sombroek's important publication is quoted the following table 7. He concluded his chapter on vegetation and soil,

Table 7. The savannahs and savannah-forests of Amazonia, in their dependence upon edaphic factors

Land form	Drainage condition	Soil	Vegetation type	Climate (after Köppen)
Parts of Early Pleistocene Terraces	excessively drained	White sand regosol (giant podzol)	patchy savannah forest (campina rana)	Am
Elongated patches, often along rivers, of Late Pleistocene sandy terraces	imperfectly drained	groundwater podzol	patchy savannah forest (caatinga amazonica)	Af
idem	idem	idem	patchy savannah (campina)	Am

insofar as podzols and white sandy regosols are concerned, as follows : "It is evident that all savannahs and the majority of the savannah-forests of the Planicie, outside the north-eastern belt, are found on terrain of imperfect drainage, with hydromorphic soils (groundwater humus podzols). These soils seem to be predominantly associated with savannahs or savannah-forests on strips of sand, relatively low upland along the rivers and on sand-filled former riverbeds. Some patches of savannah-forest occur on relatively high, freely draining terrains where the soil is deeply white sand (white sand regosols). Most of these soils seem actually to have been very deeply and intensively bleached in situ and giant podzols therefore might be a more accurate classification".

Climatic changes connected with contemporaneous changes of both vegetation and sedimentation, during geologically young times, are discussed by Ab'Saber (1957), Cailleux and Tricart (1957), Wilhelmy (1951), and van der Hammen (1961 a, 1961 b).

3. AFRICA SOUTH OF THE SAHARA

In relation to lowland tropical podzols, bleached and white sands of this continent, it has been ascertained by Richards (1961) that "there appears to be nothing closely comparable with the white sands and their characteristic vegetation of South America or SE Asia".

Scaetta (1937) takes the view that true podzols do not occur in hot regions of Africa. Ganssen (1957) citing Kubiena (1957, 1964) refers to podzols of higher elevations, in southern Africa, and Baker (1962) mentions that soils of the podzol type "are very rare in West Africa, although occurring in limited areas under mangrove and in some south-western freshwater swamps behind the coast". Schokalskaja (1953) is of the opinion that podzolization occurring in Africa is not identical with that taking place in temperate regions.

Raw humus formation is mentioned by Aubert (1960), for the Republics of Gabon, Congo, and Cameroon.

Aubert (1963) referred to sheet podzols on sandy material represented in French speaking Africa. Kellogg (1949) mentioned briefly groundwater podzols of Central Africa. D'Hoore (1964) described lowland tropical podzols occurring in the coastal zone of the Ivory Coast, in the Congo basin, and upon Madagascar. In the soils map of Africa (D'Hoore 1964) these soils are shown near Abidjan (cf. sheet 5), and in the surroundings of Yangambi (cf. sheet 2). The groundwater level in these soils is found at not more than 2 m depth (D'Hoore 1963 a, 1963 b, 1964).

A. Western Africa

Lowland tropical podzols occurring in western Africa have been studied in the Ivory Coast, Ghana, and Cameroons. Little or nothing is known of the other countries, with respect to these soils. Podzols of the Congo basin are dealt with separately.

Jungerius (1964) and Bakker et al. (1966) mentioned soils over iron pan which are relatively minor in extent, in the coastal plains of Nigeria. The latter also referred to infertile greyish-white sands on older bench ridges of the Western Region of Nigeria. Sandy regosols (Reed 1951) and bleached fine white sand, the latter on sites which formerly were occupied by lagoons, have been reported from the coastal area of Liberia, by Thirgood (1965).

In western Africa, lowland tropical podzols occur in isolated patches, in a small discontinuous savannah belt between the shoreline and the tropical rain forest area behind (Ahn 1959, Baker 1962, D'Hoore 1961, Leneuf and Aubert 1956, Mangenot 1958, Müller and Nielsen 1965). The origin of the savannah area in the Ivory Coast has been discussed by Jaques-Félix (1948). Tricart (1962) reported on these savannahs, in relation to climatic oscillations during the Pleistocene.

Guinea : Raw humus soils on quartzitic parent material have been reported by Aubert (1955, 1960), and bleached sand underlain by ortstein has been mentioned by Vageler (Harrassowitz 1926).

Ivory Coast : A glance at the soil map of this country (Leneuf and Mangenot 1960, Dabin et al. without year, D'Hoore 1964) shows that hydromorphic podzols occupy a small band running parallel to the coast, in the eastern part of the country, the vegetation of which is described by Mangenot (1958), and Leneuf and Mangenot (1960). Plant communities of river banks resembling both the Guiana consociations and Sarawak heath forests are reported by Richards (1945). Leneuf and Ochs (1956) described a groundwater podzol on littoral sand, in the Abouabou forest (Anon. 1961, Müller 1958), and a profile developed on slightly clayey littoral sand, near Fresco (See profile description No 10 and 11).

Profile description No 10

Lowland tropical podzol : groundwater podzol of the Abouabou forest.
(After Leneuf and Ochs 1956)

A_{oo}		Litter
A_o	5 cm	Crumbling red raw humus. Abundant roots.
A_1	25 cm	Weakly humic sand, less rooted.
A_2	115 cm	Greyish white sand. Some big roots.
B_h	55 cm	Brownish black humic cemented sand. Rooted. Upper boundary irregular.
G/C	20 cm	Red sand. Groundwater level.

Profile description No 11

Lowland tropical podzol : groundwater podzol near Fresco.
(After Leneuf and Ochs 1956)

A_{11}	0,1 cm	Greyish white sand.
A_{12}	9 cm	Humic sand. Upper 2 to 3 cm blackish grey, below greyish beige. Root mat.
A_2	100 cm	Beige sand. Some roots.
B_h	40 cm	Brown humic sand. More compact than upper horizons.
	30 cm	Light brownish ochre sand. Ferruginous patches of ochre colour.
G/C	40 cm	Beige-ochre sand. Groundwater level.

The authors included some analytical data for both podzols (Table 8) the groundwater level of which is found in 0.2 to 2 m depth.

"Pseudopodzols de nappe à alios humo-ferrugineux" on old littoral sand are mentioned by de la Souchère and Leneuf (1962), in the western portion of the Ivory Coast.

Ghana : The flat grass savannah patches each of small extent, are situated along the Nzima littoral a short distance behind the shore. The main grass is Hyparrhenia spec. The soil (Atuabo Series belonging to the Fredericksburg association) is a groundwater podzol (Ahn 1959, 1960, 1961 a, 1961 b, Brammer 1962), and is thought to have developed on sandy alluvium of former lagoons. These soils are flooded for parts of the year, and dry and parched at others.

The normal soil profile consists of a very poorly developed pale grey topsoil only an inch or so thick, very low in humus, over pale greyish white to white fine sand about 30 in. thick, over a massive humic pan which often extends 20 in. In some places the organic pan is not well developed; in other areas a slightly darker topsoil is formed, while in the relative minor areas of prolonged waterlogging a thin black peaty topsoil accumulates.

Analytical data for the Atuabo series show that the acid soils built up by fine earth only are very low in exchange capacity, organic matter and nitrogen as well (Table 9).

Table 8. Analytical data for lowland tropical podzols of the Ivory Coast (After Leneuf and Ochs 1956)

	Port-Bouet					Fresco			
Horizon	A_0	A_1	A_2	B_h	G/C	A_{12}	A_2	B_h	G/C
Depth (cm)	0-5	5-10	50	150	220	0-10	80	100-120	180
Coarse sand %	10.3	94.0	91.6	85.0	88.5	87.8	78.0	63.3	61.9
Fine sand %	0.5	2.2	6.6	4.8	7.7	4.4	18.7	17.0	28,5
Silt %	0	1.5	0.7	1.0	0.5	1.2	0.2	1.0	1.1
Clay %	0	0.7	0.7	0.7	0.5	3.2	2.2	6.5	6.0
Organic matter %	52,3	1.7	0	3.8		1.7	0.2	1.9	0.6
C/N	23	16	3	30	17	16	10	15	12
pH	3.4	4.1	5	4.6	4.7	5.2	5.1	4.8	5
Fe total	0.24	0.07	0.03	0.10	0.23	0.43	0.22	0.71	1.02
P_2O total °/oo						0.29	0.16	0.41	0.46
Exchangeable bases									
CaO %	2.8	0.1	0	0	0	1.43	0.43	0.93	0.29
MgO %	3.5	0.25	0.1	0.1	0.08	0.5	0.4	0.4	0.4
K_2O %	0.82	0	0	0	0	0.04	0.04	0.04	0.04
Na_2O %	0.83	0.02	0	0.03	0.01	0.08	0.06	0.13	0.10

Table 9. Analytical data for Atuabo series : Groundwater podzol under savanna (After Brammer 1962, p. 126)

	O.M. %	C/N	pH	Exchange complex m.e./100 g						P (total)
				CEC	Ca	Mg	Mn	K	Na	p.p.m.
A_1	3.47	23.76	5.25	3.47	0.50	0.31	<0.005	0.05	0.11	52
A_{e1}	0.46	22.50	5.65	0.87	0.18	<0.01	<0.005	0.05	0.14	43
A_{e2}	0.14	13.33	5.80	0.82	0.15	<0.01	<0.005	0,02	0.04	38
B_h1	5.33	27.43	4.85	25.64	0.35	0.24	<0.005	0.04	0.09	73
B_h2	6.16	40.68	4.85	41.28	0.31	0.16	<0.005	0.02	0.07	84
C	0.22	21.67	5.90	1.25	0.15	<0.01	<0.005	0.02	0.03	14

I. Horizons 1 - 3 and 6, ammonium acetate, pH 7.0.

Groundwater podzols on recent marine sand of raised beaches, dunes and sandspits are described by Ahn (1961 a). The Princes series is characterized by a thin layer of dark organic pan 2 to 4 or more feet thick which underlies white or pale grey leached sand. Completely leached soil (Assini series) consisting of white sand only are also found.

Cameroon : Grosskopf (1938) reporting on the Cameroons soils and discussing the formation of both bleached sand and humic pan layers in tropical red loams, did not refer to lowland tropical podzols in this country.

Lepoultré (after Mohr and van Baren 1959) described a groundwater podzol on beach sand, in the area between the rivers Nyong and Lokoundjé. The soil is characterized by an ashy grey sand layer 150 cm deep resisting on a humic pan 10 cm thick. There was no organic matter in the topsoil. This fact has been explained by Lepoultré, by abrasive influence of the ocean waters which eroded the original surface material when they transgressed into the mainland.

