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Title: MORPHOLOGY AND GENESIS OF GRAY PODZOLIC SOILS IN THAILAND

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Nine Gray Podzolic soils from different physiographic regions of Thailand were studied to determine their characteristics and genesis in relation to their parent materials, land form, pedogenic environment, classification and management. The clay was characterized by X-ray diffraction and standard chemical and physical analyses were performed. Mineralogy of the light and heavy minerals from the fine sand to coarse silt fractions was determined by randomized grain counts. Micromorphological study was made of thin sections from selected horizons in each profile.

Field and laboratory study showed that Gray Podzolic soils formed under distinctly different climatic zones and vegetation have quite similar characteristics. They occupy similar low terraces with nearly level topography and are associated closely with Low Humic Gley soils.

Parent materials and topography are the two most important factors influencing the genesis of these soils. Mineral assemblages in the profiles indicate the parent materials were preweathered sediments from acidic rocks. They are quartz rich, with very few if any weatherable minerals, ubiquitous heavy minerals and with dominantly kaolinitic clay. The few lower stability minerals found in several profiles can be traced to some rocks rich in those minerals in the catchment areas. Climatic variations between the soils are not consistent with the weathering stages found and differences in soil age are not enough to account for mineralogical variation through differential *in situ*, weathering. Therefore, differences in composition and preweathering of parent materials most logically account for the presence of minor amounts of relatively unweathered feldspar and hornblende in some of these soils.

Soil development has resulted in a loosely bound, clay poor, s-matrix with low degree of orientation in the upper horizons, and illuvial B horizons with more oriented plasma, illuviated cutans and vughs in the lower part of the profiles. Pedoplasmation activity by termites and other soil dwellers is partially responsible for the high porosity and mixing of the soil materials and, possibly, for the addition of lime. Plinthite formation in the lower part of some profiles relates directly to iron mobility and accumulation associated with fluctuations of the water table.

Cation exchange capacities of the soils were low and the base saturation was generally less than 20% in the lower horizons. These characteristics reflect the low organic matter, sandy texture, kaolinitic clay and high porosity of these soils and strong leaching of bases under the humid climate. Depletion of bases and organic matter has been accelerated by the clearing of forest for shifting cultivation.

Eight of the profiles were classified as Ultisols in Paleustult and Paleudult suborders; four of these with plinthite layers were grouped in plinthitic great groups. One profile with low clay content and higher, fluctuating base saturation was placed in the Ustropept great group. The CEC of less than 24 me/100 g clay placed all nine soils in ustoxic, orthoxic or oxic subgroups. Leached Ferruginous Tropical soils of Africa and Australian Lateritic Podzolic soils are similar to Gray Podzolic soils in this study except that they have higher base saturations. In northeastern Thailand, Gray Podzolic soils have been shown to have both high and low base saturations. The higher base saturation may be due to lime accumulation by termites and low buffering capacity of the sandy soils.

Characteristics of Gray Podzolic soils indicate serious problems in their management under cultivation. The nutrient level in these soils is very deficient for most crops. In the northeast, where the rainfall is less reliable, development has been most difficult. With the present crops and level of management, response to fertilization and irrigation is very poor. Multiple improvements in other essentials of production is badly needed. Improvements are taking place, but sustained efforts on all aspects of the problem are required for effective and lasting progress.

Morphology and Genesis of Gray Podzolic Soils in Thailand

by

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To my late father and mother who made this achievement possible but did not have a chance to appreciate it.

Epistemology -

It is proper for you, Kalamas, to doubt, to be uncertain. Uncertainty has arisen in you about what is doubtful. Come, Kalamas. Do not go upon an authoritative tradition; nor upon what has been acquired by repeated hearing; nor upon rumour; nor upon what is in a scripture; nor upon speculative metaphysical theories, reasons and arguments; nor upon a point of view; nor upon specious reasoning; nor upon accepting a statement as true because it agrees with a theory that one is already convinced of; nor upon another's seeming ability; nor upon the consideration 'Our teacher says thus and so'. Kalamas, when you yourselves know: 'These things are bad; these things are blamable; these things are censured by the wise; undertaken and observed, these things lead to harm and ill', abandon them.

(Anguttara-Nikaya 1, 189)

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MORPHOLOGY AND GENESIS OF GRAY PODZOLIC SOILS IN THAILAND

INTRODUCTION

Gray Podzolic soils as classified in Thailand and Southeast Asia are one of the most extensive great soil groups identified by Dudal and Moormann in 1964. These soils occur throughout Thailand on terraces of the major rivers and streams as well as on marine coastal terraces. The most extensive occurrence of Gray Podzolic soils is on the Northeast Plateau, where these soils dominate in the areas not used for rice land. Other major areas are the Southeast Coast and east coast of Peninsular Thailand as well as a large elongate strip along the west side of the Central Plain of the Chao Phraya River (Moormann and Rojanasoonthon, 1968).

Gray Podzolic soils typically have weak horizon differentiation. The surface soil has a distinctive light gray to whitish color when dry. The illuvial B horizon usually is yellowish brown and contains more clay than the surface horizon, but frequently this difference in clay can be detected only by laboratory analysis. In the lower portion of the profile, plinthite (soft laterite) or a loose, concretionary type of hardened laterite is occasionally found at or near the water table level. Gray Podzolic soils are formed in old alluvial sediments which are normally acid, coarse to medium textured and low in plant nutrients. These soils are found on old terrace levels of comparable ages in different regions in Thailand, and they occur predominantly under a wet-dry monsoon type of climate.

Gray Podzolic soils are known for their infertility and low potential for agriculture. They have been used extensively for shifting cultivation and this use continues at the present time. Unreliable distribution of rainfall, particularly in the Northeast Plateau, is an added problem in use of these poor soils. At least 12 to 14 million people in Thailand, about one third of the population, are dependent on these soils for existence. Better understanding of the genesis and characteristics of this important group of soils is urgently needed to improve their productivity and management.

In order to understand the relationship between soil characteristics and their genetic development, it is necessary to determine the primary genetic factors and their influence on physical, chemical and morphological characteristics of a soil. Field study of the soil in relation to the climate, vegetation, geology, parent materials and age of the surface, is basic to understanding the pedogenesis of its characteristics. Inference drawn from field relationships, together with data from physico-chemical analyses, provide the means to interpret the genetic history of a soil.

Knowledge of the mineralogy of soils is essential for the study of their genesis and morphology. Identification of the mineral suites and micromorphological study permits evaluation of soil genesis through alterations, transformations, transfers and additions (Simonson, 1959). The release and leaching of plant nutrients from the easily weatherable minerals are directly related to the nutrient status of any particular soil.

Kubiena (1964) stated that "If the composition of the phenomena to be investigated is given from the beginning by nature, we can never get hold of it by some kind of synthesis but only by continuous analysis" (p. 3). This is the essential role of micromorphological study where the subject to be studied, in this case soil, is a natural dynamic body. The microscopic examination of thin sections, therefore, is an important aspect of this study for evaluating mineral weathering and pedogenesis of the soils. Phenomena studied through micromorphology include clay transformation, transfer and deposition as clay skins, the weathering of minerals and formation of pseudomorphs, the translocation of iron and aluminum, cementation or fracturing of resistant grains and arrangement of minerals or fabric analysis. In addition, subsidiary examination of the grain morphology, particularly the light and heavy minerals, X-ray analysis and physicochemical analyses were utilized in completing the study and characterization of these soils.

The purpose of this investigation is to study the physical, chemical and mineralogical characteristics of the Gray Podzolic soils of Thailand in order to achieve understanding of their characteristics and genesis for the following objectives:

1. To regionally compare and contrast Gray Podzolic soils from different climatic zones with regard to geomorphic position, kind of sediments, pedogenic environment and profile development.
2. To identify the mineralogy of these profiles and determine the degree of weathering.
3. To describe the micromorphological patterns resulting from pedogenic transformation and distribution of the mineral suites, particularly the formation of clay and clay skins, and the role of iron and aluminum in the formation of lateritic nodules.
4. To relate the classification of the soils to their characteristics.
5. To relate the properties and qualities such as water holding capacity, inherent fertility, compaction and porosity of these soils to fertility and management problems and probable remedies.

THAILAND AND THE STUDY REGIONS

The Kingdom of Thailand is located centrally in the Indochinese Peninsula of Southeast Asia, between 5^{o} 40' and 20^{o} 30' north latitude and 97^{o} 70' and 105^{o} 45' east longitude. The total area of the country is 518,000 square kilometers (approximately 200,000 square miles). Thailand is about three-fourths the size of Texas or approximately equal to the size of France. The country is axe-shaped, with a long panhandle extending southward along the Malay Peninsula. The longest north-south span is about 1620 km (1000 miles) and the widest part is 750 km (500 miles) from east to west. It has common frontiers with Laos on the north and east, with Burma on the north and west and with Cambodia on the south and east. Peninsular Thailand is bounded on the south by Malaysia (Figure 1).

The preliminary figures of the official 1970 census indicated a Thailand population of 34,152,000, which signified a relatively high increase of 3.2 percent per year for the last decade. The 1960 population was only 26,258,000 (Thailand, Central Statistic Office, 1962). The present population density is 65 per km^2 (170 per mi^2). About 80 percent of the population is engaged in certain forms of agriculture, predominantly as rice farmers.

Since the distribution of Gray Podzolic soils is widespread throughout the Kingdom, general countrywide relationships of geology, soils parent materials, climate and vegetation will be described first.

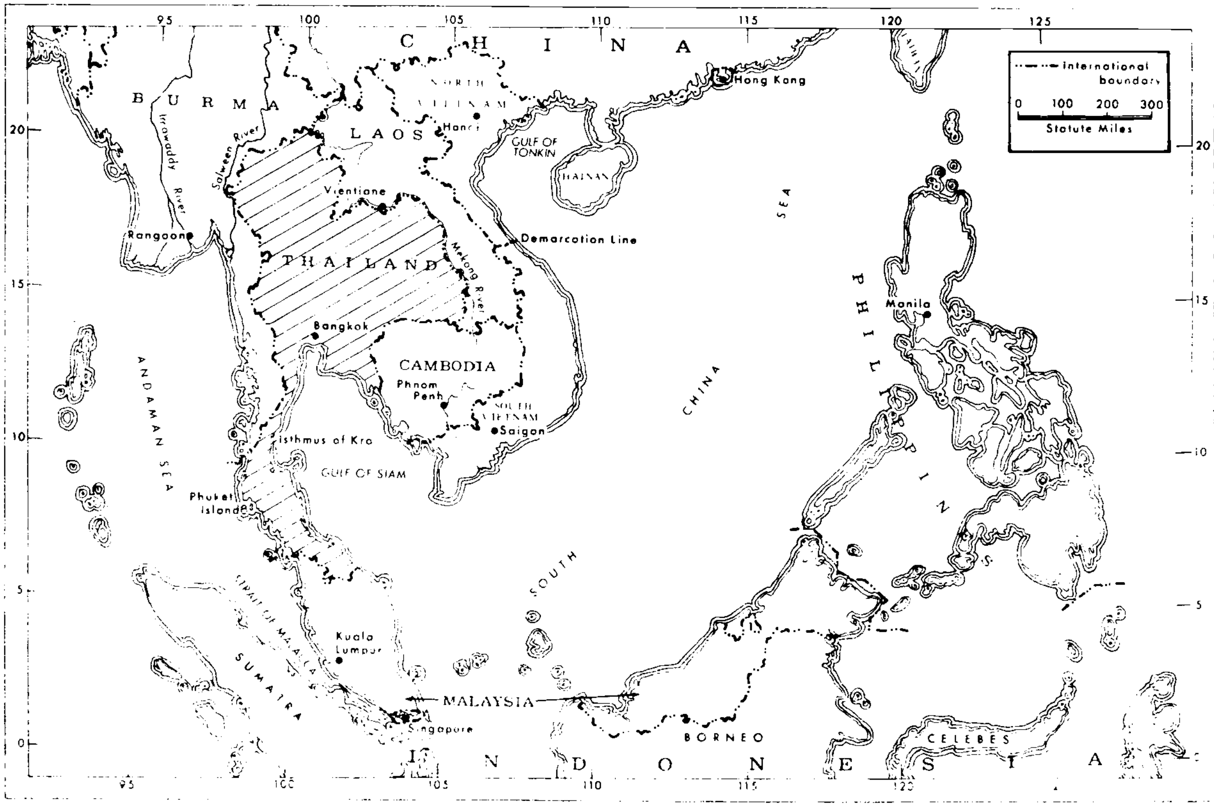

Figure 1. Location of Thailand in Southeast Asia.

The study regions for Gray Podzolic soils will then be described in relation to the individual physiographic regions where they occur. Although the nine Gray Podzolic soil profiles in this study are located in four of the six physiographic regions, they are, however, representative of all series thus far associated with the Gray Podzolic soils in Thailand.

Physiography

Brown *et al.* (1951) and Pendleton (1953, 1962) had proposed five physiographic regions for Thailand. From our current work in soil survey since 1961, it was found necessary to add another broad physiographic region or province, namely "Central Highland" (Rojanasoonthon and Moormann, 1966). These physiographic regions, as outlined in Figure 2, are listed in Table 1.

Table 1. Physiographic regions of Thailand.