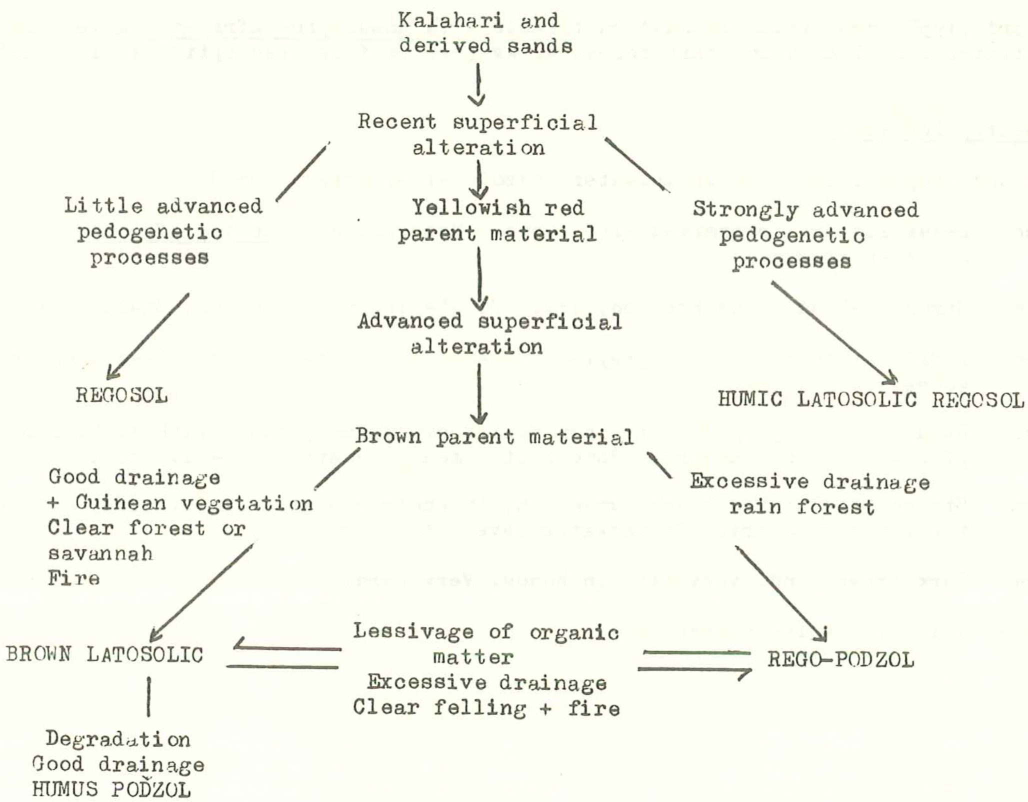
After Brzesowsky (1962) Edelmann noticed groundwater podzols developed on leached sandy beds, at a low lying site of the terrain.

B. Congo basin

It has been known for many years that blackwater rivers, peat, raw humus, bleached sand, and ortstein as well occur in this large tropical river basin (Berg 1961, Giesecke 1930, Harrassowitz 1926, 1930, Krenkel 1920, Nanson and Gennaert 1960).

Kellogg and Davol (1949) mentioned groundwater podzols in their classification scheme, but did not meet with these soils, during field studies in the Congo. Sys (1960 a, 1960 b, 1961) reported on podzols with ABC profile and podzol B horizons occurring in the Guinea vegetation zone. In 1956, Sys published a note on soil development of Kalahari sands on which finally both humus podzols and rego-podzols are formed (Table 10).

Table 10. Soil development on Kalahari sands
(After Sys 1956)



After personal communication by Sus (7.9.1967) the correlation of the soils mentioned in table 10 is in agreement with the INEAC-Congo classification and the 7th Approximation USA :

Regosol, humic latosolic regosol,

Latosolic regosol	=	Arrenoferrals = Oxic quartzic psamments
Rego-podzol	=	Arrenoferrals intergrade to podzols = Spodic quartzic psamments
Humus podzol	=	Humod

In the above cited communication it is again stated that podzols may develop from oxic quartzic psamments, if they are very coarse textured. The explanation of the existence of spodic oxic psamments with A_{oo}-A_2-C profile in Africa is that these soils occur on excessively well drained sites, meanwhile most soils with A_{oo}-A_2-B_{2h}-C profile (podzols) are groundwater podzols with a temporarily high groundwater table which hinders the leached organic and inorganic compounds to disappear, obliging them to form a B horizon.

White sands occur also in Gabon where they are not confined to the coast, and at Pointe-Noire (Anon. 1961). Meulenberg (1949) reported on white sands of 2 or 3 m upon plateaux, near Senze and Tchikai, in the coastal region. Gilson et al. (1957) described white sands of the Boonde series upon white peat formation is often observed. De Leenheer et al. (1952) found white sands in the vicinity of rivers, near Yangambi.

De Leenheer et al. (1952) reported also on a humus podzol of the surroundings of Lilanda. This soil being a groundwater podzol was investigated by the participants of the excursion to Yangambi, during the 5th International Congress of Soil Science held at Léopoldville (Anon. 1955). The soil has developed from alluvial beds of the Lilanda river. The groundwater podzols of the Lilanda and Obilotole series as well occur in small patches (Gilson et al. 1957), with inundated Entendrophragma palustris forests (D'Hoore 1964). The humus pan is 10 to 25 cm thick.

Evrard (1957) describing inundation forests with Aneulophus africanus gave a description of a groundwater podzol on which this forest grows (see profile description No 12, table 11).

Profile description No 12

Lowland tropical podzol : groundwater podzol (After Evrard 1957)

A_o	8 cm	Dense litter, intermixed with roots. Mycorrhiza of Gnetum africanum abundant. Of brown colour.
A_{11}	9 cm	Structureless humus horizon, dry. Of gleyish black colour. Small roots abundant.
A_{12}	16 cm	Infiltration horizon of greyish violet colour. Small roots, less abundant than above.
A_2	100 cm	Structureless greyish white horizon. Some black patches with lighter borders, pf 2 - 3 cm in diametre. Some roots (mean diametre 0.3 - 1.5 cm).
B_{11}/G	80 cm	Strongly indurated black humus pan, impenetrable with spade. Grey coloured at the upper boundary. Groundwater level at 213 cm.
B_{12}/G	20 cm	Dark brown sand, very rich in humus. Very hard.
C/G	233 cm+	Yellowish white coarse sand.

Table 11. Analytical data for a groundwater podzol of the Congo (After Evrard 1957)

	C %	N %	pH %	texture % 0-2	2-20	20-50	50-100	100-250	250-500	500-1000	1000-2000
A_{11}	1.61	0.153	4.2	4.9	1.7	1.7	10.2	40.4	22.5	17.0	1.6
A_{12}	0.22	0.014	5.0	0.2	0	2.7	17.3	36.8	23.9	17.5	1.6
A_2	0.004	0.001	5.9	0.1	0	3.2	14.2	48.0	20.5	11.6	0.4
B_{11}/G	1.72	0.008	4.4	11.4	0	2.4	15.2	32.8	17.9	14.7	5.6
B_{12}/G	0.47	0.011	5.3	2.1	0	2.5	11.0	41.9	21.6	17.6	3.3

The groundwater level oscillates between + 20 to 30 cm from September to December, and - 225 cm during February and March, with regard to the soil surface. The Lukome river which inundates the area is a blackwater river.

A lowland tropical podzol developed on micaschists of the Mayimbe plateau in the coastal region is described by Donis (1949). Old forest with the dominant species Ceiba pentandra, Celtis spec., Albizzia spec., and Heloptolea grandis is growing on this podzol which is associated with bleached latosols, under savannah and forest.

Very sandy acid soils of the Kwango area comparable to podzols of temperate regions are mentioned by Germain (1949).

C. Eastern Africa

Podzols, bleached sands, peat, and blackwater rivers as well occurring in the lowlands of eastern Africa, have been reported by Giesecke (1930). Soils which might be considered groundwater podzols are mentioned by Calton (1949), to occur in the Zanzibar Protectorate.

Calton (1949, 1955), and Calton et al. (1955) reported on both infertile heath sands and patches of organic podzols (ndamba) found upon the islands of Pemba. The soils grow giant heather (Philippia mafiensis).

White sands similar in character to bleached sands found elsewhere in the tropics is heathlike and dominated by the ericaceous shrub Philippia mafiensis (Walter 1962). Podzols on dune sands along the coast of Mafia are described by Vageler (1935). The thickness of the eluvial horizon below the raw humus layer varies between few centimetres to more than 1 m. The humic cemented ortstein may attain 2 m thickness (Schokalskaja 1953).

Along the East coast of Madagascar sandy lowland tropical podzols are developed under forest vegetation (Chaminade 1949, Dommergues 1954 a, 1955, Hénin 1949, Moureaux 1956, Ségalen 1951, 1956 a). Both the A and B layers are of 2 m thickness. In the opinion of Dommergues (1954 a, 1954 b, 1954 c) these soils show an instable biological equilibrium. After Pernet (1954), and Riquier (1951 a) lowland tropical podzols occur on stranded beaches of old lagunes and of the ocean, and on dunes. They are also found on quartzitic rocks of the island.

Very deep lowland tropical podzols have been reported by Riquier (1951 b), near Ambila in eastern Madagascar which in the author's opinion are due to three facts : i) high permeability of the rock which is an old dune sand, ii) high rainfall of about 3 m of the region, and iii) humus acids of the former forest vegetation which now is replaced by Philippia heath.

The humus ortstein (13.3 percent organic matter) may attain a thickness of 2 to 3 m and is used for road pavement. On younger, non-consolidated dune sands of the region, only a fair humus illuviation has been noted. Farer away from the coast, Riquier found a lowland tropical podzol on sand derived from lateritic alluvium and deposited by a river. Lowland tropical podzols have been described also from the west coast of Madagascar (Ségalen and Moureaux 1950).

Ségalen and Tercinier (1951) described lowland tropical podzols occupying a small area along the Maevarano River, in northern central Madagascar. These soils show some humys B layers, one upon the other, which correspond to former groundwater levels.

White sands, often humiferous ones, are rather widely distributed on the island (Moureaux and Riquier 1953, Pernet 1951, Riquier 1951 c, Riquier et al. 1952, Ségalen 1956 b). White sands with small humus bands or iron deposits in the subsoil have been reported by Riquier (1951 d). These deposits are said to be due to groundwater loaden with humus and iron compounds and are, therefore, no real ortsteins.

The description of a humus podzol (see profile description No 13, table 12) developed from alluvial sand, is taken from D'Hoore (1964).

Profile description No 13

Lowland tropical podzol of Madagascar (After D'Hoore 1964)

A_1	7 cm	Blackish brown sandy horizon. Rich in plant residues, little decomposed.
A_2	18 cm	Greyish white loose sand, Weakly rooted.
B_{11}	5 cm	Humus pan. Weakly rooted.
B_{12}	7 cm	Endurated humic pan.
C	93 cm	Clayey sand of yellowish colour.
G	130 cm+	As above, but with some little red mottles

Table 12. Analytical data for a lowland tropical podzol of Madagascar (After D'Hoore 1964)

	C %	N %	pH	Exchange complex m.e. per 100 g CEC	Ca	Mg	K	Base saturation %
A_1	2.1	0.073	5.7	7.4	1.15	0.60	0.10	25.0
A_2	1.36	0.012	5.6	2.0	1.35	0.70	0.03	100.0
B_{11}	4.00	0.190	5.1	31.0	1.20	0.50	0.11	5.8
B_{12}	1.92	0.065	5.5	31.4	0.45	0.75	0.15	4.2
C	0.38	0.015	5.4	4.0	1.65	0.45	0.06	54.0

	Texture % 2 - 0.2	0.2 - 0.02	0.02 - 0.002	< 0.002
A_1	47.5	28.1	7.6	7.6
A_2	45.1	46.0	4.6	1.8
B_{11}	46.7	44.5	4.1	2.2
B_{12}	34.8	52.7	6.4	5.2
C	35.3	39.0	6.8	17.6

4. ASIA

Mohr (1933, 1944) referring to his own observations in Indonesia expressed the view that, if one would find true podzols in the tropics, he must go into the cold regions, thus up into the mountains. Some years later Mohr (Mohr and van Baren 1959), however, was enables to report on lowland tropical podzols of Ceylon and Borneo described by Joachim (1935) and Hardon (1937).

Giesecke (1930) citing Lang (1915), Harrassowitz (1926, 1930), Vageler (1938), and others, reported on bleached earths in tropical Southeast Asia.

Richards (1941, 1957, 1961) referring to his own observations (Richards 1936), and to those of Beccari (1904), Diels and Hackenberg (1925), Hardon (1937), and Winkler (1914), in the lowlands of the Malayan region, established the term lowland tropical podzol.

Dudal (1957), Dudal and Soepraptohardjo (1957), Dudal and Moormann (1964), and Soepraptohardjo (1957) have reported on these lowland tropical podzols of Southeast Asia which are locally known as padang or kerangas soils (Meijer 1965). The terms groundwater or humus podzol are also common, but Southeast Asian podzols are not limited to soils developing under groundwater influence. The great majority of podzols in the region have organic matter only in the B horizon; these are the humus or groundwater podzols. Iron humus podzols developed in West Borneo beyond groundwater influence, have slightly hardened B horizons only, and there is no sign of poor drainage. Normally, podzols occur on level or slightly undulating terrain in continually wet areas. They are most extensive on old coastal terraces covered with sandy material, but are equally common on sandstone, quartzite, and acid volcanics. The natural vegetation of lowland podzols are so-called kerangas, heath forests, or padangs.

A. India and Ceylon

The recent soil map of India (Raychaudhuri 1962, 1964) includes podzolized soils which apparently occur in mountain regions only.

Bleached white sands (cinnamon soils) and similar coastal sands occur on Pleistocene and Sub-recent deposits, in areas of higher rainfall in Ceylon (Deraniyagala 1958, Joachim 1935, 1945, 1955, Joachim and Kandiah 1937, Mohr and van Baren 1959, de Rosayro 1939, 1943, Sievers 1964, Timmermann 1935). Commonly, they are poor in nutrients and characterized by a dark grey clay and humic illuvial pan, at a depth of 5 feet or so. This soil type is the nearest approach to a groundwater podzol, the only difference being the absence of the surface organic layer. Moormann and Panabokke (1961) reported on regosols partially developed from pure quartz sands, but they did not refer to cinnamon soils nor podzols, in Ceylon.

B. Southeast Asian mainland

a. Mekong basin

In the Lower Mekong basin podzols associated with groundwater laterites have been described and mapped by Dudal (1960). These hydromorphic podzols occur on both low plateaux and plains. Locally, peat is found.

In this region, lowland tropical groundwater podzols and regosols as well have been already observed by Pendleton (1939, 1940, 1962), Pendleton and Sharusavana (1942), and Mohr (1944).

b. Malayan peninsula

Lang (1915) described bleached sands of this peninsula. A modern soil map of Malaya (Panton 1962, 1964) shows that free draining podzols occur along the east coast (Hoeppe 1965) where they evolve from coarse sands of low beach ridges rising to about 20 feet above sea level. Evidently, the west coast deposits are heavier in texture, and there lowland tropical podzols are rare (Owen 1949). The ridges of the east coast are often separated by lagoonal swamps in which peat or highly sulphurous clay occur. The natural forest has been replaced by poor open shrub or low yielding coconuts, in most cases (Jin-Bee 1960). The coastal landscape in which the podzols occur resembles the 'ritsen' landscape of Suriname. Lowland tropical podzols are also developed from inland sandy alluvium (Owen 1949).

After Wyatt-Smith (1961, 1964), Robbins and Wyatt-Smith (1964), and others, high forest (Heath forest) grows on ridges with temporarily waterlogged podzols the B horizon of which is found 2 feet or more below the surface. The forest differs from the lowland dipterocarp forest being simpler in composition and structure, and lower in heigth. This type of forest has largely been destroyed.

C. Malayan archipelago

Soepraptohardjo (1957) found that podzols, mainly groundwater podzols, occur over large extensions on siliceous materials, in Borneo, Bangka and Billiton. These soils are not representative of the regions in islands other than the ones mentioned above. The podzols are mostly covered with shrubby vegetation, and are of no agricultural value. Following van Steenis (1935 a, 1935 b, 1957) soils with dark coloured organic pan at 1 to 2 m depth are known to exist in all parts of Borneo, upon several islands in the South China Sea, South Sumatra, and locally in central Celebes and upon New Guinea. After heavy rains these soils are temporarily inundated. The colour of the water is brown like that of peats.

Indonesian podzols (Dudal and Soepraptohardjo 1957) have a high raw organic matter layer over a light grey, strongly leached sandy horizon which overlies a dark brown to reddish illuvial horizon, due to accumulation of iron oxides and organic matter as well (iron humus podzols), or of organic matter only (humus podzols). These humus podzols often correspond to the definition given for groundwater podzols in which case both names can be used as synonyms. The composition of the parent material seems to be one of the forming factors of these soils. In Indonesia podzols have been found from sea level up to 2,000 m. Iron humus podzols and/or groundwater podzols have been mapped in North and Central Sumatra, on the islands of Bangka and Billiton, and in Borneo where they occupy large extensions.

a. Sumatra, Bangka and Billiton

Padangs (quartz sandy plains with an aberrant scanty flora) are known from the three islands, and occur too on Celebes. On Billiton these padangs occupy more than 40,000 hectares (van Steenis 1935 b). The soils of these padangs are lowland tropical podzols (Hardon 1937, Mohr 1944, Mohr and van Baren 1959). Hardon (1937) studied some of these soils found in a flat plain about 10 m above sea level, partly inundated after heavy rains. Lowland tropical podzols have also been reported by Dudal (1957), Lang (1915), Kostermans (1958, 1959), Richards (1941), and others. Szemian (1933) mentioned only the Malayan expression padas, for ortstein layers.

b. Borneo

One of the earliest indications of white sandy soils associated with blackwater rivers and heath forest was given by Winkler (1914). He mentioned Melaleuca leucodendron stands flooded by acidic brownish water, and shrub vegetation with Nepenthes and Carex species growing on nearly white sand in regions where pools of blackwater occur. This author holds the opinion that heath forest with Dacrydium elatum, Agathis borneensis, and Castanopsis are due to soil conditions.

Diels and Hackenberg (1925) described a soil which is a lowland tropical podzol, under heath forest of South Borneo. The term heath forest is a purely physiognomical one and has nothing to do with Epicaceae (Sleumer 1965). But Ericaceae do occur in these heath forests.

The first who dealt in detail with lowland tropical podzols (padang) of SE Borneo was Hardon (1937). This author studied two profiles from Padang Loewai, and noted an exceedingly low base content, especially of calcium, magnesium and potassium, of the raw humus the C/N ratio of which was nearly 60:1.

The vegetation of Padang Loewai was described by Posthumus (1937). After this author, the landscape in which the podzols are found, resembles some types of heather vegetation of temperate regions.

Sarawak and Brunei : Richards (1936) establishing surprisingly numerous and far-reaching analogies of heath forests with the Wallaba forests of British Guiana, regarded the heath forests on lowland tropical podzols of the Dulit area as an edaphic climax.

After Browne (1952) it is more convenient to retain the term kerangas (Beccari 1904) meaning land on which hill rice will not grow, for podzol vegetation. The agricultural value of kerangas being very limited they must be regarded as mainly a forestry problem (Brünig 1957).

After Browne (1952) kerangas usually carries small timber, but there is considerable variation, and in some areas fairly large trees are not unknown. The buttressed habit is less developed than in mixed forests, but stilt roots are fairly common. The low ground cover is sparse, and poor in species. In it, ferns, stag mosses (Lycopodium), carpet mosses, and pitcher-plants (Nepenthes) seem to be dominant forms. Characteristic kerangas trees are Casuarina sumatrana, Shorea stenoptera, and Hopea spec. Kerangas are supposed to cover some hundred-thousands of hectares (Brünig 1957).

True kerangas soils (Browne 1952) are found on marine Pleistocene deposits. The B horizon consists of organic cemented sand resting on unconsolidated layers of coarser texture. Alluvium of this kind does not occur above some 400 feet from the sea level. Lowland kerangas is usually bounded by peat swamps on its seaward side, and kerangas islands are scattered throughout these peat swamps which occupy 5,660 square miles in Sarawak (Anderson 1964). The kerangas islands are probably the last remaining traces of what was once extensive kerangas.

Lowland tropical podzols on marine sands and terraces of Sarawak are also reported by Wall (1962). Wilford and Dames (1955/56) described podzols of West Sarawak where they are developed mainly on low ridges of older alluvium, and Pleistocene sand terraces, in the lowlands up to 50 m above sea level. If there is an organic hardpan, the soils belong to the humus and humus groundwater podzols. Lowland tropical podzols occur too in the Brunei and Lawas area (Dames 1956).

Topography is considered by Wall (1964) to be the most important feature associated with the soil pattern in the lowlands of Sarawak. The soils of the beach association belong to a regosol podzol sequence, with groundwater humus podzols. In regions of the dissected terrace association humus podzols on coastal terraces are found which were possibly formed originally as groundwater podzols at sea level being stranded by subsequent sea level changes (Smit Sibinga 1953). According to Andriesse (personal communication 1965) the humus podzols of Sarawak are groundwater podzols, and many of them are fossil soils.

Wood and Beckett (1961) studying soils of the coastal strip to the north of Bintulu described kerangas soils associated mainly with lighter textured parent materials. Low level kerangas soils commonly occur as lower members of the yellow loam catena. In some cases the low level kerangas soils may owe their formation to accumulation of light textured downwash. In other cases such explanation does not seem to apply, and it is only supposed that the transition from the latosolic to the podzolic succession is due to the greater accumulation of litter, tending to produce peat podzols, in the wet foot slope position.

The observations of Andriesse (without year, 1962, 1965) on the podzols of Sarawak agree well with those by other authors. By them podzolization is attributed primarily to the high silica content of the parent material. Topography also appears to have a significant rôle.

After Ashton (1959) the valley soils in the western portion of Brunei primarily consist of a thick layer of acid peaty humus, over badly drained undeveloped pure white sand. In the eastern portion of Brunei leached white sands and groundwater podzols occur. Raised beaches and terraces consist usually of unconsolidated white sand. On medium or coarse white sand terraces giant podzols of the better drained areas give way to a zone of groundwater podzols of the poorly drained centre. The hardpan of these giant podzols can be at a depth of as much as 7 m. Podzols developed from coarse sand beds of mostly marine origin have been also reported by Blackburn and Baker (1958), from the surroundings of Brunei Town.