Rojanasoonthon and Moormann (1966) (this study)	Brown *et al.* (1951)	Pendleton (1953, 1962)
1. Central Plain	Chao Phraya Plain	Central Valley
2. Southeast Coast	Chantaburi	Southeast Coast
3. Northeast Plateau	Korat Plateau	Korat
4. Central Highlands	- -	- -
5. North and West Continental Highlands	Northwest Highlands	Continental Highlands
6. Peninsular Thailand	Peninsular	Peninsula

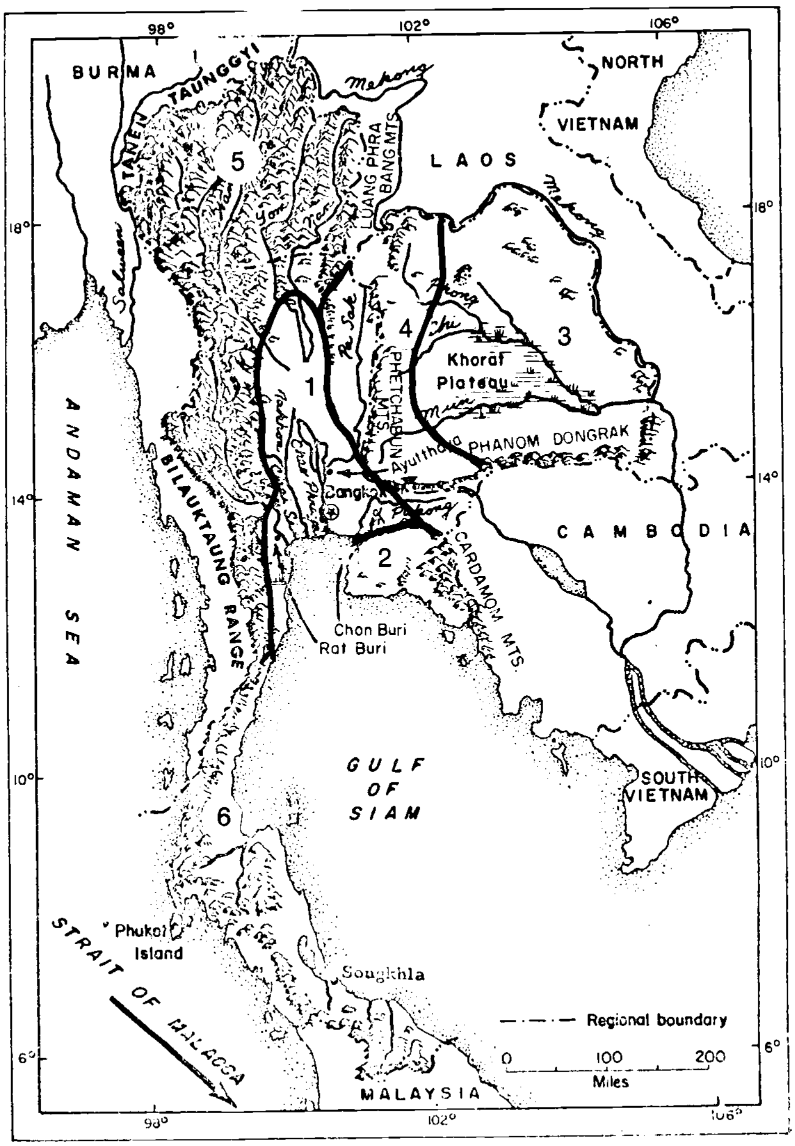

Figure 2. Physiographic regions of Thailand. 1 - Central Plain; 2 - Southeast Coast; 3 - Northeast Plateau; 4 - Central Highlands; 5 - North and West Continental Highlands; 6 - Peninsular Thailand.

The Central Plain (1), less than 100 m in elevation, occupies the central region. The Southeast Coast (2) has dissected uplands (less than 100 m elevation) extending east and south to the Cardamon Mountains of Cambodia that rise to 1500 m. The Northeast Plateau (3) has a general elevation of 150-200 m and undulating topography. Drainage of the area is south and east to the Mekong River. The low mountains (600 to 900 m high) of the Central Highland (4) separate the Northeast Plateau and the Central Plain. The North and West Continental Highlands (5) consist of parallel mountain ranges 600 to 1500 m in elevation and intermountain basins connected by narrow valleys. The highlands extend across northern Thailand and south through the western length of the country into Peninsular Thailand (6) with lower mountains, 300 to 900 m high fringed by plains between the mountain ridges and along the coast.

Geology

Information regarding geology of Thailand is taken from Brown et al. (1951) and a report accompanying the Revised Geological Map of Thailand on a scale of 1:1,000,000 (Thailand, Department of Mineral Resources, 1969).

Extensive areas of Paleozoic rocks found in the northern and southern parts of Thailand are chiefly sandstone, shale, and sandy shale with their metamorphic equivalents (Tanaosi Group, Table 2 and

Table 2. Stratigraphy of Thailand (from Thailand Department of Mineral Resources, 1969, Geology of Thailand).

Era	Period	Epoch	Brown *et al.* (1951)	Department of Mineral Resources (1969)		
Cenozoic	Quarter-nary	Recent Pleistocene	Alluvium Terrace deposits	Alluvium and eluvium River gravel		
Cenozoic	Tertiary	Pliocene Miocene Oligocene Eocene (Paleocene)	Krabi series and Mae Sot series	Krabi group		Mae Mo formation (includes Fang and Mae Sot) Li formation
Mesozoic	Cretaceous		Khorat series with Kamawkala limestone	Khorat group	Upper	Salt formation (Haworth *et al.*, 1964) Ban Na Yo (Kobayashi, 1965) or Khok Kruat (Ward, 1964)
Mesozoic	Jurassic				Middle	Phu Phan formation Phra Wihan formation (includes Sau Kua)
					Lower	Phu Kradung formation (includes Nam Phong, Huay Hin Lat) and Red formation
Mesozoic	Triassic			Lampang group		Marine formation Volcanic formation
Paleozoic	Permian		Rat Buri limestone	Rat Buri group		
Paleozoic	Carboniferous		Kanchanaburi series	Tanaosi group		Kaeng Krachan formation
Paleozoic	Devonian					
Paleozoic	Silurian					Kanchanaburi formation
Paleozoic	Ordovician		Thung Song limestone	Thung Song group		
Paleozoic	Cambrian		Phuket series	Tarutao group		
Eozoic	Pre-Cambrian		Inferred from pebbles in Phuket series	Granite pebbles in Phuket formation		

Figure 3). Also widespread, are the limestones of Ordovician and Permian periods.

Mesozoic rocks of the Korat Group are of widespread occurrence in the northeastern part of the Kingdom. The Group contains sandstone, shale, siltstone, conglomerate, and limestone and is capped by a thick salt formation.

Tertiary rocks, apart from some scattered basins of unconsolidated sediments bearing lignite (Krabi group), are mostly igneous in origin (i.e., andesite, rhyolite porphyries, tuff, diorite, basalt and granite). Flood plains and terraces of Quarternary age are widespread throughout the country.

There have been at least four distinct orogenic movements in Thailand followed by four intrusions of granite: Carboniferous, Triassic, Cretaceous and Tertiary. Only the younger granite (Cretaceous) contains tin mineralization. Tertiary orogeny (Wallachian?) caused the elevation and down warping of the Northeast Plateau associated with depression of the Central Plain and faulting along the scarp.

Climate

Thailand like all southern Asia, is dominated by the monsoon. General climatic characteristics of the six physiographic regions are summarized in Table 3. Thailand average annual rainfall, mean

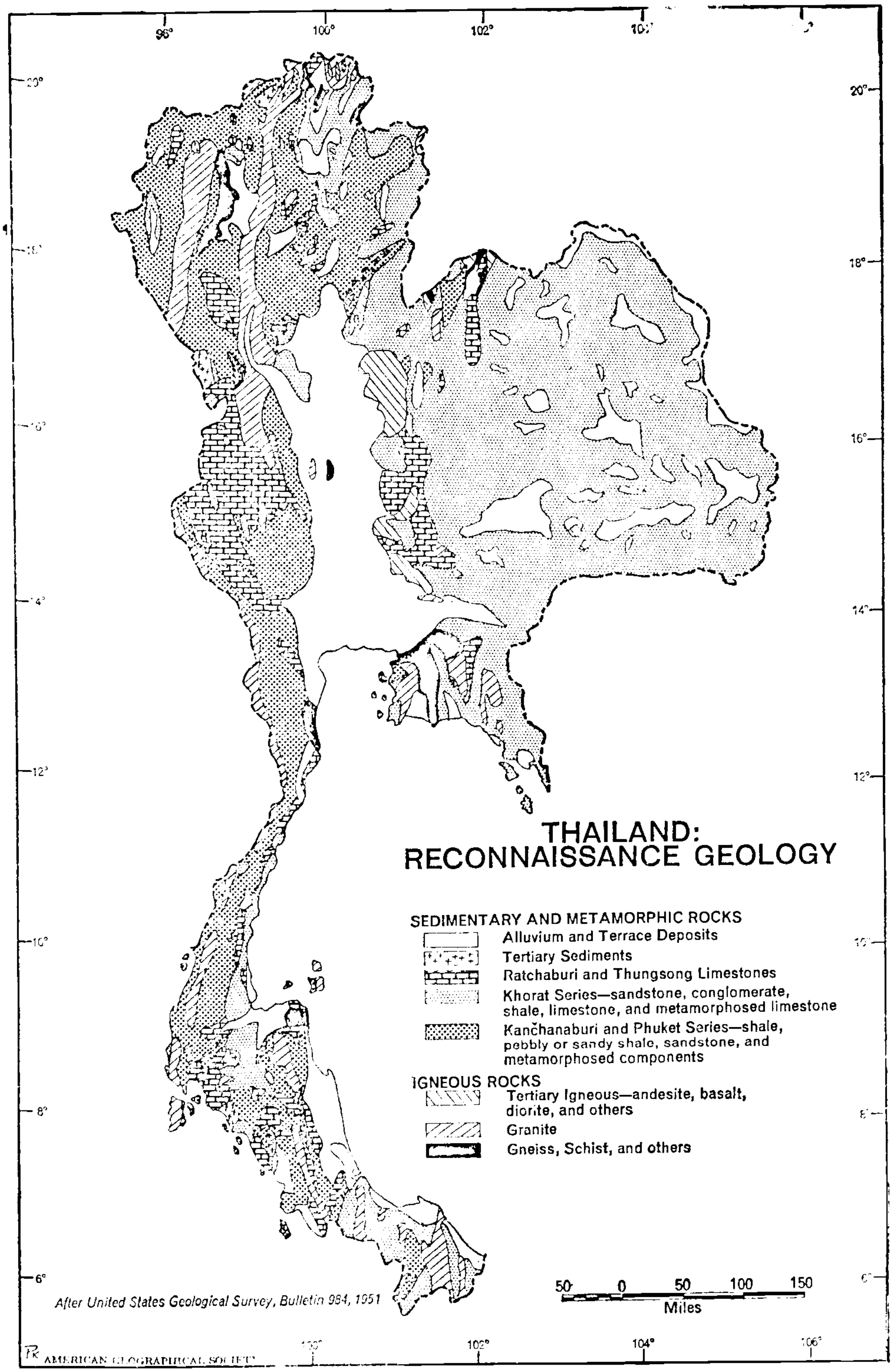

Figure 3. Major rock types simplified and adapted from 1951 geologic map of Thailand (from Pendleton, 1962).

Table 3. Generalized climatic data for the six physiographic regions of Thailand.

	Central Plain	Southeast Coast	Northeast Plateau	Central Highlands	North and West Continental Highlands	Peninsular Thailand	
						West coast	East coast
Annual rainfall (mm)	1220-1592	1312-4456	1089-2163	1352	1045-1744	2177-5106	1018-2568
Annual mean humidity (%)	64-76	74-78	68-73	70-73	71-75	77-83	78-82
Annual mean temperature (°C)	27-29	27	26.7-27	26-28	24-28	27	27-28
Absolute maximum temperature (°C)	39-44	38	42-43	41-43	40-43	35.5	38-39
Absolute minimum temperature (°C)	5-12	9	2-4	2-7	2-6	19	14-18

monthly rainfall and mean monthly temperature are shown in Figures 4, 5 and 6, respectively.

Most of continental Thailand and part of Peninsular Thailand can be classified as Tropical Savanna (Köppen - "Aw"). In the northern mountainous areas, higher elevations produce sufficiently cool temperatures to place most of the area in the Humid Subtropical Zone ("Cw"). In the easternmost section of the Southeast Coast, the western mountains and Peninsular Thailand where rainfall is very heavy, the area can be classified as Tropical Monsoon Climate ("Am"). On the west coast of the Peninsular Thailand, although vegetation reaches the true rain forest type, it fails to fit Köppen's Tropical Rain Forest ("Af") type, because there are two or three months of dryer winter when rainfall is under 60 mm (Pendleton, 1962).

Broadly speaking the climate of Thailand includes a rainy season from May to October, a cool dry season from November to February and a hot dry season or intermonsoon period from March to May, except in the south where there is no pronounced dry season. The Southwest Monsoon blows steadily from May to September, when it gives way to the cool, drier Northeast Monsoon. Annual temperature ranges are small throughout the country, with somewhat wider ranges in the northern part at higher altitudes. The hottest month is generally April and the coolest month January (Nuttonson, 1963).

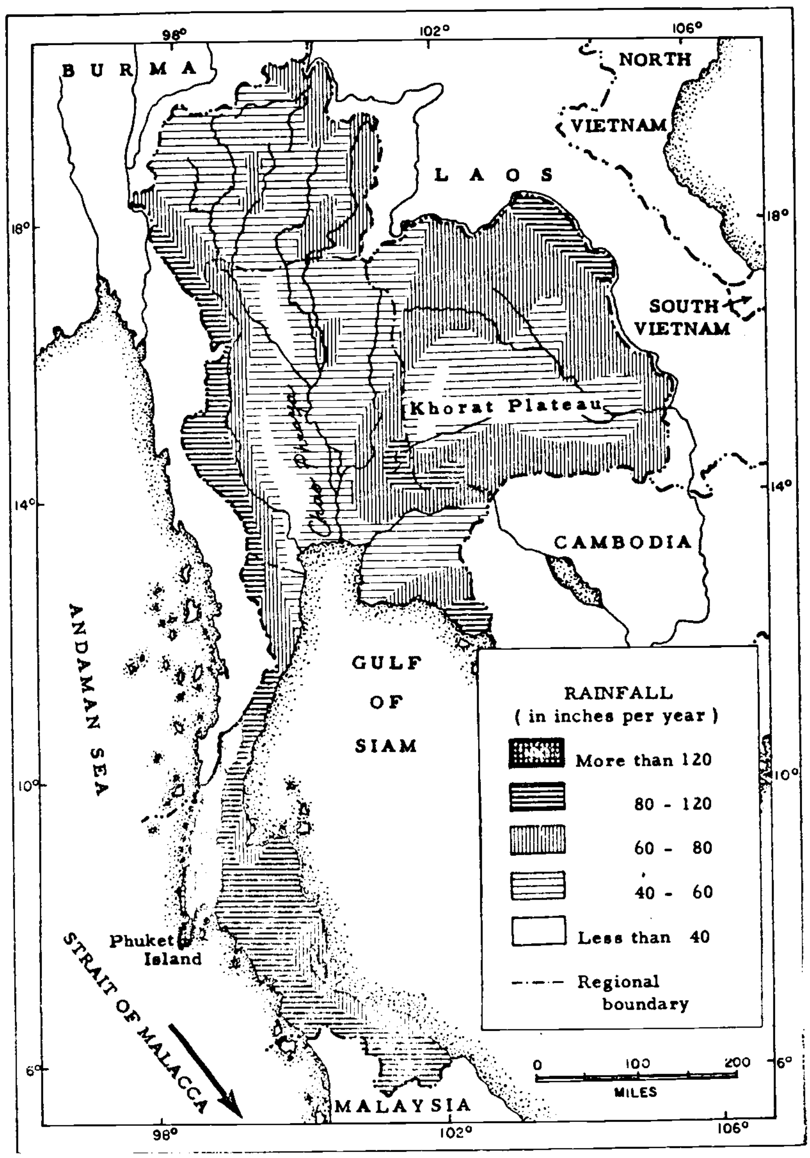

Figure 4. Rainfall in Thailand (from Smith et al., 1968, Area Handbook for Thailand). Millimeter equivalents of the limits are: less than 1000, 1000-1500, 1500-2000, 2000-3000, and more than 3000, respectively.