In the contribution of Dames (1962) to which a general soil association map of Sarawak is attached, the kerangas soils are described which occupy 1,691 square miles, or 4 per cent of the land area, one quarter of the kerangas area being in the lowlands, and three quarters in higher terrain. Humic grey hydromorphic soils have important characteristics in common with both the humus podzols and grey hydromorphic soils. The latter have developed from sandy clay loams and sandy clays as well. Both soils are characterized by a humus podzol B horizon with iron mottles, and conspicuous dark brown to black, very coarse organic mottles and streaks as well. Humus podzols (groundwater podzols) are found on both low ridges and flats of alluvial deposits, and Old Pleistocene or Late Pliocene, Preglacial terraces in the lowlands. They occur too in the Tertiary of older sandstone hills. On Pleistocene terraces they are on slopes from nil to ten degrees. In sandstone hills they occur on level terrain, and on slopes with gradients up to twenty degrees. All groundwater podzols of Sarawak have B horizons wholly free of iron, being therefore pure humus podzols. In some localities there may be a permanently or periodically high fluctuating watertable in the solum or C horizon, but in most soils there is, at present, no such watertable. In many cases the greater part of the drainage seems to occur by lateral movement through the A horizon. Dames distinguishes between

Shallow humus podzols. B_h at less than 25 cm below the mineral surface.

Normal humus podzols. B_h at 25 to 100 cm below the mineral surface. Within this group three subdivisions are made :

Soils with a hard to firm B_h pan at a depth of 25 to 45 cm.

Soils with a hard to firm B_h pan at a depth varying from 60 to 100 cm.

Soils with a firm to friable B_h at a depth of 50 to 70 cm.

Giant podzols humus. B_h at over 100 cm below the mineral surface.

Humus podzols have a matted-mor surface layer less than 10 cm thick. If the thickness of this layer varies from 10 to 30 cm, these soils are groupes in humus podzols transition bog soils. Bog soils have an organic surface layer of over 30 cm, and are subdivided in shallow bog soils (A_0 30 to 150 cm), and deep bog soils (A_0 more than 150 cm).

Kerangas grow too on shallow humus podzols occurring in rocky terrain of the sandstone hills. Especially the conifer Dacrydium elatum has been found on these soils the B_h horizon of which is developed in the upper few centimeters of the hard sandstone. The weakness of the B horizon is explained, by lateral movement of water.

Normal humus podzols with a hard to firm B_h horizon at a depth of 25 to 45 cm are found on both Pre-glacial terraces and sandstone ridges of the Tertiary sandstone hills. Normal humus podzols in which the B_h pan occurs at a depth of 60 to 100 cm are found on raised beaches and sand terraces as well, where the sand covering over the Tertiary beds is comparatively thin.

On low lying beach sands of the Anduki Forest Reserve normal humus podzols with a firm to friable B_h pan at a depth of 50 to 70 cm occur.

Giant humus podzols (see profile description No 14) are found on raised beaches and sand terraces as well, of mostly Pre-Pleistocene age, in the lowlands at elevations between 5 and 50 m above sea level.

On recent coastal sand shallow soils are developed. They show a high mobility of iron. When the iron compounds have been wholly removed from the soil, a humus podzol develops on these sands. This soil development is accompanied by a change in the vegetation and the early formation of a surface peat mat.

Pat (1963) described a podzol under kerangas (coastal padang) upon the Semporna Peninsula, North Borneo. The main tree growing on this soil is Tristonia abovata, dipterocarps being absent.

Additional information on lowland tropical podzols, and relationships existing between these soils and their vegetation may be found in the literature on Bornean vegetation (Ashton 1961, 1965, Brünig 1961, 1965, Fosberg 1965, Dilmy 1965, Kostermans 1959, Muller 1965, Purseglove without year, Richards 1965, Wood 1965, and others), being quite similar to that of both the Guianas, and Amazonia (Richards 1945).

So, Gilliland (1959) and Smythies (1965) draw the attention to the pitcherplants (Nepenthes) typically growing in Bornean padangs and kerangas as well which are characterized by a nitrogen shortage.

Profile description No 14

Lowland tropical podzol : giant podzol (After Dames 1962, p. 61/62)

A_{00}	2 cm	Litter consisting almost exclusively of bindang leaves, twigs and fruits.
A_{01}	2 cm	Mat of roots with very dark, partly decomposed fragments of leaves, fruits, etc. and a little mor (F layer).
A_{02}	8 cm	Dark red greasy mor (2.5YR 3/6, moist) in a mat of roots; some F material and some white quartz grains (H layer).
A_{11}	5 cm	Very pale brown (10YR 8/3, dry; dark reddishgrey 10YR 3/1, moist) humus, soft, loose medium and fine sand in the lower part of the root mat; weak fine crumb structure; very many large and fine roots, mostly horizontal; wavy (5 cm vertically) boundary.
A_{12}	10 cm	Pinkish-grey (7.5YR 7/2, dry and moist) medium and fine sand; pepper and salt; single grain structure; many roots mainly up to 5 mm thick and many of them horizontal.
A_{21}	15 cm	Pinkish-grey (5YR 7/2, dry; moist light grey 5YR 7/1) medium and fine sand.
A_{22}	85 cm	White (2.5YR 8/ , moist 7.5YR 8/) soft medium and fine sand; fairly loose; fair number of vertical roots; abrupt boundary.
A_{23}	140 cm	White medium and coarse sand; more compact than A_{22}; roots few, some large vertical roots bend sharply to horizontal at a depth of 170 cm; larger roots are surrounded by a ring of pinkish-grey sand similar in colour to the A_{12} horizon; with increasing depth the soil becomes wetter and at a depth of 180 cm the soil is wet and dark brown, humus water seeps from the sides; deeper some brown, organic splotches.
B_h	145 cm	Sampled from nearby exposure in cliff face; by boring in the soil pit the B_h was found at the depth of 267 cm; the watertable occurred at a depth of 257 cm and is perched on top of the B_h dark brown cemented humus-sand pan breakable by hand; some root remnants.
B_i	1 cm	A thin layer with a more or less hardened reddish-yellow ferruginous sheet varying in thickness from 5 to 10 mm; in places there is, directly below the brown B_h, a very thin, but sometimes up to 15 cm thick, lens of greyish-yellow silty clay; the bottom of the B_h or to the bottom of the clay lens.
C	401 cm+	White, prominently coarse yellowish-red mottled, loose sand.

c. Java

Bleached earths of podzolized lateritic soils of this island have been reported by Dames (1949, 1955). True podzols have not been found on Java (Dames 1949). But some years later Dames (1955) shortly reported on red yellow podzolic soils associated with groundwater podzols occurring in depressions with periodical water-logging.

d. New Guinea and Fiji

Schroo (1963 a, 1963 b, 1964) has given an inventory of the soils of West Irian. He reported on "*Agathis* soils" which partly are lowland tropical podzols derived from basaltic tuff, upon the island of Biak. Tropical lowland iron podzols may be found in the coastal areas south of Merauke where the soils are often grown with bamboo.

From a sketch map showing areas in which peat growth may occur (Reynders 1962 a) the conclusion may be drawn that in these areas also lowland tropical podzols may occur. These soils (groundwater podzols under *Agathis* trees, at 400 m elevation, and peaty aluminum podzols under moss forest, at 780 m elevation, have been studied by Reijnders (1964).

e. Hawaii

After Ayres (1943) evidence of podzolization in certain soils of the islands has been established by Hough and Byers (1937), and Kelley et al.

5. AUSTRALIA

After Stephens (1955, 1961, 1962) the podzols and groundwater podzols of Australia are predominantly coarse textured. These strongly bleached soils are markedly acid and have organic sesquioxide, and sometimes clay illuvial horizons. The junction between the horizons A_2 and B_1 may be exceedingly undulatory, often rising and falling several feet in comparable lateral distance.

The more humid areas of southern and eastern Australia, Cape York Peninsula, and a small portion of the wetter northern part of the Northern Territory are dominated by leached, principally podzolic soils (Prescott 1933, 1950, Stephen 1961, Stewart 1959). Typical podzols of western Australia were recognized by Teakle and Samuel (1930), at places which receive more than 20 inch. of rain per year. Hosking and Greaves (1936) reported also on both deep white sands (Wowra Sand) along short tributary creeks, and wet podzols (Muchea Sand), in western Australia. In South Australia, where normal podzols are very restricted to regions of higher rainfall (Crocker 1946 a, Ganssen 1957), the inland boundary of podzolic soils corresponds to a wet season of nine months' duration (Prescott 1950). Podzols with solonized subsoils were reported to occur in South Australia, by Jessup (1946). Crooker (1946 b) described shortly podzols and residual podzols from the Eyre Peninsula, South Australia. Podzols for the most part seem to be of both the humus and humus iron type; some have relatively thin profiles, some are giant podzols (Thorp 1957). Most of the podzols lack any distinct raw humus horizon. It is believed that this fact is due to frequent fires characteristic for Australia, even before it was settled by white men.

In marked contrast to the identity of the lower horizons the horizons A1, A_0, and A_{00} exhibit marked differences between Australian, European and North-American podzols (Stephens 1949). In Australia where forest and shrub vegetation are almost entirely of a sclerophyll character with litter fall slow and relatively continuous, and where the podzolic soils extend into areas where grass species are widely present, the A_{00} is thin and discontinuous as well, and frequently composed as much of twigs and bark as of leaves (Stephens 1962). The A_0 is certainly absent in all but the rain forest areas. The A_1 is generally thick. Ants and termites rather than earthworms play a predominant role, a fact which may explain the differences of A horizons between Australian, European and North-American podzols.

The profile of Australian podzols is formed as a result of movement of clay, sesquioxide, and organic matter downwards in the profile following the removal of cations in drainage water (Stephens 1962). These soils occur on a wide range of parent materials but persist into areas of lower leaching factor quite considerably, on sandy and siliceous rocks. Topography does not appear to influence their development greatly. In the main they are mature soils in equilibrium with surrent climatic conditions.

Hosking (1934/35) reported on C/N ratios of Australian podzolic and other soils.

Groundwater podzols have B horizons formed by accumulation of both organic matter and iron compounds, sometimes singly, sometimes together. The B horizons are often referred to as 'coffee rock' (Teakle and Southern 1937 a, 1937 b). The watertable which is an essential feature associated with these soils, is commonly found at a point in the profile below the B_1 horizon ,but occasionally, by saturation of the soil above the indurated pan, it rises to the surface. The B horizons of organic matter, iron compounds, and clay, if present, are due to eluviation from the A horizon. These soils are found in association with normal podzols. The average phosphorous content is 0.022 per cent P_2O_5 (Wild 1958).

Generally, Australian podzols are very deficient in trace elements (Donald et al. 1952).

Certain laterites were classified as residual podzols, by Prescott and Pendleton (1952), and Stephens (1961, 1962), or lateritic podzols (Baker 1960). After Teakle (195 0) there is no reason to introduce the concept of podzols for these soild a group of which shows evidences of leaching and segregation of clay and sesquioxides in the subsoil.

Organic matter of Australasian and overseas podzols has been studied by Martin.(1960).

A. Northern Australia, New South Wales, and North Island of New Zealand

The areas included in the tropical region for this chapter are northern Australia, New South Wales, and the North Island of New Zealand. Northern Australia is considered to belong to the tropical climatic zone V, by Troll (1964), and Burbridge (1960), while New South Wales, the southern part of Queensland, and the North Island of New Zealand, except the southernmost portion of this island, belong to Troll's warm-temperate subtropical zone IV.

In eastern Australia the coastal lowland (Gardener 1955) extending from Cape York Peninsula southwards to Newcastle (cf. map attached to Coaldrake's publication 1961) are of particular importance to lowland tropical podzols.

Small rivers which occurring in northern coastal Queensland might be classified as blackwater rivers (I. Douglas, personal communication to H. Sioli 1965) let suppose that lowland tropical podzols occur in this region (Douglas, personal communication 1965).

Prescott and Skewes (1941) published a soil map of tropical Australia in which podzols are represented in an area East of Port Darwin and along the Pacific coast of northern Queensland. Few analytical data relating to these soils are also given.

Teakle (1950) studied the soils of coastal Queensland between Mossmann to Brisbane, in the so-called "Wallum country". The soils of this region are generally low in phosphorus (Coaldrake and Heydock 1958, Wild 1958).

After Young (1946) the term Wallum country is loosely applied to the whole of the sandy coastal plain extending from the southern border of Queensland to near Rockhampton in central Queensland. The land growing wallum (Banksia aemulia) is designated true wallum country. It usually occurs in patches from a few to many acres in extent. It is typically a few feet above the treeless swamps into which it often grades. The soils are podzols (Stephens 1948, Teakle 1950, van Wijk 1964). They are often subjected to seasonal inundation. Prominent among them are flats with "wet heath" vegetation. The groundwater podzols are similar to the Plantagenet soils of western Australia (Hosking and Burvill 1938), and podzols of northern Tasmania (Hubble 1946) as well. Normally, these soils have a humic cemented pan. The hardpan may also be ferruginous.

Andrew and Bryan (1955) studying the soils of the coastal lowlands of southern Queensland and northern New South Wales found groundwater podzols in areas of considerable extent.

Coaldrake (1961) described the soil pattern of the wallum ecosystem (see profile descriptions No. 15 and 16) in which in poorly drained areas with a mantle of Quaternary sand.

Profile description No. 15

Lowland tropical podzol: groundwater podzol (After Coaldrake 1961, p. 111.)

A_{11}	9 in.	Grey (5YR 6/1M) loose sand speckled with finely divided organic matter. Dense root mat. Diffuses into
A_{12}	6 in.	Pale grey (5YR8/1M) loose sand. Organic matter and roots decreasing. Diffuses into
A_{21}	15 in.	White (5Y 8/1M) mottled with pinkish grey (5YR 6/2M) and dark grey (5YR 3/1M) loose sand.
A_{22}	20 in.	White (5Y 9/1M) mottled with dark grey (10YR 3/1M) and small lenses of black (5YR 2/1M) sand impacted into a massive pan layer; extremely hard in profile but frets easily when removed. Fairly abrupt but uneven boundary into
B_{11}	7 in.	Black (5YR 2/1M) organic sandy pan; massive; hand specimen desintegrates easily in water.
B_{12}	6 in.	Dark brown (7.5YR 3/2-5/2M) sandy trending to loamy sand. Moderately developed organic pan.

Profile description No. 16

Lowland tropical podzol: groundwater podzol (After Coaldrake 1961, p.111/12.)

A_1	6 in.	Dark grey (5Y 4/1M) granular, loose, sand flecked with a light amount of organic matter. Numerous fine roots. Diffusing into
A_2	24 in.	White (2.5Y 8/2M) granular, loose, sand. Scattered fine roots.
B_{11}	2 in.	Dark brown (10YR 3/3M) sand, mildly cemented into an organic pan.
B_{12}	12 in.	Dark yellowish brown (10YR 3/4 M) trending to light yellowish brown (10YR 6/4M) organic sandy pan strongly cemented in the profile.
B_{13}	4 in.	Pale brown (10YR 6/3M) mottled with darker brown. Very strongly cemented organic sandy pan.
B_2	30 in.	Pale brown (10YR 7/3M) mottled with reddish yellow (7.5YR 6/8M) clayey sand. A few ferruginous nodules less than 1 in.in diameter.
B_3	4 in.	Dark brown (10YR 3/3M) weakly cemented organic sandy pan.
C_{11}	12 in.	White (2.5Y 8/2M) loose, coarse sand.
C_{12}	30 in.	White (5YR 8/2M) finely mottled with red (2.5YR 4/6M) plastic, sandy clay.

After radiocarbon determination the podzols have an age of 30,000 years(Coaldrake 1962). Due to age and environmental conditions as well, the thickness of the pan varies from few inches to many feet. According to Coaldrake (1961) these pans are forming today from Tasmania to tropical Queensland. Three types of pans are known:

Organic pans may be over three feet in tickness, in typical groundwater podzols.

In more or less flat country, there is an organic pan on clay which is more likely to have a zone of iron accumulation underneath it than the first type.

Under myrtaceous shrub, the organic pan is over a clay illuvial horizon, on sloping ground.

In the region studied by Coaldrake (1961), Cassidy (1944), and Bayly (1964) investigated acidic blackwater lakes the majority of which is apparently originated by the formation of an impermeable ortstein pan, in dune depressions (Coaldrake 1962, Gardener 1955). Most of the studied lakes are situated on small islands consisting of high sand dunes, off the coast of southern Queensland.

Fossil podzol illuvial horizons have been observed by Coaldrake (1955). McElroy (1962) found fossil podzols in sand dunes at Port Kembla. McGarity (1956) discussed the origin of "sandrocks" which may be A or B horizons of podzols, or A horizon of peat bog soils. Maze (1941) described humus, humus iron and iron podzols developed from the Tomago Sandbeds, in the Newcastle-Sydney district.

Lowland podzols have been also described by Hallsworth et al. (1953) in New South Wales.

A very interesting paper on lowland podzols in New South Wales is published by Burges and Drover (1953). These authors concluded from their studies of podzols of the Woy Woy district that during about 200 years all the calcium carbonate, originally present in the parent material (marins sand), has been leached out, the removal of carbonate being accompanied by lowering of the surface pH from 8.8 to about 6. When the calcium was removed from the soil, leaching of iron began. During the following 800 years, a weakly developed iron podzol was formed, under Angophora intermedia. About 1,000 years later, a humus podzol began to develop. The change in soil formation from iron podzol to humus podzol was accompanied by replacing of A. intermedia, by A. lanceolata, In the podzol formation no groundwater influence was involved.

The podzols found under tropical and subtropical climates extend to South Australia. Baldwin and Crocker (1941) described acid soils very low in phosphoric acid (0.002 - 0.003 %) and supporting Eucalyptus Baxteri - E. Diversifolia associations which appear healthlike. These soils show light grey and white sand, most frequently about 30 in. thick, overlying cemented ironstone gravel (locally referred to as "conglomerate ironstones". Sometimes there are organic gravel pans above the conglomerate ironstone.

McLennon and Ducker (1957) reported on Mortierella ramanniana which is dominant on podzols with ortstein, near Frankstone, Victoria, where the podzols are found in Eucalyptus viminalis 'kratts', while M. nana is dominant in bleached sand overlying yellowish-grey clay, near Anglesea, Victoria.

Caroll (1933/34) reported on Myponga sand which is a coffee brown layer often present between 30 to 60 in. depth. It is regarded to be an organic cemented podzol ortstein.

Podzols are one of three main genetic soil types, in the North Auckland peninsula, North Island of New Zealand (Aubert 1964). Taylor et al. (1950) described a typical podzol profile on mudstone, formed under kauri (Agathis australis) forest (Aubert 1964). This soil has a 4 in. thick silica pan, at 3 in. depth. Podzols derived from rocks containing an appreciable percentage of quartz grains have light texture, and show both well developed humus and iron pans (Taylor and Cox 1957). There are also gley podzols, or "pakihi" soils.

Barrat (1966) studied the micro-morphology of some podzols of New Zealand. She concluded that one important aspect of the vegetation factor is probably the nature of the litter as a substrate for decomposition, but another important aspect is the effect of canopy on soil micro-climate and soil organisms. The progressive weathering and leaching of soils appear to be largely related to climatic factors. In general, the results of this study agrees well with those obtained by other authors in tropical regions, mainly South America and Southeast Asia.

Podzolization seems to be intimately associated with kauri forests (Aubert 1964, Leeper 1964, Mückenhausen 1963, Swindale and Jackson 1956, Anon. 1962c), under which a remarkably white bleached horizon may be found which is referred to as 'sugar-sand' (Leeper 1964), in the region under discussion. Whitmore (1965), however, described a red latosol developed under kauri (Agathis macrophylla) on Vanikoro (Solomon Islands); there no differences between the soils under kauri and thise with other vegetation were observed. The technical name for podzols is podiform, in New Zealand (Taylor and Pohlen 1962).

B. Tasmania and South Island of New Zealand

Tasmania and the South Island of New Zealand belong to the cool-temperate climatic zone III with oceanic and highly oceanic woodland climates (Troll 1964). This climatic zone includes the southernmost parts of Australia (area around Melbourne), and the North Island of New Zealand as well.

Areas belonging to an ectropical climatic zone should not be considered in a report on tropical podzols. But for completeness' sake reference is made to some papers on podzols of both islands mentioned above.

Podzols being similar with those of tropical Australia (Prescott 1933) are quote common in coastal lowlands of Tasmania and adjacent small islands as well (Thorp 1957, Stephens 1941). Moor podzol peats occur practically entirely in Tasmania, down to sea level (Stephens 1949, 1961, 1962). Peat podzols closely associated with Gymnoschoenus sphaerocephalus occur exclusively in Tasmania, particularly in the perhumid cold southwestern quarter. Normal soils of Tasmania's North-east coast are podzols. The most extensive types are groundwater podzols (Hubble 1946, Stephens and Cane 1939). The native vegetation is heathlike in character, or consists of Eucalyptus forests.

Podzols of King Island have been reported by Stephens and Hosking (1932), and Jennings (1957). These soils are associated with frequently occurring dune lakes. The major factor responsible for this association of both podzols and lakes, is the coffee rock (podzol B_h horizon) which tends to raise the watertable.

Blackwater lakes associated with sandy or peaty soils have been reported by Schwenfurth (1962).

In the South Island of New Zealand podzols including gley podzols are developed on sand, gravel, and sandstone, in the lowlands. In the uplands there are podzols too which are found on loamy and clayey parent materials (Anon. 1962 c, Taylor and Cox 1957, Mückenhausen 1963).

III. UPLAND TROPICAL PODZOLS

It is a well known fact that, if altitude increases, temperature lowers, and rainfall increases (Troll 1955, 1956, 1961). In response to the change of climatic conditions, primarily to the fall in average temperature, both soil and vegetation change too: Productivity is accordingly modified (Ellenberg 1964 b), and there is a marked increase in the humus content of soils (literature reviewed by Finck 1963). There is also evidence that laterization tends to give way to podzolization as chief process in soil development, in tropical regions (Reijnders 1964, Richards 1957). As shown by many authors (Dudal and Moormann 1964, Gassen 1961 a, Pagel 1964, Papadakis 1964, Senstius 1930 a, 1930 b) upland tropical podzols occur, under upland tropical climates, which are altitudinal variations of tropical climates, at low elevation.

I. CENTRAL AMERICA AND SOUTH AMERICA

Podzolic soils are said to occur in mountain regions of Guatemala and Honduras as well (Anon. 1953).