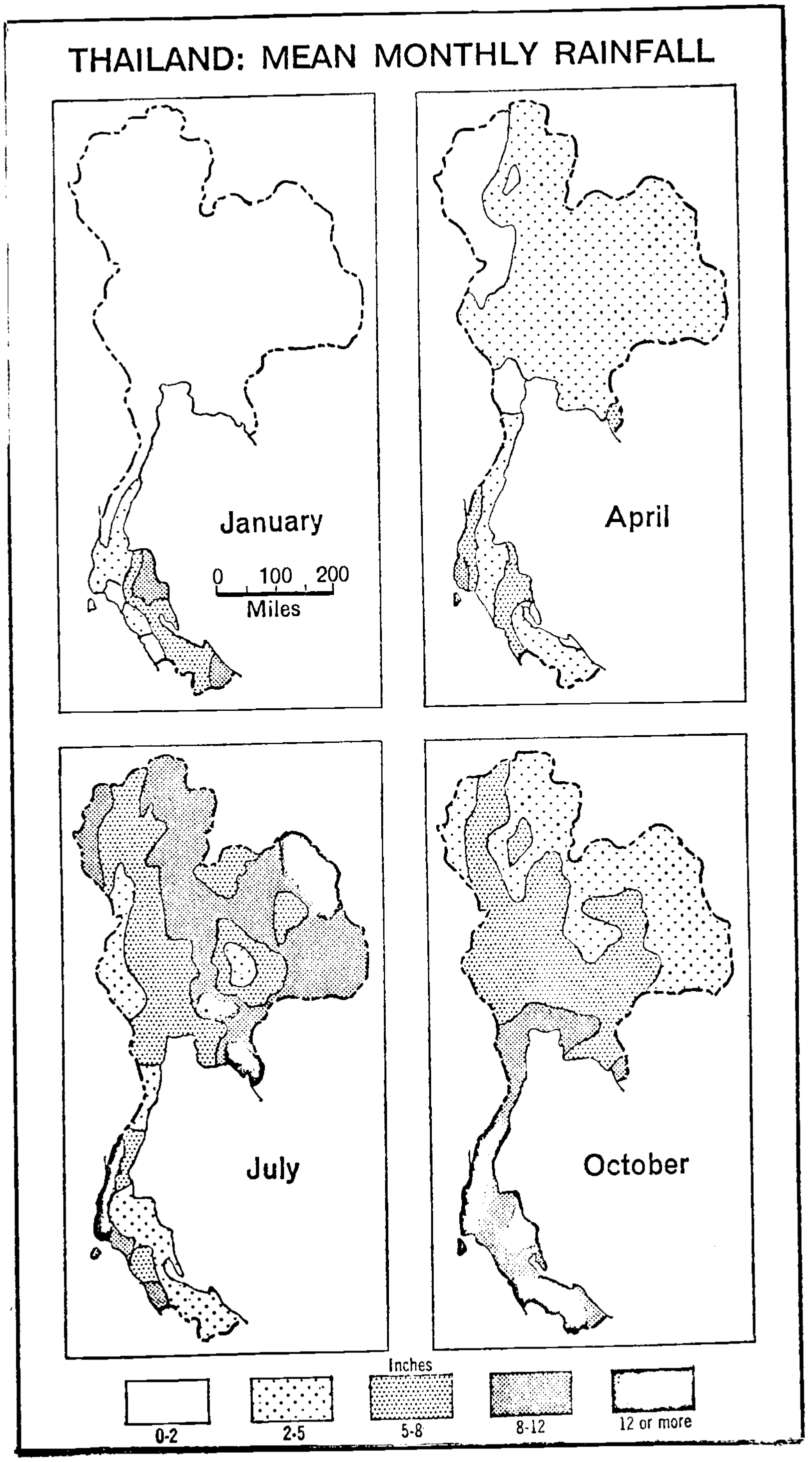

Figure 5. Mean monthly rainfall of Thailand (from Pendleton, 1962). Millimeter equivalent of the limits are: 0-50, 50-125, 125-200, 200-300, and 300 or more respectively.

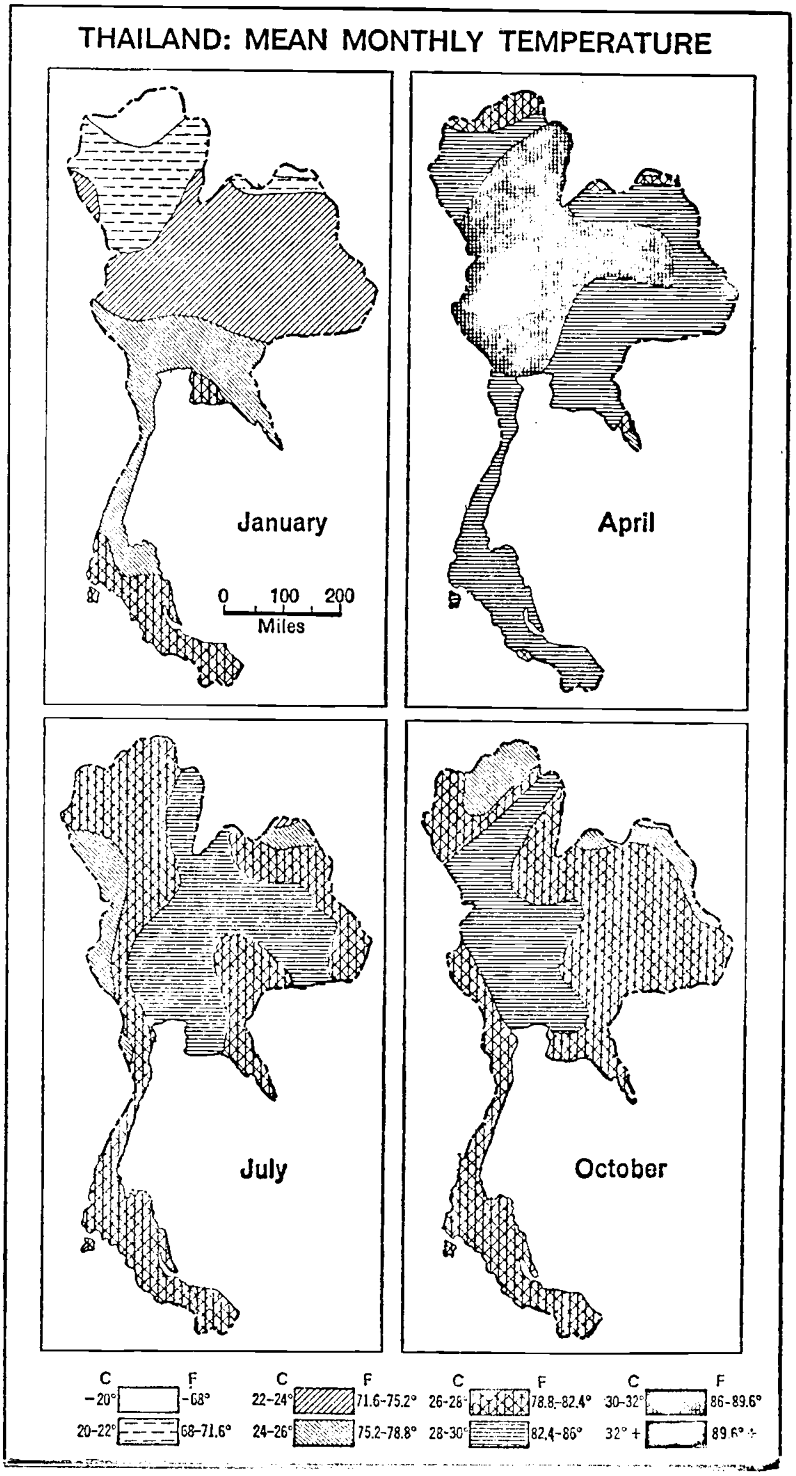

Figure 6. Mean monthly temperature of Thailand (from Pendleton, 1962).

Vegetation

Thailand has about 70 percent or approximately 360, 000 km^2 covered with forest vegetation (Royal Thai Forestry Department, 1955). The present percentage may be somewhat lower since clearing in the last two decades had been rather extensive. The natural vegetation of Thailand reflects strongly the differences in climatic conditions (Figures 4 and 7). The modified version of forest types in Thailand is based on reports of Royal Thai Forestry Department (1955), Pendleton (1962), Nuttonson (1963) and Smith *et al.* (1968).

1. The Evergreen Forest occupies the windward (west) slopes of the mountains, higher altitudes of all mountains, and all altitudes of Peninsular Thailand but are now interrupted by numerous clearings for cultivation. Hill Evergreen Forest is found at an elevation of 1000 m and above. If rainfall drops below 2000 mm, Semi-evergreen Rain Forest becomes dominant. Dipterocarpaceae is the dominant family for the type.

2. The Mixed Deciduous or Monsoon Forest occurs widely in Thailand, generally in the non-cultivated hills and mountains in areas with a definite dry season. It is commonly divided into Moist and Dry Monsoon forests. The Moist Monsoon areas occur under 1500 to 2000 mm annual rainfall and teak (*Tectona grandis*) is the main constituent. The Dry Monsoon forest is common in the Northeast Plateau with less than 1500 mm rainfall and elsewhere in rain shadow areas

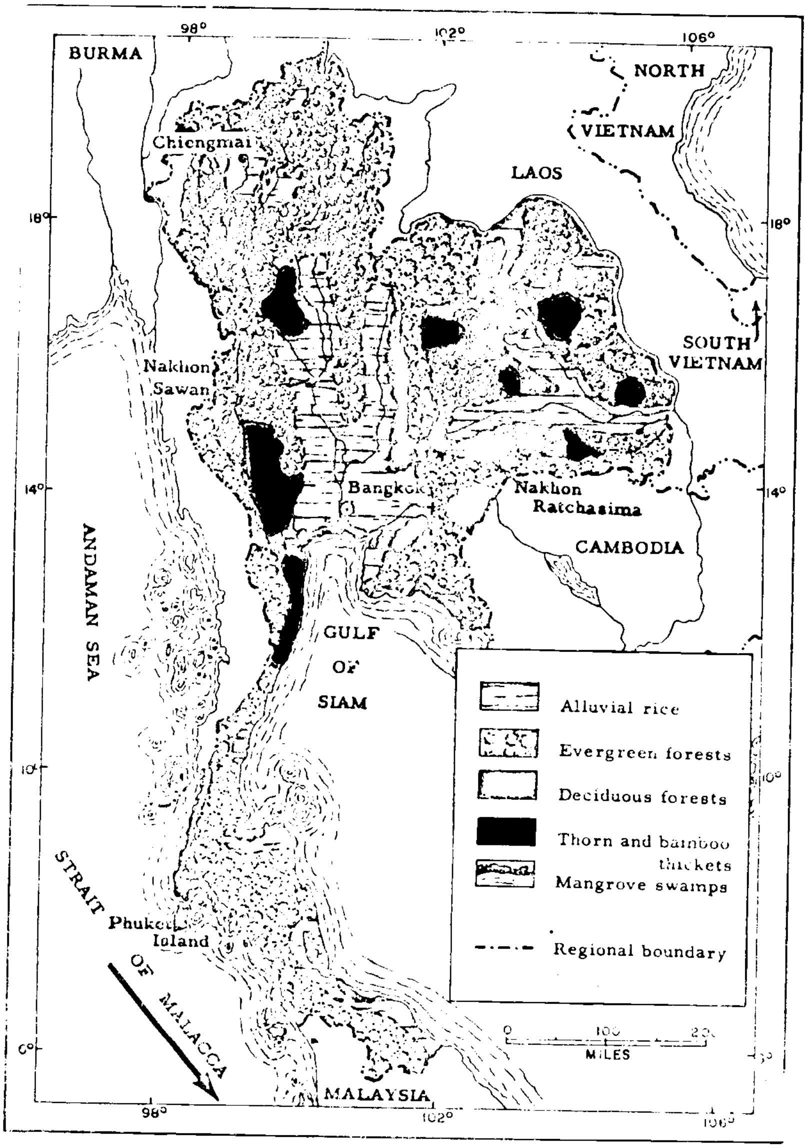

Figure 7. Vegetation of Thailand (from Smith et al., 1968).

or on poor, droughty soils. Dwarf Dipterocarp forest (only 15-20 m high) occupies this dry forest. Bamboo dry forest and thorny bushes are other dry forest types occurring.

3. The Coastal Vegetation of the protected coast associated with the muddy estuaries is mangrove swamp and nipa palm. On exposed coasts, which are usually sandy beaches and rocky shores, tree-like Casuarina, Terminalia and coconut are common.

4. Cultivated Lands are widespread in Thailand, particularly rice production in the alluvial lowlands. Many cultivated crops typical for the regions are grown (e.g., rubber in the south, cassava in the southeast, kenaf by shifting cultivation in the northeast, corn, cotton and sorghum in the Central Plain.

Soils

Study of the soils of Thailand originated with the late Dr. Pendleton and resulted in a series of publications dating back three decades (Pendleton, 1940, 1947). In 1949 a soil map was published at a scale of 1:2, 500, 000 and in 1953 it was accompanied by extensive discussion and notes of Thai soils (Pendleton, 1953), followed by a later publication dealing with soils of Thailand and the provisional soil map (Pendleton and Montrakun, 1962; Pendleton, 1962).