In the Guiana uplands, patches of leached white sand have been observed by Myers (1936) Otremba (1954) and Bleackley (1964) as well. Lopéz et al. (1956) reported white sand deposits from the lower Caroni River. The association of organic sand and podzols in the Guiana highlands is shown in the most modern draft of the soil map of South America (Bramao 1966).

Wright and Bennema (1965) pointed out that the paramo soils intergrade to shallow podzols, along the eastern margin of the high Andes, especially in the equatorial sector, where also gley podsols and podzolized gley soils occur, under cloud forests.

After Hueck (1961 a), podzols predominate in the upper cloud forest region (2,800 - 3,200 m.) of Venezuela. Podzols and podzolic soils as well are said to occur in patches in the Venezuelian Andes (Lasser 1956).

Jenny (1948) described both andino and giant podzols near the timberline in Colombia, at about 12,000 feet elevation. One profile of the giant podzols developed on semi-consolidated crystal tuff (see profile description no. 17, and table 13) has been studied by Barshad and Rojas-Cruz (1950).

Profile description No. 17

Upland tropical podzol: giant podzol. Elevation 2,460 m. (After Barshad and Rojas-Cruz 1950; cf. Espinal and Montenegro 1963).

A_0	2 in.	Humus layer, black, very soft
A_{11}	18 in.	Grayish brown, 10 YR 4/2, moderately cloddy, of high friability and high permeability to water, air and roots.
A_{12}	14 in.	Pale brown, 10 YR 6/3, otherwise similar to A_{11}.
A_{21}	13 in.	Light gray, 2.5 Y 7/2, moderately bleached, moderately cloddy, of medium friability and high permeability.
A_{22}	11 in.	White, 2.5 Y 8/3, strongly bleached, otherwise similar to A_{21}.
B_1	4 in.	Yellowish red, 5 YR 5/8, laminated with iron oxide and full of iron concretions, of low friability and with low permeability to water, air and roots, an ortstein horizon.
B_2	20 in.	Yellow, 10 Yr 8/6 of medium friability and with fairly good drainage.
	82 in. +	Hard kaolinitic shaly rock.

Table 13. Analytical data for an upland tropical giant podzol
(After Barshad and Rojas-Cruz 1950)

	O.M. %	C/N	pH	CEC m.e./100 g	Exchangeable bases, as per cent of total bases				Texture %		
					Ca^{++}	Mg^{++}	K^{+}	Na^{+}	2.0 – 0.05 mm.	50–2 μ	< 2 μ
A_{11}	19.94	13.1	5.3	50.05	58.5	27.5	4.0	10.0	25.61	67.11	7.28
A_{12}	10.61	15.7	5.4	45.78	41.6	42.8	3.9	11.7	67.93	29.33	2.74
A_{21}	7.54	19.1	5.6	41.43	38.7	27.4	2.3	21.5	62.36	34.36	3.38
A_{22}	4.95	15.8	5.7	31.0	48.8	30.6	2.1	18.5	50.90	44.82	4.28
B_1	8.74	40.5	5.6	42.34	48.9	22.0	13.5	15.6	75.59	19.93	4.48
B_2	2.85	16.2	5.3	21.79	53.4	21.0	9.9	15.7	29.38	26.96	43.66

	whole soil		organic free clay < 1 μ	
	SiO_2/Fe_2O_3	SiO_2/Al_2O_3	Fe_2O_3 % (by Tamm's method)	Al_2O_3 % (by Tamm's method)
A_{11}	60.8	6.52	1.7	11.3
A_{12}	56.1	3.59	1.8	19.2
A_{21}	38.5	3.44	0.7	18.2
A_{22}	50.8	4.77	0.7	15.4
B_1	1.42	2.37	45.7	6.3
B_2	15.71	2.68	8.4	6.3

Both humus and iron podzols developed on granite of the Central Andes have been reported by Schaufelberger (1952). The altitude was more than 3,000 m.

In the cloud forest belt of Bolivia, there are weakly weathered, rather strongly enleached intergrades between red yellow podzolic soils and podzols, typical weakly weathered podzols, well developed podzols, and gley podzols as well, at elevations ranging from 3,000 to 3,500 m. (Anon. 1964 b, Wright 1964). The detailed legend for the third draft of the soil map of South America (Anon. 1965 b) mentions podzolized soils and podzols occuring in both equatorial and Andean highlands of Colombia, Peru and Bolivia, and podzolized soils and shallow white sands of the uplands of Venezuela and British Guiana.

2. AFRICA

Incipient podzolization was found by Scaetta (1937), under mountain forest. Pécrot (1959 a) noted upland podzols, in small areas of Ruanda (Kivu). Sys (1960 b) described kaolisols with B_{2h} horizons developed under upland savannah of Ruanda.

Pitt-Schenkel (1938) observed soils which were grouped as tropical forest podzols, by Milne (1936) (cf. Troll 1937, and Mohr and van Baren 1959), at 2,000 m. elevation.

Pécrot (1959 b) reported on soils occurring in the Kivu region at elevations above 1600 m. which show certain analogies with podzols of temperate regions, and on podzols at over 1800 m. elevation where they occur in very reduced small areas.

Van Zinderen Bakker (1965) reported shortly on not very typical podzols developed on basalt, from the Drakensberg Mountains in South Africa where they occur above 3,000 m.elevation.

After Schokalskaja (1953) podzolization occurs at elevations of more than 1,800 to 2,000 m., in East Africa where rainfall exceeds 3,000 mm., and mean annual temperature is less than 10°C. But the unique soil with definite podzol character which was known in 1935 was found at Shume, Tanzania, under camphor forest (Moffet 1955). In the opinion of this author, podzolization is a vegetation induced effect of no regional significance, in Tanzania. Some soils of Tanzania have mistakenly referred to as podzols (Spurr 1954). After Calton (1954) podzolization in Tanzania can only be regarded as rare superficial phenomenon possible, under extreme conditions of base poverty.

After Heske (1966) the existence of podzols in Ethiopia is proved.

After Hénin (1949), Erhart noted podzols at about 2,000 m. elevation on Madagascar.

3. ASIA

A. India and Ceylon

Even at high elevations of the Himalaya no true podzols have been found (Misra and Puri 1954). Podzolic soils, less acid and with higher base saturation than usually found in podzols, occur at high altitudes of the region (Raychaudhuri 1964).

Moormann and Panabokke (1961) observed a soil which belonging to the subgroup of the red-yellow podzolic soils showed a B horizon the upper part of which was dark coloured by organic matter. This soil was found in the Nuwara Eliya region (Ceylon) under wet montane grassland at about 6,000 ft. above sea level.

Pans have been observed in soils under wet montane grassland (patana) of Ceylon by de Rosayro (1945/46), too.

B. Malayan archipelago

In the opinion of Mohr (1933) the best chance for the development of podzols exists in New Guinea, above 3,000 m. elevation. But thus far no podzols had been found before 1944 (Mohr 1944).

Van Schuylenborgh (1958), van Schuylenborgh and van Rummelen (1955) and Kiel and Rachmat (1948) studying soils developed in Indonesia on tuff, noted that brown podzolic soils occur as low as 1,000 to 1,500 m. above sea level, and podzols might already be present at approximately 2,000 m. above sea level, on acid rocks. On andesitic material, grey brown podzolic soils occur at an elevation ranging from about 700 to 2,000 m. A zone of brown podzolic soils follows from 2,000 m. upwards, which finally gives place to a zone of true podzols.

Tan Kim Hong and van Schuylenborgh (1959, 1961 a, 1961 b) reported briefly on both C/N and Al_2O_3/Fe_2O_3 ratios and light absorption of organic matter extracts of Indonesian upland podzols.

After Dudal (1957) and Dudal and Moormann (1964) podzols develop on coarse siliceous parent material like sandy alluvium, weathered sandstone, or acid volcanic tuff, from sea level up to 2,000 m. in Indonesia (Sumatra, New Guinea) and Malaya.

Heath forests with podzols of the Koyan valley in Sarawak extend from an altitude of about 750 m. upwards to over 1,000 m. (Richards 1936, Browne 1952). Kerangas at altitudes of 670 m. to 1,330 m. have been reported from North Borneo by Meijer (1965). Humus podzols of high elevations in Sarawak have been also reported by Dames (1962) and Fosberg (1965).

Beckett and Hopkinson (1961) described an acid soil under keranga forest, at about 1,000 m. altitude in Sarawak. The profile showed a thick peat layer, over grey and white sandy clay loan which is probably the eluvial horizon of a podzol. Deeper horizons have not been excavated.

Ashton (1959) referred to groundwater podzols in badly drained sites of Brunei, at 1750 m. above sea level.

Lang (1915) reported on bleached earths found in Java at 1,200 m.elevation. This soil type has been mentioned too by Dames(1949). True podzols, however, do not occur in Java (Dames 1949). But little data are available concerning the high mountain regions, and it may be well that podzols do occur locally (Dames 1955).

Senstius (1930 a, 1930 b) concluded from his soil studies that podzols are not present in the oriental tropics (Java, Philippines), at high elevation.

Lam (1945) reported on blackwater swamps, small level patches of white sand, dark coloured by humus, found at an elevation of over 1,000 m. in New Guinea. Myrtaceae, Ericaceae, and Nepenthes as well grow on these soils.

Hardon (1936) investigated upland tropical podzols of the Arfak Mountains of North-west New Guinea where they occur at elevations ranging from about 1,900 to 2,400 m. above sea level. The parent materials are Jurassic shales, and quartzy sandstone as well. Up to about 2,000 m. altitude, a forest prevails of trees about 13 to 16 m. high which is composed especially by Podocarpus, Darrydium and Phyllocladium species, with undergrowth of Sphagnum and other mosses. Araucaria forests predominate near lake banks. The open parts are covered with Vaccinium, Styphelia, Gleichenia, and Baeckia frutescens. At about 2,000 m. the forest becomes lower and less dense. Pteridium aquilinum, Sphagnum, and the ever present Baeckia predominate.

Hardon described four more or less identical profiles developed on shales, quartzites and quartz sandstone (see profile description No. 18). A fifth soil described by Hardon consists of peat 70 cm. thick, over bleached material.

Profile description No. 18

Upland tropical podzol: humus podzol. Elevation about 2,000 m. (After Hardon 1936).

A_0	25 cm.	Cover of undecomposed twigs and roots, intermixed with brown coloured soil.
A_1	15 cm.	Find sandy, grey to greyish-brown, rather plastic and humic horizon, sharply demarcated from A_0, grading into the underlying bleached zone A_2 .

A_2	10 cm.	Loamy, white to greyish-white, rather plastic horizon without structure and with a sharp boundary to B_1.
B_1	30 cm.	Yellow to orange coloured layer with red flecks and streaks, more plastic than the overlying A_1.
B_2C	80 cm.+	Lighter in colour than B_1, with red flecks and streaks too, containing unweathered parent material.

After Schroo (1963 b, 1964) the soils of New Guinean highlands are intensively leached. Quartzitic mountain soils of the Wissel Lake area display classic features or iron podzols. Podzolic soils become predominant over 1,000 m. altitude, in the Amberbaken coast.