A limited number of soil units, commonly called "soil series," was distinguished for Pendleton's provisional soil map. At this level of generalization, however, those soils units should not be considered soil series as defined in the Soil Survey Manual (USDA, 1951). They are in fact at the level of great soil groups or the association of two or more of such groups. For example, Pendleton's Roi Et fine sandy loam is mainly equivalent to Low Humic Gley soils but includes some Solonetz and Alluvial soils.

From 1962 onward, when aerial photographs and topographic maps became available throughout the Kingdom, the shortcomings of the soil units and the Pendleton's provisional soil map became apparent. A Key for the Soils of Northeastern Thailand was first prepared in 1962 and later revised in 1964 (Moormann et al., 1964a). The report outlined procedures and delineated soils using the generally accepted methods described in the Soil Survey Manual (USDA, 1951). At the same time, the first edition (1962) of the Major Soils of Southeast Asia was used in classifying soils in Thailand (Dudal and Moorman, 1964).

A general soil map at the scale of 1:250, 000 was drafted in 1966 and printed in 1967, using systematic soil survey work done by the Soil Survey Division, Department of Land Development, at the level of detailed reconnaissance with a scale of 1:50, 000. Full use was made of data available at the time as well as extensive additional field work throughout the country. A simplified version with accompanying report showing general soil conditions in Thailand at a scale of 1:2, 500, 000 was also prepared (Moormann and Rojanasoonthon, 1968). The great soil groups used on the general soil map were those of Dudal and Moormann (1964). Table 4 lists all great soil groups identified in Thailand and their main characteristics. More detailed descriptions of the soils in Thailand are given in Rojanasoonthon (1966) and various Soil Survey Reports of the Department of Land Development. Figure 8 shows a much simplified soil map indicating major associations of soil groups with particular emphasis on the Gray Podzolic-Low Humic Gley soils association. In updating the classification of soils in Thailand, diagnostic characteristics of the new soil classification system (USDA, 1960 and supplement, 1967) were applied where possible. The latest version of the system (USDA, Soil Survey Staff, 1970) was also applied. A tentative correlation is reported in Table 5.

The Study Regions

The following description of the Gray Podzolic soil areas in each physiographic region includes relationships of these soils to geomorphic position and other soil groups as well as regional aspects of geology, climate, vegetation and land use.

Central Plain

This plain includes the flat alluvial delta of the Chao Phraya

Table 4. Major characteristics of Great Soil Groups in Thailand.

Great Soil Group	Geomorphic position	Parent material	Genetic soil horizons	Drainage class	Uses	Notes (main occurrence and particular characteristics)
Regosols	Recent, semirecent beach or dune and river sand	Beach, or dune and river sand	A-C, A-Cg	Excessive	Shrub, open forest	Coastal areas and river sandy terraces of the Northeast
Alluvial soils	Alluvial plains	Recent alluvium (fresh, brackish and marine)	A-C, A-Cg, Ag-Cg	Poorly drained	Flooded rice	Widespread in Thailand
Grumusols	Peneplain areas (connecting to river alluvial plain)	Old alluvium from marl, limestone and basalt	A-C, A-Cg	Poorly drained	Rice, (corn)	Major areas associated with limestone and marl
Redzinas	Peneplain areas, marl terrace, marl and limestone derived terrace	Old alluvium and residuum from marl and limestone	A-C	Well drained	Corn, cotton	Major areas associated with limestone and marl
Low Humic Gley soils	Semirecent and low terrace	Semirecent to old alluvium	A, or Ap-A2-Bt	Poorly drained	Rice, ditched field	Rain water fed transplanted rice
Non-calcic Brown soils	Semirecent terrace (old levee)	Semirecent alluvium	A1-A2-Bt	Well drained	Usually cultivated, orchard	High potential for agriculture if irrigated
Red Brown Earths	Terrace and peneplain (hillslope?)	Old alluvium, basic rocks, limestone	A1-(A3)-Bt	Well drained	Intensive corn and orchard	High potential for field crops
Reddish Brown Lateritic soils	Hillslopes	Residuum from intermediate, basic rocks	A1-(A3)-Bt	Well drained	Upland crops, rubber or good forest	Associated with basic, intermediate rocks

(Continued on next page)

Table 4. (Continued)

Great Soil Group	Geomorphic position	Parent material	Genetic soil horizons	Drainage class	Uses	Notes (main occurrence and particular characteristics)
Red Yellow Podzolic soils	Hill slopes and old terraces	Acid to intermediate rocks and old alluvium	A1-A2-Bt	Well drained	Forest, rubber plantation	Most widespread in Thailand, mainly in hilly areas
Gray Podzolic soils	Low to middle terrace	Old alluvium	A1A2-Bt	Well to excessive	Kenaf shifting cultivation	Widespread in Northeast, low fertility
Red Yellow Latosols	High terrace	Old alluvium	A-B	Well to excessive	Orchards	Mostly in the Northeast
Minor Occurrence						
Reddish Brown Latosols	Incised plateau of high elevation and on small basalt plateaus	Basic rocks (basalt, gneiss)	A-B	Well drained	Secondary forest, shifting cultivation	Hill tribe shifting cultivation
Peat and Muck soils	Depressions	Plant remains	A-C	Poorly drained	Not cultivated	Coastal peat
Humic Gley soils	Drainage valleys of alluvial plain, associated with limestone derived materials	Alluvium associated with limestone	A-(B)-C	Poorly drained	Rice	Good potential for rice and upland irrigation if area large enough
Solodized Solonetz	Marine or beach terrace	Old alluvium	A1-A2-Bt	Poorly drained	Rice or grass	Old saline, marine terrace or salt infested area (NE)
Groundwater Podzols	Old beach or dune and old riverine sandy terrace	Old beach and river sand	A1-(A2)-Bh-Cg	Well drained	Too small and too poor for use	High rainfall area
Brown Forest soils	Steep hillslope	Basic rocks, limestone	A-(B)-C or R	Well drained	Too steep, too shallow for use	Associated with limestone crags

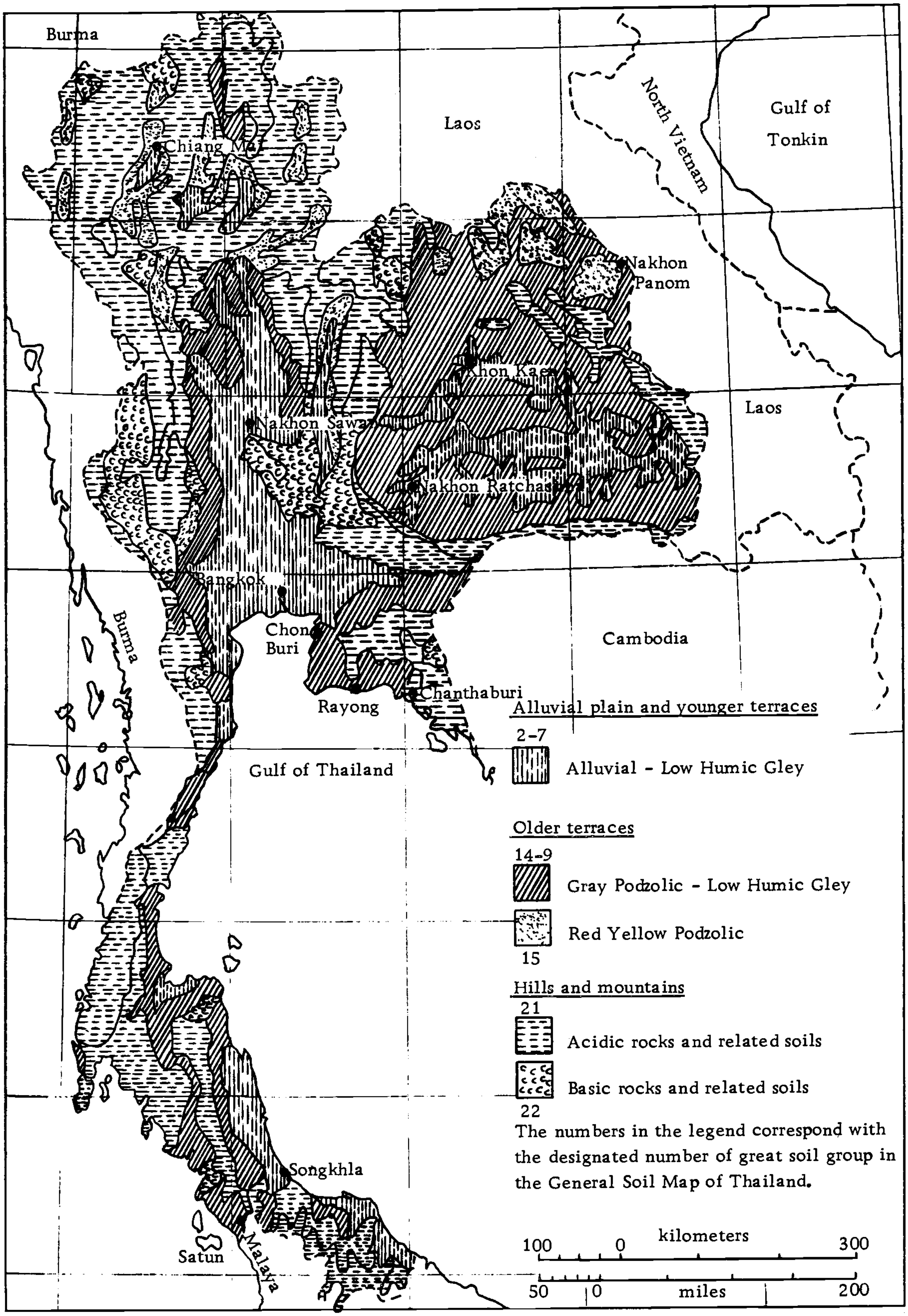

Figure 8. Simplified soil map of Thailand showing major distribution of the Gray Podzolic soils and other soil groups (after Moormann and Rojanasoonthon, 1968).

Table 5. Tentative classification of soils of Thailand[1] in the United States soil classification system (USDA, Soil Survey Staff, 1970).

Great Soil Group (Dudal and Moormann, 1964)	Soil Taxonomy (USDA, Soil Survey Staff, 1970)		
	Order	Suborder	Great Group
Alluvial soils	Entisols	Aquents	Sulfaquents
			Hydraquents
			Fluvaquents
			Tropaquents
			Psammaquents
		Fluvents	Ustifluvents
			Tropofluvents
	Inceptisols	Aquepts	Sulfaquepts
			Tropaquepts
			Plinthaquepts
			Halaquepts ?
		Tropept	Ustropepts
Regosols	Entisols	Psamments	Quartzipsamments
			Tropopsamments
			Ustipsamments
Grumusols	Vertisols	Uderts	Pelluderts
		Usterts	Pellusterts
			Chromusterts
Brown Forest soils	Inceptisols	Tropepts	Ustropepts
			Eutropepts
			Dystropepts
Humic Gley soils	Inceptisols	Aquepts	Tropaquepts
	Mollisols	Aquolls	Haplaquolls
Rendzinas	Inceptisols	Tropepts	Eutropepts
			Ustropepts
	Mollisols	Rendolls	Rendolls
Ground water Podzols	Spodosols	Aquods	Tropaquods
Low Humic Gley soils	Inceptisols	Aquepts	Tropaquepts
			Plinthaquepts

(Continued on next page)

Table 5. (Continued)

Great Soil Group (Dudal and Moormann, 1964)	Soil Taxonomy (USDA, Soil Survey Staff, 1970)		
	Order	Suborder	Great Group
Low Humic Gley soils (cont'd)	Alfisols	Aqualfs	Tropaqualfs Plinthaqualfs Paleaqualfs
	Ultisols	Aquults	Tropaquults Plinthaquults Paleaquults
Solodized Solonetz	Alfisols	Aqualfs Ustalfs	Natraqualfs Natrustalfs
Noncalcic-Brown soils	Alfisols	Ustalfs	Haplustalfs Plinthustalfs
Red Brown Earths	Alfisols	Ustalfs Udalfs	Rhodustalfs Tropudalfs
Reddish-Brown Lateritic soils	Ultisols	Udults	Rhodudults Plinthudults
		Ustults	Rhodustults Plinthustults
		Humults ?	Tropohumults ?
Red Yellow Podzolic	Ultisols	Udults	Tropudults Plinthudults Paleudults
		Ustults	Haplustults Plinthustults Paleustults
Gray Podzolic soils	Alfisols	Ustalfs Udalfs ?	Paleustalfs Paleudalfs ?
	Ultisols	Ustults Udults	Paleustults Paleudults
Regosolic Gray Podzolic soils	Entisols	Psamment	Quartzipsamments
	Inceptisols	Tropepts	Ustropepts

(Continued on next page)

Table 5. (Continued)

Great Soil Group (Dudal and Moormann, 1964)	Soil Taxonomy (USDA, Soil Survey Staff, 1970)		
	Order	Suborder	Great Group
Reddish-Brown Latosols	Oxisols	Ustox	Haplustox
		Orthox	Eutrorthox
Red-Yellow Latosols	Oxisols	Ustox	Eutrustox
			Haplustox
		Orthox	Haplorthox
Organic soils	Histosols	Hemists	Tropohemists
			Sulfihemists
		Saprists	Troposaprists

[1] With assistance from D. L. Gallup, E. G. Knox and F. R. Moormann.

River system. It is bordered by hilly areas on the east, west and north, and by the Gulf of Thailand in the south. The Alluvial soils of the main channel of the Chao Phraya River are flanked, on the east and west, by old terraces occupied by Gray Podzolic and associated Low Humic Gley soils (Figure 8). Along the southeastern part of the plain, Grumusol and Rendzina soils on marl and limestone-derived alluvial terraces predominate. Peneplain areas or piedmont belts occupy the area of the plain marginal to the hills. Monadnocks of limestone, quartzite-phyllite and andesite are found scattered throughout the region.

This area is under intensive rice cultivation and is influenced strongly by the southwest monsoon and cyclonic storms from May to September and November to February, respectively. The dry season is not distinct and frequently has some rain. Evergreen Forest components remain only along streams of lowlands, mainly on the natural levees, where fruit crops, corn, tobacco, etc. are commonly grown. The soil series identified in the southern part is similar to the Sattahip series of the Southeast Coast, whereas in the northern section, Gray Podzolic soils belong to the San Pathong series.