Reynders (1962 b, Reijnders 1964 a) published data on upland tropical podzols of the Star Mountains, New Guinea, which cover extent areas (Reijnders 1964 b). At elevations ranging from 1,260 to 3,250 m. above sea level, iron humus podzols (see profile description No. 19, and table No. 14), ortstein podzols (see profile description No. 20, and table No. 15), and intergrades between podzols and brown podzolic soils as well occur.

Profile description No. 19

Upland tropical podzol: shallow iron humus podzol. Elevation 1,260 m. (After Reijnders 1964 a, p.82).

A_{oo}	10 cm.	Moist to wet, very dark brown (10YR 2/2) peaty organic matter layer, well-rooted, on:
A_1	8 cm.	Moist to wet, gray (2,5Y5/1) sand, loose and structureless, very poorly rooted; merging into:
A_2	10 cm.	Wet white (2,5Y8/2) sand, compact and hardened, intermitted with dark gray brown humic bands, always underlain by a small white sandy zone; merging quickly into:
B_2	10 cm.	Wet, yellow to yellowish brown (10YR7/6-5/6) mottled loamy sand, firm and compact to slightly blocky structure; merging quickly into:
B_2Cg	12 cm.	Wet, olive gray (5Y5/2) sandly loam, with scattered small brown mottles; merging gradually into:
Cg	30 cm.	Wet, light gray (2,5Y6/2) sandy loam, with scattered vague, small, gray mottles. Deeper in the profile 90- 110 cm. a cobble layer occurs bedded in loam, in which many yellowish brown mottles; at a depth of about 2 m., and again at about 3 m. small peat layers are found.

Table 14. Analytical data for an upland tropical humus podzol of New Guinea. (After Hardon 1936).

	O.M.%	C/N	pH(KCl)	CEC m.e./100g.	2 mm	2-0.05mm.	0.05-0.005 mm.	0.005 mm.
A_o	85.00	74.8	2.2	-	-	-	-	-
A_1	6.15	30.0	3.1	10.48	10	35	54	11
A_2	0.59	4.5	3.3	7.50	0	3	70	27
B_1	1.77	13.6	3.9	6.80	0	4	60	35
B_2C	0.60	5.6	4.0	5.59	29	13	62	26

	P_2O_5 %	Fe_2O_3	Al_2O_3 %	SiO_2 (combined) / Al_2O_3 + Fe_2O_3
A_1	0.09	2.10	26.36	2.28
A_2	0.07	2.52	36.72	1.96
B_1	0.06	21.78	30.76	1.35
B_2C	0.12	18.93	34.50	1.27

Profile description No. 20.

Upland tropical podzol: peaty ortstein podzol. Elevation 3,250 m. (After Reijnders 1964 a, p. 115).

A_{oo}	15 cm.	Wet, brown peat layer, with some sand, intensively rooted; undulating merging into:
	5 cm.	Wet, dark brown peat, with some sand; rooted; a little undulating; quickly merging into:
A_1	2 cm.	Wet, grayish (10YR5/2) humic sand; poorly rooted; on:
B_{2ir}	0,5 cm.	Wet, grayish (10YR5/2) humic sand; poorly rooted; on:
C_1	12,5 cm.	Moist, yellowish (10YR 8/3) sand; consisting of rotten rock material.
C_2	80 cm.	Parent material, solid rock.

Table 15. Analytical data for upland tropical podzols

(After Reijnders 1964 a, p.80, 114)

Shallow iron humus podzol. Elevation 1,260 m.

Horizon	C%	pH(KCl)	Fe_2O_3 %	Al_2O_3 %	Clay minerals	SiO_2 / Al_2O_3	SiO_2 / Fe_2O_3
A_1	0.86	3.0	0.11	n.d.	Destructed kaolinite	n.d.	2,315.00
A_2	0.37	4.0	0.21	1.25	cristobalite, gibbsite	126.04	1,177.00
B_2	0.63	4.2	6.79	12.50		9.59	27.70
B_2Cg	0.62	4.5	4.03	16.25	Kaolinite, gibbsite	7.54	47.66

Peaty ortstein podzol. Elevation 3,250 m.

Horizon	C%	C/N	pH(KCl)	CEC m.e./100g.	Fe_2O_3 % total	Al_2O_3% soil	Clay minerals
A_{oo}	-	-	-	-	1.35	3.44	-
A_1	2.82	14.8	3.8	18.70	2.02	12.96	Kaolinite, gibbsite
B_{2ir}	-	-	-	-	29.56	12.47	-
C_1	0.38	19.0	4.8	8.56	7.64	14.17	Gibbsite

	SiO_2 / Al_2O_3 (Clay fraction)	SiO_2 / Fe_2O_3 (Clay fraction)
A_{oo}	-	-
A_1	1.40	43.32
B_{2ir}	-	-
C_1	0.43	12.85

4. AUSTRALIA

Various types of upland podzols occurring in Australia have been described by Hallsworth et al. (1953). Costin (1955, 1957) reported on gley podzols. Upland podzols are also found in New Zealand (Taylor and Cox 1957).

IV. FINAL REMARKS

1. DISTRIBUTION PATTERN OF TROPICAL PODZOLS

It has been shown in this report that groundwater and normal podzols as well occur more frequently in the tropics than generally assumed.

Usually, podzols occupy isolated patches which are widespread throughout the tropical zone, any individual unit being of limited extent. But there are regions in which podzols occupy larger areas. In other regions podzols are more widespread than usual.

Tropical podzols occur on both uplands and lowlands. No exact data are available on total area occupied by tropical podzols. Recently, Klinge (1966 e) made an attempt to estimate the area occupied by lowland tropical podzols in America, Africa, SE Asia and Australia plus New Zealand. The following table (Table 16) is quoted from the above reference.

Table 16. Lowland tropical areas podzol of the world (in million hectares)

	I	II	III	IV	Total
Tropical zone[1)]	1560	2170	400	345	4475
Tropical rain forest climate[1)]	680	230	240	2	1152
Lowland tropical podzols					
a) under tropical rain forest climate	0.6	0.052	1.25[2)]	-	1.4
b) in other tropics	0.004	0.003	0.2	2.5	2.7
c) in the subtropics IV 7[1)]	1.0	0	0	2.1	3.1
d) total	1.6	0.055	1.45	4.6	7.705

1) After C. Troll (1964)

2) After Smythies' (1963) and Brünig's (personal communication 1966) information, the acreage of 0.7×10^6 hectares given in Klinge (1966e) was enlarged to the value given here.

I. Caribbean region and South America (Central America, West Indies, Florida)

II. Africa south of the Sahara, Madagascar

III. SE Asia (without India, Pakistan, China and Philippines)

IV. Australia, Fiji Islands, New Zealand

Despite the fact that the above values are estimates only, it is obvious that lowland tropical podzols occupy a total surface of much less extension in Africa than in any other continent. This difference in total area occupied by lowland tropical podzolz is another feature which D'Hoore (1956) when comparing both continents of Africa and America from the pedological point of view, could have taken into consideration.

Lowland tropical podzols, although occupying only 0.16% of the entire tropical zone, play a relatively great role in this zone which is deduced from the fact that after Stephens (1961) in Australia about 2.5 x 10^6 hectares are occupied by non-tropical podzols , mainly occuring in western and southern Australia, whereas the same surface is occupied by podzols in the tropics of zone IV 7. In Sarawak, lowland tropical podzols occupy 3.6% of the whole territory, or 5% of the wood area. The total area occupied by lowland tropical podzols is of the order of 7.7 million ha.

Usually, tropical podzols occur in coastal areas (Guianas, the territory of Panama, western and eastern Africa and Australasia) where both unconsolidated beach and derived dune sands, poor in clayey material are frequent. But also farther inland podzols occur, which have developed from river sediments similar in composition and texture to marine coastal sands, or raised beaches which, related to eustatic sea-level changes during the Pleistocene and Holocene are widely distributed throughout the tropical zone (Woldstedt 1965).

Upland tropical podzols mostly develop from acid hard rocks rich in quartz, of different geologic age, or river deposits. Both upland and lowland tropical podzols may also develop from outwash material.

In conformity with the young geologic age of most coastal and river deposits tropical podzols, geologically spoken, are young formations.

Striking differences exist between tropical South America, Africa and Australasia as well, with regard to the distribution of lowland tropical podzols.

In South America these soils are very frequent in Amazonia, where they occur in small isolated "isles", and the Guianas as well. Altogether occupying an extent area, they are associated with peats, in the Guianas. But there seems to be no such association between podzols and peat, in Amazonia.

In Africa where lowland tropical podzols are mostly related to coastal regions, their frequency is generally low. Only very few occurrences of these soils are known from the biggest African river basin.

Lowland tropical podzols are very frequent in Australasia where they are intimately related to extent moor and swamp land as well.

In the above tropical regions, blackwater rivers are very common. In America, these rivers flow mostly from podzols. In Africa, they originate predominantly in swamps, moor and inundated terrain as well. Blackwater rivers of Australasia come from both podzols and moor and swamp land.

Lowland tropical podzols extend from the tropics into sub-tropical regions like Florida or Southeastern Australia, where adequate parent materials occur. Topography plays an important role for the formation of both groundwater and normal podzols as well.

2. VEGETATION/SOIL RELATIONSHIPS IN TROPICAL PODZOL AREAS

By far the greater part of tropical primary forests consist of mixed associations on optimum soils. The majority of species composing these mixed forests is represented in a small sample by very few individuals, none of the species being dominant by itself.

There are, however, consociations with a single dominant species, in areas of permanently high water table, or regions occupied by podzols and other non-optimum soils as well. A proof of the intimate relation between these consociations and their soils is given by the remarkably close correspondence between the soil boundaries and those of the forest type.

After Richards, consociations with a single dominant species have in common:

Larger number of trees per unit area.

Smaller amount of buttressing of trees.

Better illumination of lower levels.

Denser undergrowth

Smaller number of species of ground herbs.

Scarcity of larger lianes.

Tendency of epiphytes to grow at lower level.

Tendency towards the dominance of a single species of tree.

They differ in these characteristics, from tropical mixed forest.

The following consociations with a single dominant species of tree have been mentioned in this report:

Wallaba (Eperua) forest of northern South America.

Muri (Humiria floribunda, Clusia nemorosa) bush and dakama forest, both of the Guianas .

Caatinga forest which replaces Wallaba forest in the Rio Negro region.

Campina and campo of the Lower Amazon.

Heath forest (kerangas, padang) of Australasia showing remarkably close resemblance in both structure and floristic composition, and general aspect as well, with Wallaba forest, the actual species of trees being totally different.

Agathis forest of Australasia

In the opinion of Richards, in Africa there appears to be nothing closely comparable with the characteristic vegetation of lowland tropical podzols of America and Australasia as well. But Lemée (1961) compared sublittoral forests of the Ivory Coast with Wallaba, muri, padang, and heath forest as well, and Evrard compared the Aneulophus africanus forest of the Congo, with both muri and padang vegetation, which resemble the fourrés of South America(Aubréville 1961). Brown podzolic soils and podzols, when they occurred in the Congo region, were often observed under either Gilbertiodendrum dewevrei or Brachystegia Laurentii forest (Germain and Evrard 1956).

Well (1965) reported on physiognomic and structural homologues between evergreen simplified vine forests of East Australia and heath fores s of Borneo and Wallaba forests of British Guiana as well.

The resemblance depending on similarities of climate and soil as well, which were found to exist between all the above communities on lowland tropical podzols shows that there is a parallel differentiation of edaphic climaxes, in widely different regions.

Some plants like Drosera, Cladonia and Sphagnum as well also occur on podzols of temperate regions.

No data are available neither on both nutrient content and nutrient cycle (living biomass-litter-soil) of vegetation typically growing on tropical podzols, nor on microbiology of these soils, in relation to both decomposition of litter and humus formation. Sombroek (1966), in relation with imperfectly drained Planicie soils of Amazonia including groundwater podzols, referred to the considerably lower timber volume of the forests growing on these soils, compared with free draining Planicie soils which are latosols.

/ Author's note:

Refer here to Laudelot (Congo), Popenoe (Florida) - eventually introduce chapter on soil fertility. /

3. SOIL BIOLOGY OF TROPICAL PODZOLS

Investigations on tropical soil fauna have recently been started by Delamare (1951), Kühnelt (1960), and Schaller (1960, 1961, 1962). Faunistic studies of tropical podzols, however, are apparently lacking. Efforts should be made towards the reconnaissance of interrelations between soil fauna and humus formation of podzols (Kubiena 1955), under tropical environmental conditions.

Harrison (1965) draws the attention to the most marked scarcity of vertebrates in the kerangas of Borneo which might be caused by shortage of water in this peculiar habitat.

Another promising field of work will be the microbiology of tropical podzols, for there are no investigations in this field, except one contribution of Dommergues (1955). Nitrogen fixation by both free-living and symbiotic micro-organisms (Becking 1961 a, 1961 b), and mycorrhiza (Melin 1959) which are supposed to be of great ecological significance (Richards 1957) for plant nutrition on tropical podzols, and microbial activity in the formation of podzol B horizons (Aristovskaya 1956, 1964, Crawford 1956, 1962) as well, deserve particular interest of microbiologists.

4. BLACKWATER AND PODZOL IN THE TROPICS

It has often been mentioned in this report that both lowland and upland tropical podzols are associated with blackwater rivers.

Acidic, brownish ground and surface waters as well are usually referred to as blackwater (Browne 1919, Giessler 1965, Leichleitner 1964, Schneider 1961), or creosote coloured water (Clayton 1958).

Blackwaters occur mainly in areas built up by primitive rocks, low in lime (Ryhänen 1964), in both tropical and ectropical regions (van Beneden 1955, Dietrich 1941, Harrassowitz 1926, Potonie 1908, 1911, Senstius 1930 a, 1930 b).

The colour of blackwater is due to dissolved or suspended organic substances, of acidic nature (huminic acids, fulvic acids (Berg 1962, Obenaus 1963), humolimnic acids (Gessner 1964, Shapiro 1957), flavons (Brennemann 1957), and mostly allochthonous origin. Blackwater is typically low in nitrogen (nitrates being nearly absent), and other plant nutrients as well, due to absorption by organic matter. Free aluminium, however, is present. Due to the low mineral content, blackwater of Amazonia has been described as fairly impure distilled water (Sioli 1957 c). Drainage water of European heather habitats also is chemically very poor (Tüxen 1965).

Water bodies of blackwater type are dystrophic (Gessner 1958 a, Järnefelt 1956, Naumann 1929 a, 1931, 1932, Thienemann 1925, Wasmund 1929).

By sedimentation of organic matter of blackwater, dy is formed as bottom sediment, or subaquatic soil (Kubiena 1953).

A. Origin of blackwater humus

There is no doubt that soil humus is the source of much of the organic material that gives the distinctive colour to blackwater rivers (Beck 1958, Richards 1957).

Many authors hold the opinion that both bleached and white sands, and podzols as well are the source of blackwater humus, in the tropics (Altemüller and Klinge 1964, Bleackley and Khan 1963, Chaves 1963, Dudal and Moormann 1964, Gorham 1961, Klinge and Ohle 1964, Ramann 1911, Rice 1921, Sakamoto 1960, 1965, 1966 b, 1966 c, 1966 d, Sapper 1929, Sioli 1954 b, 1955, 1956 b, 1957 b, 1964, Sioli et al. 1962, Sioli and Klinge 1961, van Steenis 1957, and others).

Richards (1957) pointed out: " 'Blackwater' streams are also found flowing from Tropical Moor forest (peat swamp), but where no extensive swamps are known to exist 'blackwater' is a trustworthy guide to the presence of bleached sands".

Proofs of genetic relations between both tropical blackwater and podzol, apart from their association, are found anywhere in tropical countries:

Blackwater of areas where no swamps are known to exist, flow from podzols, and groundwater of podzol areas is of the blackwater type.

Other sources of both blackwater and water humus in general may be:

Dead planctonic (Kolkwitz 1942/45), and other aquatic organisms as well.

Plant residues brought into the water from surrounding land.

Seepage from surrounding land (swamp and moor)(Giessler 1965, Lam 1945, Lechleitner 1964, Potonie 1912, Schneider 1961, Vageler 1938); temporarily inundated land (Huber 1906, Zimmermann 1963).

Extracts of living plants of riverine vegetation (Beebe 1927, de Civrieux and Lichy 1950, Davies and Richards 1933, Koch-Grünberg 1909).

Phytotelms (in bromeliads and other plants)(Nünning 1947, Klinge 1966 a, Laessle 1961).

Blackwater of higher latitudes was first studied (Aschan 1907, 1908, Birge and Juday 1934, Gessner 1929, Naumann 1929 b, Ohle 1940, and others).

Nothing can be said about the chemical composition of tropical blackwater humus, due to lack of detailed studies. Recently, an investigation of blackwater humus of Amazonia has been started by F. Scheffer and co-workers.

B. Tropical blackwaters

Tropical blackwaters have already been reported by Giesecke (1930), Rüger (1929) and Tacke (1930).

Given below, in geographical order, is a list (not fully complete) of literature on tropical blackwaters:-

Southeastern United States and Central America: Beck (1958), Bick et al.(1953)Helbig (1959);

South America: Bauer (1919), Bleackley (1964), Braun (1952), Carter (1934), Chaves (1963), de Civrieux and Lichy (1950), Fochler-Hauke (1963), Foldats (1962), Gessner (1955, 1958 b,1959, 1960 a, 1960 b, 1962 a-c), Heyligers (1963), von Humbolt (1958), Jaeger (1940), Katzer (1903), Keller (1961, Klinge and Ohle (1964), Muntz and Carcano (1888), Reindl (1903), Richter (1966), Schichtel (1893), Schütze (1927), Schulz (1960), Sioli (1951, 1954 a, 1956 a, 1956 b, 1957 a, 1957 b, 1959, 1961, 1964, Scott et al. (1965), Sioli and Klinge (1961, 1965), Sioli et al.(1962), Vila, 1964);

Africa: Berg (1961), Bouillenne et al. (1955), Clerfayt (1956), Deuse (1960), Dubois (1959), Germain (1965), Krenkel (1920), Marlier (1951, 1958 a, 1958 b), Marlier et al (1955), Range (1930), Rougerie (1958), Vosseler (1904), Walter (1936);

Asia: Anderson (1963, 1964), Beckett and Hopkinson (1961), Behrmann (1917), Browne (1952), Brünig (personal communication, 1964), Bünning (1947), Chaper (1893), Dames (1962), Dilmy (1965), Febn (1933), Fosberg (1965) Hardon (1937), Helbig (1955), Kobayashi (1959), Lang (1915), Mohr (1933, 1944), Posthumus (1937) Reinhard (1924), Richards (1936), Ruttner (1931), Senstius (1930 a, 1930 b), Sewandono (1938), Winkler (1914), Wood (1965), Wood and Beckett (1961), Wyatt-Smith (1961, 1964);

Australia: Douglas (personal communication), Bayly (1964), Cassidy (1944), Jennings (1957), Leeper (1964).

5. SOME CHARACTERISTICS OF TROPICAL PODZOLS

The misconception that tropical soils are poor in humus is proved true inasmuch as some tropical podzols show an organic surface horizon of reduced thickness in comparison with the often enormous thickness of both eluvial and illuvial horizons of these soils, or even absence of a raw humus layer. It is supposed that in these cases the soils have lost their surface organic matter by fire, erosion, or man's activity.

Generally, tropical podzols have the reputation of being low in plant nutrients. Ellenberg (1964 a), however, mentioned that extreme podzols with more than 15 cm.of raw humus, developed on dune sands in the Peruvian rain forest area, are as productive as neighbouring red or yellow latosols, provided that neither the forest nor the high amount of nitrogen accumulated in the raw humus layer are attacked by fire or man. This author believes tropical podzols not to be of low productivity, but to be very sensitive to perturbation of their nitrogen economy, by man. In Africa (Yangambi area), the Lilanda ground water podzol was as productive, if not more productive, than neighbouring latosols. But this may be due to groundwater supply (yan Wambeke, personal communication 1967).

Leigthy (1961) showed that without fertilizer the organic pan of Florida podzols produced a better growth of oats in pots than did the surface soil.

There are no data available that under tropical environmental conditions podzol development is due to man's activity, according to the way in which secondary podzols form in temperate regions, but tropical podzols seem first of all to be related to adequate parent materials.

There are no investigations on organic matter production of tropical podzols. Accordingly, it is not known whether production of both wood and litter is about 2,5 times greater than in temperate regions (Becking 1962).

As to chemical characterization of tropical podzols, data are given only on texture, both organic matter and nitrogen content, pH, CEC., exchangeable cations, and phosphorus content. In a few cases clay minerals have been determined. Apparently, there are no studies on humus compounds. Much work is to be done in the field of analytical pedology, with regard to tropical podzols.

As to soil systematics and genesis of tropical podzols, humus podzols are more frequently found than iron podzols. Tropical podzols are associated with regosols, lithosols, latosols, red yellow podzolic soils, and often peat or swamp often forming catenary sequences.

Generally, it may be concluded that tropical podzols may develop from degraded sandy latosols, and red yellow podzolic soils as well. But tropical podzols need not pass through a latosolic stage. Tropical podzols may also develop from regosols.

6. LANDSCAPE - ECOLOGY IN RELATION TO TROPICAL PODZOLS

Tropical podzols are not only soils which occur within the whole tropical zone but are-as repeatedly mentioned in this report - intimately related to both speficic plant communities and blackwater rivers. Taking also into account relief, climate, rock and soil fauna as well, which are likewise related to the above soil - vegetation - freshwater complex, the whole forms what is known to be an ecosystem (Tansley 1939) made up by both biotope (or ecotope - complex of climate, rock, topography, water, soil, and so forth) and biocoenosis (fauna plus flora).

Like soils in general, tropical podzols should not be studies as soils of a definite region, the tropical zone, but as a part of one complex, the land (Taylor and Whyte 1959), or ecosystem (Miller 1966).

The field of research which intends to study soils as a part of the ecosystem is landscape-ecology (Troll 1958, 1963) making use of appropriate pedological principles like tessera (Jenny 1958), and catena (Milne 1936, Troll 1937). Tropical podzols and their ecosystem, therefore, should be studied by means of landscape-ecology.

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