Southeast Coast

This region is bordered on the north and east by hills and on the south and west by the Gulf of Thailand. The region includes a strongly dissected upland in the northern and central parts and a coastal plain in the south and west. In general, the region is composed of north-south oriented hills and broad terraces between these hills. The hills are mainly quartzite-phyllite, granite and gneiss. The terraces are mainly marine in origin but river terraces occur further inland. Along the coast, small discontinuous marine and brackish water alluvial plains occur.

On old marine terraces, Gray Podzolic soils dominate, with Red Yellow Podzolic soils on numerous knolls and low hills of quartzite-phyllite, granite and gneiss. Better soils (Reddish Brown Lateritic) are found in the few remaining forest areas and the eastern-most section of the region where rainfall also is higher, approaching a tropical rain forest zone.

Most land occupied by Gray Podzolic and Red Yellow Podzolic soils which is not too steep has been cleared for upland crops, mainly cassava and sugar cane. Rubber and fruit trees are more common toward the east in the high rainfall zone. Two distinct Gray Podzolic soil series are found. The Sattahip series which is sandy and low in clay represents soils of the western part of the region under the low rainfall zone. The more clayey, Huai Pong series occurs in the wetter portion towards the east.

Northeast Plateau

This is a young, saucer-shaped plateau draining to the south-east, with intermittent lakes in the north and flooded land in the south during the rains. The Plateau (150-200 m elevation) is bordered by the Mekong River on the north and east and by a fault zone of hills and peneplains of the Central Highlands on the west and south.

The main landscape features are the three or more levels of old, broad river terraces, interspersed by outcrops and cuestas of sandstone, shale and conglomerate (Korat geological group) throughout the region. Gray Podzolic soils and the associated Low Humic Gley soils on low and middle terraces dominate the south and central part of the region. The terrain is interrupted by large and small areas of Alluvial soils of the river alluvial plains, which are cultivated for rice. Red Yellow Podzolic soils with frequent lateritic concretions are more common in the northern part. Red soils (Red-Yellow Latosols) associated with the high terrace remnants occur at random at the higher elevations. Laterite (iron stone) surfaces are found in many places throughout the region. The main soil series identified is the Korat series with the associated less well drained Renu series and some sandy soil series, which grade into Regosols. Upland crops, mainly kenaf, which are grown under shifting cultivation, and secondary Dry Deciduous (Dwarf Dipterocarp) forest occupies the widespread terrain of the Gray Podzolic soils area.

Wide fluctuations in temperature and rainfall are common and more extreme than for other regions.

Central Highlands

The region comprises ranges of hills, generally oriented in a north-south direction, with intervening valleys and peneplains situated between the Central Plain and the Northeast Plateau. The southern boundary of this region grades into Tonle Sap plain of Cambodia. In cross-section from west to east, these hill ranges are made up of andesite, craggy limestone and sandstone hills or cuestas respectively. The main landscape features of the region are hills, high plateaus, peneplains and terraces, including marl and limestone derived alluvial terraces. Old alluvial terraces with Gray Podzolic soils are not extensive and when they occur they are more fertile than the Gray Podzolic soils in other regions. The soil pattern consists of complex groups of the following soils: Low Humic Gley, Gray Podzolic, Red Yellow Podzolic, Reddish Brown Lateritic, Rendzina and Red Brown Earth.

Due to the hilly terrain, clearing is less widespread than in other regions and the vegetation is still mainly the Tropical Rain Forest type. Because there are more basic rocks in the adjacent catchment areas, soils of the Pasak River Valley are generally more fertile. The Gray Podzolic soils, in general, have been mapped with the San

Pathong series of the Northern Highlands.

North and West Continental Highlands

This region may be subdivided into the Northern Hills and Valleys (Phi Pan Nam subprovince) and the Western Mountains (Tanaosi or Tenassarim subprovince).

The Northern Hills and Valleys include the northern mountains of Thailand which are the watershed area of the Chao Praya River. It comprises a series of north-south oriented mountainous ridges, separated by valleys of varying width. The four major valleys of the Ping, Wang, Yom and Nan rivers contain large elongate level-floored basins filled with river sediments.

The Western Mountains form a strip along Thailand's western frontier. They consist of high rugged mountains through which streams have cut deep canyons and narrow valleys. Wide, level basins of the northern mountains are lacking.

In the large alluvial valleys, Low Humic Gley and Alluvial soils are dominant. Significant areas of old alluvial terraces (low terraces) with Gray Podzolic soils supporting Dwarf Dipterocarp forest are also found in these major valleys. The series identified is the San Pathong series which is also found in the Central Plain and in the Central Highlands. Shifting cultivation is commonly practiced throughout the hilly part of the region, mainly on less stony and deeper areas of Red Yellow Podzolic and Reddish Brown Lateritic soils.

Because of the terrain, the amount of rainfall (southwest monsoon) decreases inland or on the leeward side of the mountains. Wide fluctuations in temperature and precipitation are common. Throughout these mountain ranges, the Tropical Rain Forest type occupies most of the wetter western slopes. The eastern slope and northern mountains are mainly covered by Deciduous or Moist Monsoon Forest.

Peninsular Thailand

The region is made up of an extension of the Tanaosi Range forming short ridges in echelon, with a north-south trend. These parallel granite-cored mountain ranges are separated by limestone of Ordovician and Permian age, shale and sandstone or quartzite-phyllite of the Tanaosi geologic group. Interspersed between these hills are dissected valley terraces usually filled with old alluvial sediments. Marine and riverine coastal terraces occur on both sides of the range. As a result of tilting toward the northeast, smooth sandy beaches and dunes occupy most of the Peninsular east coast. On the western side, drowned valleys and irregular shorelines rimmed with mangrove swamp are widespread.

Red Yellow Podzolic soils on acidic rocks, Reddish Brown

Lateritic soils on intermediate or basic rocks and included limestone, and some Latosols are the dominant soil groups of the region. Apart from rubber plantations on low hills and plains and numerous patches of shifting cultivation, most of the area is under Tropical Evergreen Forest. There are two well-marked rainy seasons of the southwest monsoon during May to November and northeast cyclonic storms during October to December. High temperatures and high rainfall throughout the year, with no marked dry season, are characteristic of the region.

The Gray Podzolic soils under study are from a slightly drier zone than typical for the region. However, this zone lacks the distinct dry season of most areas where these soils occur. The soils integrade toward either Latosols or Reddish Brown Lateritic soils, probably because of the wetter climatic regime. The soils are identified as the Kho Hong series and the associated, less well drained Nam Krachai series.

THE GRAY PODZOLIC SOILS

Gray Podzolic soils were first identified in Southeast Asia, mainly on the basis of the survey in countries along the lower Mekong River, by Dudal in 1960 and Moormann in 1961. The French studies in Vietnam have called these soils "terres grises" or gray earths (Dudal and Moormann, 1964; Maignien, 1966). The name was also referred to in the reconnaissance survey by the French company for parts of Khon Kaen, Udon and Kalasin provinces of Thailand (SOGREAH, 1960). Pendleton's Korat fine sandy loam (1953, 1962) is largely equivalent to Gray Podzolic soils, Red Yellow Latosols and Non-Calcic Brown soils (Moormann et al., 1964a). In addition to the major occurrence of Gray Podzolic soils on old sandy terraces, the group also includes minor amounts of soils formed in residuum and slope colluvium from acid rocks (e. g., granite, sandstone and quartzite-phyllite).

Generally, indistinct horizon development is quite characteristic of Gray Podzolic soils. When dry, the surface color is light gray to whitish, contrasting strongly with subsoil colors of strong brown to yellowish brown. Under open vegetation, when subjected to heavy rainfall, these soils show a strong "shifting" or splash effect at the surface, i. e., separation of the humus and fine particles from the coarser mineral fraction (Figure 9-A). A weakly compacted layer, not attaining the status of a hard pan, is commonly found beneath the

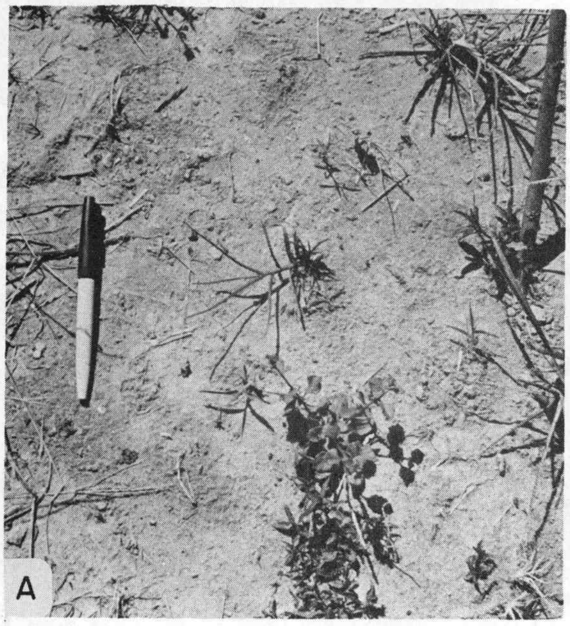

Figure 9-A. Shifting surface or microerosion of Gray Podzolic soils in Thailand similar to splash erosion.

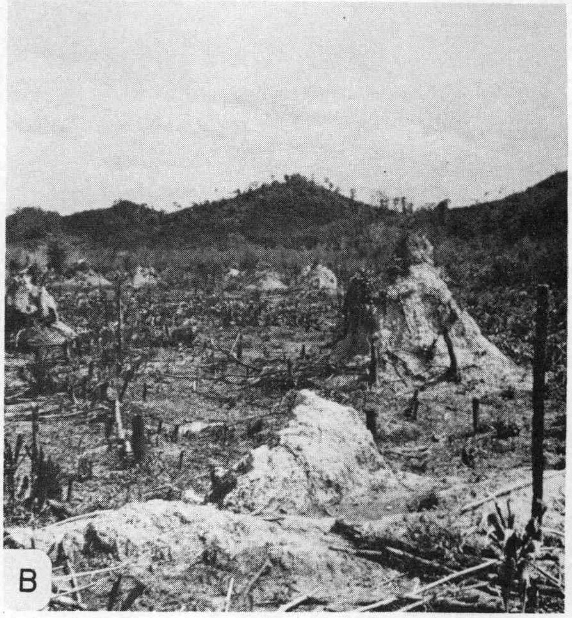

Figure 9-B. Termite mound in recently cleared area, southern Thailand.

Figure 9-C. Open Dwarf Dipterocarp forest in northeastern Thailand, interplanted with kenaf under shifting cultivation.

A horizon. The horizon sequence is usually A1 (or Ap)-A2-Bt, with gradual transition between the A and Bt horizons. The illuvial B horizon normally contains more clay and generally fits the definition of an argillic horizon (USDA, Soil Survey Staff, 1970). In sandier profiles, distinction of the Bt may not be apparent, unless the determination is supported by laboratory analysis or micromorphological study.

Gray Podzolic soils frequently contain plinthite in the lower part of the B horizon, usually at or near the water table. Concretionary laterite nodules may also be present in the profile. However, in the current survey program in Thailand, redder soils with concretionary laterite layers or hardened, compacted laterite at shallow or medium depths have been classified into different great soil groups.

The soils of the Gray Podzolic great soil group occupy most of the Northeast Plateau undulating terrains not in use for rice cultivation. They are excessively to moderately well drained and do not show any distinct signs of wetness in the upper horizons. Gray Podzolic soils occur in close association with the lower and wetter Low Humic Gley soils which are generally in use for paddy rice.

A level or gently undulating topography with relatively slow surface runoff appears to be an essential factor in the formation of these soils. No soils of this type have yet been found on steeper slopes with excessive runoff.

Climatically, these soils occur in the monsoon areas, with annual rainfall approaching or in excess of 1500 mm. However, the condition of an alternating wet-dry climate, with a distinct dry period, is typical for the occurrence of Gray Podzolic soils. The natural vegetation is dominantly Dry (secondary) Dipterocarp forest and savanna. The latter is usually a result of clearing. In higher rainfall areas, evergreen forest is also found. Diverse upland crops are grown in a haphazard, shifting cultivation pattern. Once used for a few years, these soils are abandoned for an indefinite period. Continuous cultivation on Gray Podzolic soils occurs only rarely.

Kenaf[1] (Hibiscus cannibinus) is a common crop increasingly grown under shifting cultivation in northeastern Thailand (Figure 9-C). The meager fertility of Gray Podzolic soils does not permit sustained cropping without adding some fertilizer as well as some use of irrigation.

Attempts to classify Gray Podzolic soils as a separate grouping in the USDA Seventh Approximation system (1960) were not entirely successful. Gray Podzolic soils could not be consistently separated from the associated Red Yellow Podzolic soils. The 1967 Supplement

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[1] A jute substitute fibre crop used in manufacturing burlap.

of the Seventh Approximation and the recent, unedited chapters from Soil Taxonomy (USDA, Soil Survey Staff, 1970) permit Gray Podzolic soils in either the Alfisol or Ultisol order depending on the base saturation, with further classification into the Ustalf or Ustult sub-order and possibly Paleustalf or Paleustult great group.

The Importance of Laterite

Gray Podzolic soils have been classified in association with laterite or lateritic soils. Pendleton's Korat fine sandy loam of northeastern Thailand in his Provisional Soil Map of Thailand (1953) included Gray Podzolic soils as one of the main components in that soil group (Moormann, et al., 1964a). Pendleton also indicated that his Korat fine sandy loam contained laterite in the profile in the sense that Buchanan used it in India in 1807. He also preferred to refer to soils that contain horizons of soft lateritic character, which will become true laterite if the appropriate conditions persist long enough, as 'lateritic soils' (Pendleton, 1936, 1941a; Pendleton and Sharasuvana, 1942, 1946). This is similar to what Alexander and Cady (1962) referred to with the following definition:

> Laterite is a highly weathered material rich in secondary oxides of iron, aluminum, or both. It is nearly void of bases and primary silicates, but it may contain large amounts of quartz and kaolinite. It is either hard or capable of hardening on exposure to wetting and drying (p. 1).

Gray Podzolic soils as classified by Dudal and Moormann (1964) may contain laterite, usually in the deeper layers, either as soft or concretionary types. Maignien (1966) referred to Gray Podzolic soils in connection with a global correlation of laterite and lateritic soils. An earlier worldwide synthesis of knowledge of the distribution of laterite was attempted by Prescott and Pendleton (1952). The most up to date review of the laterite as a material was by Sivarajasingham et al. (1962).

Laterite associated with Gray Podzolic soils is mainly of the mottled clay or plinthite type. This is similar to what Maignien (1961) called an "incrusted horizon" forming beneath the clay horizon of the Leached Ferruginous Tropical soils or Sols Ferrugineux Tropicaux Lessivés.

Concretionary laterite horizons have been recognized in Gray Podzolic soils of Thailand, some as true concretions by oxide accumulation around a nucleus, usually of quartz grains, and some as what Maignien (1966) called fake concretions, which consist of altered rock debris impregnated by ferruginous solutions. The major soils with concretionary laterite in Thailand are however classified into a different great soil group (Red Yellow Podzolic soils-Phon Phisai series).

Distribution of Gray Podzolic and Related Soils Outside of Thailand

Since FAO and UNESCO initiated the joint project for the preparation of the Soil Map of the World in 1961, much knowledge in correlation of soil units used in various parts of the world has been gained. The series of meetings for field correlation led to the preparation of the successive drafts of the legends for the Soil Map of the World by World Soil Resources Office, FAO, Rome.

Dudal[2], through his connection with the project as soil correlator, has on many occasions referred to the correlation of Gray Podzolic soils of Southeast Asia with Sols Ferrugineux Tropicalaux Lessivés (Ferruginous Tropical Soils) of the French classification system in Africa, and the Lateritic Podzolic soils in Australia (Dudal, 1964, 1968). They are all listed in the Luvisols soil unit (Dudal, 1968, p. 16). Further correlation and more detailed descriptions of soils in tropical zones containing laterite and lateritic material are presented and discussed by Maignien (1966).

Southeast Asia

Gray Podzolic soils have been mapped and/or reported forming on terraces of southwestern Laos on the Vientiane Plain. In

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[2] Dr. R. Dudal, Chief, Soil Resources, Development and Conservation Service, Land and Water Development Division, FAO, Rome. Personal communication.

Cambodia, they occupy large areas of higher terrain around Tonle Sap and coastal terraces of southeastern Cambodia, which have been called terraces by Platteborze (1969). Extensive areas of Gray Podzolic soils in South Vietnam are found on the somewhat higher ground of the vast lowland to the north, northwest, and east of Saigon. Minor areas are on the upper reaches of several tributaries of the Mekong (i. e., in Darlac and Pleiku provinces (Moormann, 1961; Nqugen Hoai Van, 1962). In Burma, these soils are found on terraces of lower Irrawaddy River and minor streams as well as coastal plains. Gray Podzolic soils are probably included in the so-called Light Colored Degraded Meadow soils or Red Brown soils of dry savanna as identified by Karmanov (1968, p. 215). A few small areas have been reported in the most humid areas of central Vietnam, Sarawak, Borneo and Islands of Bangka and Billiton (Dudal and Moormann, 1964).

Australia

Correlation of Gray Podzolic soils to the Lateritic Podzolic soils in Australia has been confirmed by Dudal (1964, 1968) and Maignien (1966). The Lateritic Podzolic soils, of major importance in the southwestern part of Western Australia (Stace *et al.*, 1968, p. 344), occur in all states of Australia but mainly in humid to subhumid lands with annual rainfall of 500 mm or more. However, they are commonly associated with remnants of old land surfaces or ancient weathering crusts on which a new soil is developing (Mulcahy, 1960, 1961). Many also occur as relicts in dryer regions. Gray Podzolic soils may be similar to Lateritic Podzolic soils in having a fluctuating water table in the lower part of the profile. Lateritic Podzolic soils have deep weathering with sufficient removal of bases and silica to form a thick zone of kaolinitic clay, and much mobilization, removal, and redistribution of iron and aluminum in the pallid and mottled zones. Nodular or concretionary horizons are almost always present in the profile.

Australian Yellow Earths and Yellow Podzolic soils, which have a somewhat restricted occurrence (Stace *et al.*, 1968), also appear to have characteristics similar in many respects to those of the Gray Podzolic soils in Thailand.

Africa

Dudal (1968) listed both Leached Ferruginous Tropical soils and Gray Podzolic soils in Ferric Luvisols and Plinthic Luvisols. Further comparisons are possible through the SPI (Service Pédologique Interafricain) which provided the definition of the Ferruginous Tropical soils or Fersiallitic soils (D'Hoore, 1963) and the French classification system (Aubert, 1964). Since Gray Podzolic soils always have very small amounts of weatherable minerals, they are more comparable to the Leached Ferruginous Tropical soils as described by Maignien (1961) in Senegal. Further descriptions of these soils with or without concretions or ironstone were also reported by Fauck (1955, 1963) and Charreau and Fauck (1970). In the Belgian classification system these soils will be called Xero-ferrisols (Sys et al., 1961; Tavernier and Sys, 1965). Occurrence of Ferruginous Tropical soils is also reported from other areas in Africa such as in Ivory Coast (Leneuf and Riou, 1963) and western Nigeria (Smyth, 1963). Portuguese workers called similar soils Tropical Fersiallitic soils (Botelho Da Costa et al., 1964).

South America

Dudal (1968) places the Red Yellow Podzolic soils of high base status (in Brazil) in the same group with Gray Podzolic soils in his definition of soil units for the soil map of the world. Many of the Red Yellow Podzolic soils intergrading to Kaolinitic Yellow Latosols in the Amazon (Sombroek, 1966) may correlate with Gray Podzolic soils in Thailand.

Others

Although it is most unlikely that Gray Podzolic soils occur in the U.S.A., the new soil classification (USDA, Soil Survey Staff, 1960, 1967, 1970) has been often referred to as a means of correlation. Sys (1969) referred to Leached Ferruginous Tropical soils as Xeroferrisols intergrading to Brown Tropical soils in the INEAC[3] (Belgian Congo system) classification and Haplustalfs in the USDA classification. Our work in Thailand tentatively classified Gray Podzolic soils as either Paleustalfs or Paleustults and they may include other great groups in addition to these.

[3]Institut National Pour L'etude Agronomique Du Congo.

MATERIALS AND METHODS

Field Procedure

Site Selection

Soil profile samples were selected and described from nine selected locations throughout Thailand. These samples are identified from SR-1 through SR-9 inclusively. Figure 10 shows the sample locations in different parts of Thailand and Table 6 indicates the soil series identification, area location, geomorphic position, elevation and average precipitation of the sample sites.

The regional variation in occurrence of the Gray Podzolic soils was stressed in the selection as follows:

1. Marine alluvium and riverine alluvium. Profiles SR-2, SR-3, SR-4, SR-8 and SR-9 are on terraces presumably with marine influence, whereas profiles SR-1, SR-5, SR-6 and SR-7 are from riverine terraces located further inland.

2. A combination of physiographic positions and climatic regimes. The San Pathong series (SR-1) represents typical Gray Podzolic soils in large alluvial valleys of the north and on the broader old terraces of Chao Phraya and Pasak river systems (Central Plain and Central Highlands).

Profiles SR-5, SR-6 and SR-7 represent Gray Podzolic soils on

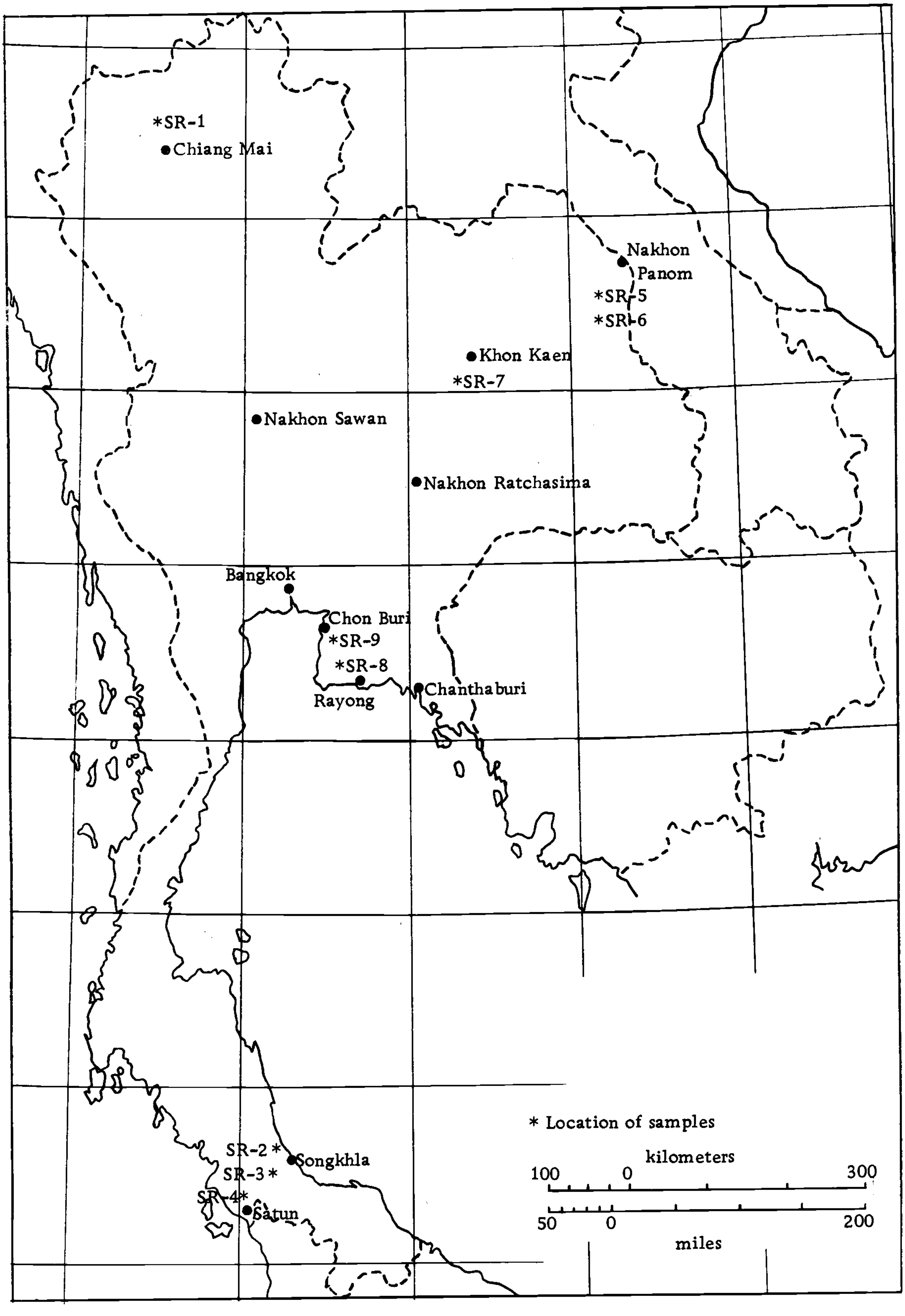

Figure 10. Location of the Gray Podzolic soil profiles under study.

Table 6. Series names, profile symbol, region and changwat, elevation, physiographic position and annual rainfall of the nine soil profile sites.

Soil series	Profile symbol	Changwats (provinces)	Elevation (m)	Physiographic position	Rainfall (mm)
North					
Sp - San Pathong	SR-1	Chiang Mai	315	Low Terrace	1257
Northeast					
Kt - Korat	SR-7	Tha Phra, Khon Kaen	170	Low to Middle Terrace	1208
Kt - Korat	SR-5	Nakhon Panom	150	Low Terrace	2163
Rn - Renu	SR-6	Renu Nakhon, Nakhon Panom	142	Low Terrace	2163
Southeast					
Hp - Huai Pong	SR-8	Huai Pong, Rayong	35	Higher Terrace	1343
Sh - Sattahip	SR-9	Siracha, Chon Buri	45	Higher Terrace	1335
South (east coast)					
Kh - Kho Hong	SR-2	Hat Yai, Songkla	10-12	Lower Terrace	2231
Ni - Nam Krachai	SR-3	Hat Yai, Songkla	7-10	Lower Terrace	2231
South (west coast)					
Kh - Kho Hong	SR-4	Kuan Kalaong, Satun	20	Lower Terrace	2415

low to middle terraces of the vast, uplifted Korat Plateau. The Korat series (SR-7) is a widespread Gray Podzolic soil of the Northeast where rainfall is generally 1,200-1,500 mm. Profiles SR-5 and SR-6 represent the higher precipitation soils (generally above 2000 mm) of the Northeast Plateau, SR-6 also represents the less well drained soils in lower positions, associated with Low Humic Gley soils.

In the south, the Nam Krachai series (SR-3) similarly represents the less well drained soils associated with the better drained Kho Hong series (SR-2) on higher positions. These profiles from the south represent soils with the shorter dry season of Peninsular Thailand, possibly integrating toward Yellow Latosols. SR-4, the only profile from the west coast of Peninsular Thailand, with an annual rainfall of 2,415 mm, appears to intergrade toward the Red Yellow Podzolic or Reddish Brown Lateritic soils.

SR-8 and SR-9 profiles are representative of relatively widespread Gray Podzolic soils of the Southeast Coast. The Huai Pong series (SR-8) has more clay and is from a slightly higher rainfall zone than SR-9. Both profiles are on the higher, old marine alluvial terraces.

Site Characteristics

Most of these sample sites are currently under cultivation or have been in the past. Only profile SR-1 was under secondary

Dipterocarp forest. Site characteristics associated with the profiles are described with the profile descriptions (Appendix A). Slopes at the sites range from 1 to 2% except the Sattahip profile (SR-9) site with a slope of 4 to 5%. Profiles SR-2 and SR-3 are located between rows of rubber plantation. These soils are extensively used for rubber growing throughout Peninsular Thailand. Profiles SR-5, SR-6 and SR-7 are in the Northeast Plateau, in areas frequently cleared for growing kenaf. SR-4 and SR-8 are in cultivated orchards. The SR-9 profile site was used for cassava, the common field crop of the Southeast Coast.

Sample Collection

All soils in this study have developed on old, stable alluvial terraces. Profiles SR-7, SR-8 and SR-9 have relatively deep sola. Samples were obtained to depths of 2.5 to 3 m in order to reach the lowest parts of the sola and substrata.

Samples were collected by horizons (with arbitrary subdivision of thick horizons). These samples were used to make physical and chemical determinations as well as X-ray studies of clay and microscopic examination of grain morphology. In addition, undisturbed, oriented block samples measuring 15 x 8 x 5 cm were collected at selected depth intervals for thin section study. An average of four undisturbed samples were collected for each profile. Four deeper, undisturbed, unoriented samples of SR-7, SR-8 and SR-9 were also obtained from their respective profiles.

Laboratory Procedures

Preparation of Soil Samples

All bulk samples were air dried, crushed and passed through a 2 mm sieve. In horizons where iron oxide nodules were common, care was taken to avoid crushing them. Many of these nodules were of plinthitic origin and were rather soft.

Physical and Chemical Analyses[4]

Mechanical analyses of 10 g samples were done by the pipette method (Kilmer and Alexander, 1949) after organic matter removal by digestion with 30% hydrogen peroxide. Calgon (sodium hexametaphosphate) was used as the dispersing agent.

Cation exchange capacity was determined by the sum of cations. Extractable acidity was determined by barium chloride mixed with triethanolamine adjusted to pH 8.0. Extractable calcium and magnesium were determined by atomic absorption spectroscopy and the flame photometer method was used to determine extractable potassium

[4]Physical and chemical analyses were performed by the Soil Survey Laboratory of the Soil Survey Division, Department of Land Development, Thailand, except for mechanical analysis.

and sodium. pH was measured by glass electrode in 1:1 soil-water and 1:1 soil-normal KCl suspensions. Total nitrogen was determined by the Kjeldahl method. Percent carbon was determined by the Walkley-Black wet digestion procedure. Electrical conductivity was determined on a 1:5 soil-water mixture and reported in microohms (EC x 10^3). "Available" phosphorus was determined by Bray's no. 2 method and "available" potassium was extracted with normal ammonium acetate and measured by the flame photometer method.

Heavy Minerals Separation

Heavy mineral separation of the 250-50 μ fraction (fine sand and very fine sand) was adequate for the study since the majority of the heavy minerals are in this size range. The separation method as described by Krumbein and Pettijohn (1938, p. 335) and Brewer (1964, p. 428) were used. This method is simple and reasonably accurate for the purpose required.

Bromoform, with specific gravity of 2.879, was used as the separation liquid. Acetone, which is miscible in all proportions with bromoform, was used for washing the grains during the procedure. Bromoform-acetone solution was recovered for reuse by adding a large volume of water as described by Krumbein and Pettijohn (1938, p. 337).

The light and heavy sand fractions were washed with acetone, dried and weighed. It was found that the amount of magnetic materials, notably magnetite, was quite small, therefore, it was not necessary to remove this material prior to examination of the heavy mineral suites.

The grain samples were mounted in Permount[5] for general observation and counting purposes. For identification, the heavy minerals were mounted by spreading the grains on a gelatinized slide. By this means the different index oils can be easily washed off and changed. The method of preparing the gelatin-coated slides was similar to that described by Marshall and Jeffries (1945, p. 402) and Olcott, 1960, p. 1099-1101).

Thin Section Preparation

Thin sections were prepared from undisturbed, oriented blocks previously collected in metal boxes (15 x 8 x 5.5 cm). Seven to eight thin sections were made at selected intervals throughout the profiles for each of the nine profiles under study. Four to five additional thin sections were made for the deeper horizons of the SR-7, SR-8 and SR-9 profiles.

Impregnation of the clods was accomplished using a "Laminac"[6] polyester resin diluted with acetone. It was found that due to the

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[5] Fisher Scientific Company, Pittsburgh , Pennsylvania.

[6] Laminac polyester resin, Cyanamid Company, Stamford, Connecticut.

rather porous nature of these soils, less dilution with acetone (i.e., 4:1 resin to acetone) gave better impregnation than the normal 1:1 dilution as used in an earlier study (Rojanasoonthon, 1963). Catalyst P-102[7] was added to the mixture (one drop to every 6-7 ml of the resin used) before impregnation.

Slabs or clods were arranged in a flat bottomed container. The resin mixture was poured in along the side of the container in small increments, in order to let the clods soak up by capillary action. Addition of the mixture was continued until it was about 4-5 mm above the slab surface. Impregnation was completed under low vacuum using a water aspirator (approximately 14-20 inches of mercury). The vacuum pressure was regulated to control the amount of bubbling that occurred from the clods in order to avoid clod rupture. The samples were held under vacuum for about 30 min. The container was later placed under a hood with air drawing slowly for 12 to 24 hours to allow the acetone to evaporate and the resin to harden. Final setting was done in an oven by raising the temperature slowly to 70°C and holding it for 6 to 7 hrs, followed by heating at 100°C for 1 hr.

After cutting with a diamond saw, thin slabs were ground with waterproof abrasive papers, using only a small amount of water, and mounted with Lakeside-70 on microscopic slides. The thin sections were then ground down with successively finer grades of emery paper

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[7] Methyl ethyl ketone peroxide, Fiberlay Company, Seattle, Washington.

to the right thickness (0.03 mm), then mounted with cover slip in the usual manner using "Permount." A similar procedure, but with a different type of resin, was described in more detail by Parfenova and Yarilova (1965, p. 104-108).

X-ray Diffraction Analysis of Clay ($< 2\ \mu$)

X-ray diffraction analysis of the clay fraction was carried out on representative A, B1, B2t and B3 horizons of each profile. For SR-7 (Khon Kaen series), SR-8 (Huai Pong series) and SR-9 (Sattahip series), X-ray analyses were also made for the B3, IIC, IIIC1, IIIC2, B23, IIC1 and IIIC2 horizons.

A 50 g sample was treated for removal of organic matter and free carbonates using hydrogen peroxide and NaOAc buffer (Jackson, 1956, p. 32-36). Dispersion of the clay fraction was carried out by suspension in 2% Na_2CO_3 using an air-jet stirrer (Chu and Davidson, 1953). The size fractions were separated by centrifuge in the presence of dilute Na_2CO_3. After centrifuging at 900 rpm for a time depending on the temperature (e.g., 4 min at 24°C), using an international centrifuge with head number 242, the supernatant clay fraction was decanted into a large 2000 ml Erlenmeyer flask. Resuspension, centrifugation and decantation were continued until the supernatant liquid was clear (Jackson, 1956, p. 101-141). The concentrated clay suspension was then flocculated with excess NaCl and the clear supernatant solution was siphoned off and discarded. This is a mild pretreatment as used at the Department of Soils, Oregon State University.[8]

Clay samples were prepared for X-ray determination by washing separate sub-samples of approximately 50 mg of clay twice in normal chloride salts of magnesium and potassium, followed by two washings in distilled water to remove excess salt solution. A small portion of the treated clay was removed from a vertical section in the centrifuge tube and smeared evenly on a petrographic slide with a micro-spatula (Theisen and Harward, 1962).

The prepared slides received different solvation, equilibration at controlled humidity and heat treatments. The humidity was controlled by equilibration prior to, as well as during, analyses. Magnesium saturated slides were equilibrated at 54% relative humidity in a desiccator over a saturated solution of $Mg(NO_3)_2 \cdot 6H_2O$ for 24 hr. X-ray diffraction analysis was done with air to the goniometer passed through a saturated solution of $Mg(NO_3)_2 \cdot 6H_2O$. Solvation with glycerol was done by condensation of the vapor in a desiccator, heating to 105°C for 3 hr and equilibrating at room temperature for 12 hr (Brown and Farrow, 1956). Solvation in ethylene glycol liquid was similar to the procedure of Kunze (1955) by condensation from the

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[8] M. E. Harward, 1970. Methods and criteria for clay mineral identification (mimeographed).

vapor formed by heating to 65°C for 3 hr followed by 12 hr at room temperature. Desiccators were evacuated each time before being placed in the oven.

Slides of potassium saturated clay were dried at 105°C for at least 6 hr. X-ray analysis was done with air to the goniometer passed through two columns of drierite (approximately <10% R.H.). Rehydration of the dried, potassium saturated slides was done by placing over a saturated solution of $Mg(NO_3)_2 \cdot 6H_2O$. X-ray diffraction analysis was then carried out in a controlled R.H. of 54%. These slides were subsequently heated at 300°C for 3 hr and analysed in dry air. If a 2:1 type component at 14 Å still persisted, further heating at 550°C for 3 hr was performed before analysing again in dry air.

The X-ray diffraction analyses were performed with a North America Phillips Norelco unit equipped with a Geiger-Muller tube and a Honeywell-Brown recorder and/or Norelco recorder. The radiation source was Cu K_{α} with power settings of 30 milliamperes and 50 kilovolts. The scanning speed was one degree 2θ per minute with divergence and scatter slits of 1/4° and 4°, respectively. A 1/2 in receiving slit was used for the scanning from 2° to 14° 2θ. The goniometer was equipped with an A.M.R. focusing crystal monochromator replacing the nickel filter to help reduce background scattering, a technique which is particularly effective when samples are strongly contaminated with sesquioxides.

RESULTS

Soil Morphology

The major morphological characteristics of the nine soil profiles are shown in abbreviated form in Table 7. Detailed profile descriptions of the nine profiles are given in Appendix A.

The sola of Gray Podzolic soils are usually deep, varying from 1 to 2 m, and they are moderately well drained to well drained. The deep sampling of profiles SR-7, SR-8 and SR-9 illustrates the thickness of the old alluvium under the profiles of this study. Plinthite, or in most cases, a variegated color of prominent mottles is frequently found in the profiles, usually at a depth greater than 1 m. This condition is indicated in profiles SR-1, SR-2, SR-3, SR-6, SR-8. The relatively lower and less well drained profiles SR-3 and SR-6 have intense mottling at depths of 50-60 cm.

The subsurface color of these soils is generally strong brown to light yellowish brown with hues of 7.5YR to 10YR. The color is redder only in the Sattahip series (SR-9) which is usually yellowish red. In general, the surface color is brown to grayish brown with 10YR hue.

Surface textures are predominantly in the sandy loam range with larger amounts of clay at greater depth. Profiles SR-8 and SR-9 have the highest (30-40%) and lowest (8-10%) amount of clay,

Table 7. Morphologic descriptions in abbreviated form of the nine soil profiles.[1]

Profile	Depth (cm)	Color: Hue	Color: Value/ chroma	Mottle	Texture[2]	Structure	Consistence	Boundary	Cutans, other
North: SR-1									
A1	0-5	10YR	3/1	-	sl	1fsbk	h	cw	
A2	5-11	10YR	5/3	-	sl	2fsbk	vh	gs	
B1	11-40	10YR	6/4	-	sl	2msbk	f	gw	t-p-cu
B2t	40-73	10YR	6/4	1fd	scl(sl)	2msbk	fr	gs	t-p-cu
B3g	73-122+	10YR	6/2	3mp	c(cl)	1msbk	fr	-	mth-cu
		10R	4/6						
		(variegated color)							
Northeast: SR-7									
Ap	0-6/10	10YR	5/2	3fd	sl	1fgr	sh	cw	-
A2	6/10-34	7.5YR	6/4	1ff	sl	1fsbk	h	gs	-
B1	34-62	7.5YR	6/4	-	scl(l)	1-2fsbk	fi	gs	t-mth-cu
B21t	62-94	7.5YR	6/4	-	scl(l)	1-2fsbk	fr	gs	c-th-cu
B22t	94-130	7.5YR	6/4	1f	sc(cl)	2f-msbk	fi	gs	b-t-cu, few nodules
B3	130-198	7.5YR	6/4	1-2fd	sc(cl)	2f-msbk	fi	gs	c-th-cu
IIC	198-270	10YR	7/6	2md	c	3f&msbk	fi	-	c-th-cu, saprolite
Northeast: SR-5									
Ap	0-8/12	10YR	3/3	-	sl	2fgr/pl	h	cw	-
A21	8/12-40	10YR	4/3	-	sl	1fsbk	fi	cs	bleached s. grain
A22	40-53	7.5YR	5/6	-	sl	1fsbk	v fi	gs	p-t-cu
B1	53-72	6YR	5/6	-	scl	1msbk	fi	gs	b-t-cu
B21t	72-119	5YR	5/6	1ff	scl	2msbk	fr	gs	c-th-cu
B22t	119-147	10YR	5/4	2ff	scl	1fsbk	fr	gs	c-th-cu
B23tg	147-153+	10YR	6/4	2fd	sc	1fsbk	fr	-	p-t-cu

(Continued on next page)

Table 7. (Continued)

Profile	Depth (cm)	Color Hue	Color Value/ chroma	Mottle	Texture[2]	Structure	Consistence	Boundary	Cutans, other
Northeast: SR-6									
Ap	0-5/7	10YR	6/2	-	sl	1fgr	h	aw	-
A2	5/7-17	10YR	6/4	1ff	sl(1)	1fsbk	vh	gs	-
B21t	17-39	7.5YR	6/2	2f-md	sl(1)	1f-msbk	vh	ds	p-t-cu
B22t	39-70	7.5YR	7/2	2f-md	scl(1)	1fsbk	vfi	gs	c-t-cu
B23tg	70-100+	7.5YR	6/2	3f-mp	scl(1)	1fsbk	fi	-	c-t-cu
Southeast: SR-8									
Ap	0-15	10YR	5/2	-	cl(scl)	1gr-1fsbk	vh	cw	-
A2	15-25	10YR	6/4	-	cl(scl)	1fsbk	vh	gs	-
B21t	25-53	10YR	6/3	1ff	sc	1fsbk	h	gs	p-t-cu
B22t	53-88	10YR	7/4	2ff	sc	1-2fsbk	vfi	gs	b-t-cu
IIB31	88-105	10YR	7/4	2md	sc(scl)	1msbk	fi	cs	b-t-cu
IIB32	105-140	10YR	7/4	1fp(5YR6/8)	sc(c)	1-2msbk	fi	cw	35% nodules
IIIC1	140-165	10YR	7/3	2mp	sc(c)	massive	fi	cw	36% nodules
IIIC2-1	165-185	10YR	8/3	3m&cop	c	massive	fi	-	50% nodules
IIIC2-2	185-235								
Southeast: SR-9									
Ap	0-19	10YR	4/3	-	fsl(sl)	1fsbk	fi	as	-
A2	19-36	6YR	5/6	-	fsl(sl)	1fsbk	fr	gs	-
B21	36-68	5YR	5/6	-	sl	1f-msbk	fr	gs	p-t-cu
B22	68-105	5YR	5/6	-	sl	1-2fsbk	fr	gs	p-t-cu
B23	105-155	5YR	4/6	-	cosl(sl)	1-2fsbk	fr	gs	9% quartz fragment p-t-cu
B3	155-210	4YR	4/6	-	cosl(sl)	1fsbk	fr	gs	12% fragments p-t-cu
IIC1-1	210-235	2.5YR	4/6	-	ls(sl-ls)	noncoherent	loose	gs	40% fragments p-t-cu
IIC1-2	235-265								

(Continued on next page)

Table 7. (Continued)

Profile	Depth (cm)	Color: Hue	Color: Value/ chroma	Mottle	Texture[2]	Structure	Consistence	Boundary	Cutans, other
Southeast: SR-9 (cont'd)									
IIIC2	265-280	variegated color 2.5YR 4/6, 10YR 7/1 10YR 5/6			scl(sl)	massive	fi	-	47% fragments
South: SR-2									
Ap	0-15	10YR	5/3	-	sl	1fsbk	v fr	cw	-
A2	15-53	10YR	5/4	-	sl	1fsbk	fr	gs	t-p-cu
B1	53-67	7.5YR	5/6	-	scl(sl)	1fsbk	fr	gs	mth-cu t- on peds
B21t	67-91	7.5YR	5/6	1ff	scl(sl)	1msbk	fr	gs	mth-cu
B22t	91-125	7.5YR	5/6	2md	sc(scl)	1msbk	sp	gs	mth-cu 10% nodules
B3t	125-143+	10YR	6/6	3mp 10R 4/6 7.5YR 5/8	sc(scl)	massive	sp	-	80% nodules
South: SR-3									
A1 (Ap)	0-17	10YR	5/3	-	sl	2f-msbk	v fr	gw	-
A2	17-35	10YR	6/3	1ff	sl	2msbk	fr	ds	-
B1	35-63	10YR	7/2	2fd(10YR6/8)	scl(sl)	2msbk	fr	ds	-
B21t	63-89	10YR	7/1	2ff	sc(l)	2f-msbk	fr	cw	mth-cu t- around peds
B22t	89-120t	10YR	7/1	3mp	sc(sl)	2msbk	sp	-	t-p-cu
South: SR-4									
Ap1	0-7	10YR	3/3	-	l	2fgr	fi	cs	-
Ap2	7-13	10YR	3/3	-	l	2fgr (compact)	fi	as	-
A2	13-28	10YR	5/4	lcof	sl(l)	2fsbk	h	gs	l-f charcoals
						(compact)			

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Table 7. (Continued)

Profile	Depth (cm)	Color Hue	Color Value/chroma	Mottle	Texture[2]	Structure	Consistence	Boundary	Cutans, other
South: SR-4 (cont'd)									
B1	28-41	7.5YR	4/4	1ff	scl(l)	2fsbk	fr	gs	t-b-cu
B21t	41-68	7.5YR	4/4	2ff	sc(cl)	2msbk	fr	gs	th-c-cu
B22t	68-86	7.5YR	4/4	2fd	sc(cl)	2f-msbk	fr	cs	th-c-cu
B3	86-120	10YR	5/6	3fd	c(cl)	2fsbk	fr	-	th-c-cu

[1]Symbols used are the same as given in Soil Survey Manual (USDA, 1951, p. 139-140) and indicated below for quick reference.

Amount:	1 = few; 2 = common; 3 = many
Size:	f = fine; m = medium; co = coarse
Color:	Munsell notation
Mottles:	f = faint; d = distinct; p = prominent
Texture:	s = sand; si = silt; c = clay; l = loam; cl = clay loam, etc.
Structure:	gr = granular; pl = platy; sbk = subangular blocky 1 = weak; 2 = moderate; 3 = strong
Consistence:	h = hard; vh = very hard; sh = slightly hard; fi = firm, fr = friable; s = sticky; p = plastic
Boundary:	c = clear; g = gradual; a = abrupt; d = diffuse; s = smooth; w = wavy
Cutan:	p = patch; b = broken; c = continuous; th = thick; mth = moderately thick; t = thin; cu = cutan

[2]Textural classes in parentheses are from laboratory determinations.

respectively.

Structure in these profiles is generally weakly expressed. A few have granular structure in the surface horizons, but most of the profiles have a weak, fine to medium subangular blocky structure throughout.

Consistence ranges between friable and firm, with hard to very hard consistence at the surface when dry. Consistence is related primarily to the clay content in the profile. Profile SR-9 has a friable to loose consistence as compared to the firmer condition in the clayey profile of SR-8.

One of the major characteristics of the Gray Podzolic soils is the gradual to diffuse nature of the horizon boundaries, particularly between A and B horizons. This condition was observed in all of the profiles under study.

Clay skins (Buol and Hole, 1961) or cutans (Brewer, 1960, 1964) were usually discontinuous and thin in the profiles studied. Small scattered patches of cutan are evident on ped faces or as linings in pores throughout the B horizon and the thickness is microscopic. Clay content also increases in this horizon as compared to the A horizon.

In profiles where deeper substratum samples were taken, lithologic discontinuities due to the stratified nature of the alluvial deposits are evident, mainly through differences in color, particle size distribution and the structure or arrangement of the components of the parent materials.

A slightly compact layer commonly occurred in the A2 or B1 horizons. This layer may result partly from previous tillage but also has been observed under apparently undisturbed conditions. This compaction may reduce infiltration somewhat but root penetration does not appear to be affected. Root distribution of these soils was quite good, reflecting the generally porous condition of the soils with numerous pores, channels, cracks, etc. Most of the large pores and channels were the result of soil fauna activities, usually ants and termites. Animal activity, particularly by termites, was probably quite significant in the Gray Podzolic soil profiles, since termite mounds are found widespread throughout Thailand and were observed in the vicinity of the sample sites.

Physical Measurements

The particle size distribution of the nine Gray Podzolic soil profiles under study is presented in Appendix B, Table 1. The relationship of clay percentage with depth is shown in Figure 11. All except profile SR-9 have an increase of clay percentage with depth. The increases in the percentage of clay meet criteria for argillic horizons as used in soil classification (USDA, Soil Survey Staff, 1970).

In general, these soils have a high percentage of sand, and

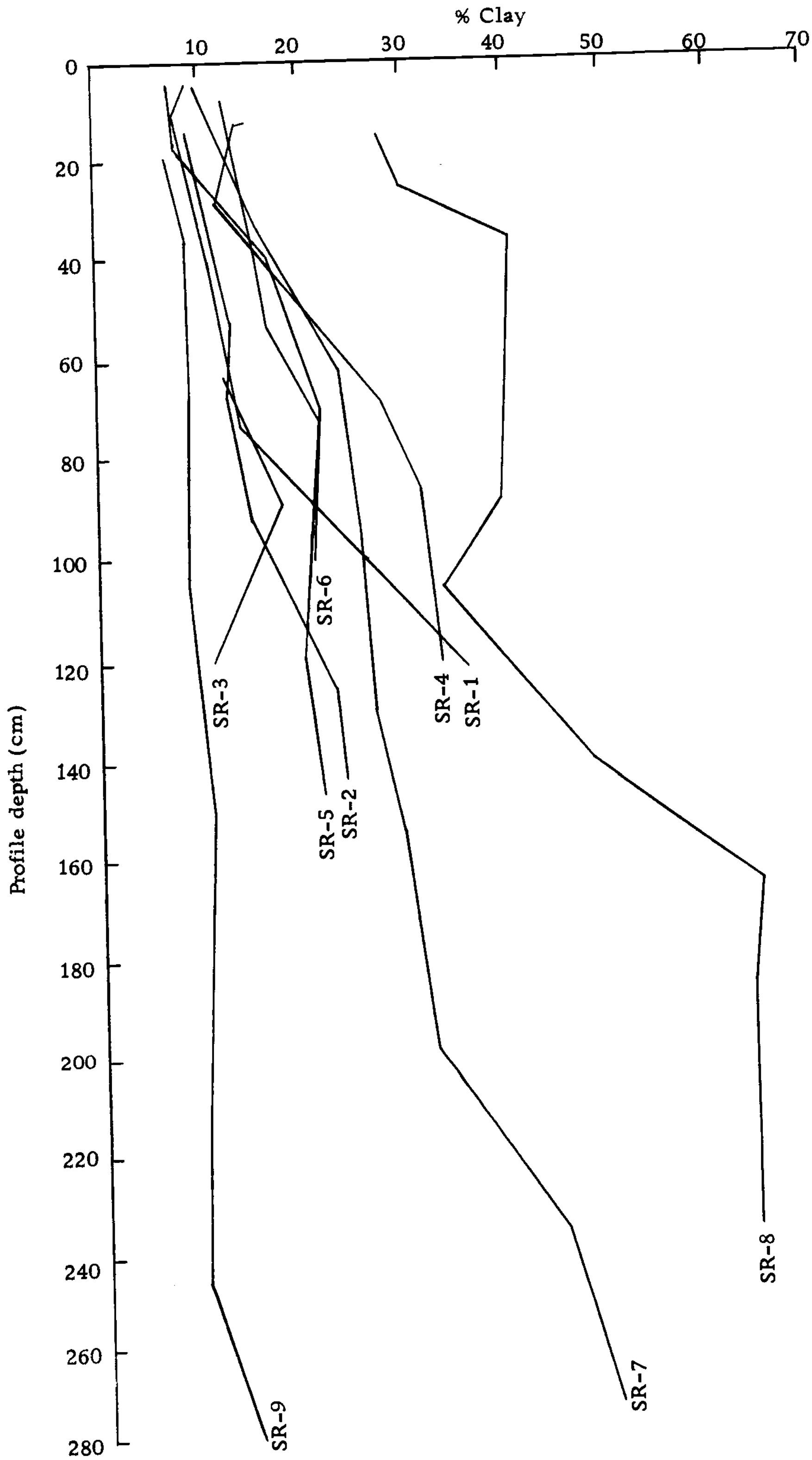

Figure 11. Percent clay with depth in the nine Gray Podzolic soils by region. North: SR-1; Northeast: SR-5, SR-6, SR-7; Southeast: SR-8, SR-9; South: SR-2, SR-3, SR-4.

surface horizons usually fall in the sandy loam textural class. The profiles are sandy loam in the surface and sandy clay loam or clay loam to clay in the B horizon. The transition from B to C or IIC horizons shows a sharp increase in clay content accompanied by a decrease in the amount of sand. Profile SR-8, in particular, displayed a high percentage of clay as well as a high amount of coarse and very coarse sand throughout the profiles. High percentages of the coarse and very coarse sand (0.5 to 2.0 mm) were also found in profiles SR-1 and SR-9. All other profiles contained relatively high percentages of the very fine sand and fine sand (0.05 to 0.25 mm). Silt content was fairly uniform in the majority of the profiles (20 to 30%), or slightly lower in the lower portions of the southeast profiles. Appreciable amounts of silt were found in profiles SR-4 and SR-6 (40 to 45%). Silt content was very low in profile SR-8 (6 to 10%). The total sand content was high in most profiles and tended to decrease with depth.

In most of these soil profiles, varying amounts of mottles or lateritic nodules were abundant in the lower part of the profiles, ranging in intensity of color, size and distinctness. In profiles SR-1, SR-3, SR-8 and possibly SR-2 and SR-6 (Appendix A), the concentration of such mottles and concretions was intense enough so that they are believed to fit the definition of plinthite (an iron rich, humus poor, mixture of clay with quartz and other diluents (USDA, Soil Survey Staff, 1970)). Plinthite or soft laterite is also commonly called other names (i.e., mottled clay, fleckenzone, argile tacheté, horizon bariolé (Sombroek, 1966, p. 95)).

Chemical Measurements

Cation exchange capacities of the nine soils were consistently low. All CEC (by sum of the cations) were under 10 me per 100 g of soil (Table 8). The majority of the horizons had CEC values ranging from 4 to 7 me. Typically, the values fluctuated slightly and with few exceptions increased slightly in the surface horizons and the lower portions of the profiles. The increase in the surface was believed to be the influence of the organic matter whereas increase of clay percentage probably accounted for the increase in lower horizons.

The base saturation of all these profiles except the Sattahip series (SR-9) decreased with depth (Figure 12). The values generally ranged from 30 to 40% at the surface to approximately 10 to 20% in the lower B horizons (100-150 cm). Decrease of base saturation with depth was also accompanied by generally decreasing pH values (Appendix B, Table 2). The profiles were generally acid with pH values mostly between 5 and 6. Profile SR-9 was near neutral in upper horizons.

Calcium and magnesium were the dominant exchangeable cations with combined values of 0.5 to 2 me per 100 g soil indicating the overall low amount of exchangeable bases in all the soil samples

Table 8. Relationships of percent clay, CEC and percent carbon with depth.

Samples	Depth (cm)	Horizon	% Clay	CEC/ 100 g soil	% Carbon
North					
SR-1-1	0-5	A1	9.1	7.6	0.93
1-2	5-11	A2	8.3	3.1	0.25
1-3	11-40	B1	11.6	3.6	0.03
1-4	40-73	B2t	14.2	3.0	0.04
1-5	73-122	B3	37.2	5.2	0.08
Northeast					
SR-7-1	0-6/10	Ap	10.1	4.6	0.48
7-2	6/10-34	A2	16.2	4.0	0.25
7-3	34-62	B1	24.2	6.0	0.18
7-4	62-94	B21t	26.3	6.6	0.15
7-5	94-130	B22t	27.5	6.4	0.15
7-6	130-155	B3-1	30.2	7.1	0.07
7-7	155-198	B3-2	34.4	8.0	0.07
7-8	198-235	IIC-1	46.6	9.8	0.08
7-9	235-270	IIC-2	52.1	12.1	0.07
SR-5-1	0-8/12	Ap	12.9	5.7	1.07
5-2	8/12-40	A21	16.0	6.4	0.63
5-3	40-53	A22	17.6	4.8	0.36
5-4	53-72	B1	21.9	5.8	0.29
5-5	72-119	B21t	20.4	5.2	0.26
5-6	119-147	B22t	22.2	6.0	0.22
SR-6-1	0-5/7	Ap	7.5	6.2	0.92
6-2	5/7-17	A2	8.5	3.4	0.31
6-3	17-39	B21t	17.4	5.4	0.14
6-4	39-70	B22t	22.4	5.8	0.22
6-5	70-100	B23tg	21.4	4.5	0.21
Southeast					
SR-8-1	0-15	Ap	28.2	6.9	0.91
8-2	15-25	A2	30.0	5.6	0.69
8-3	25-35	B21t	40.8	5.2	0.46
8-4	35-88	B22t	40.1	4.9	0.53
8-5	88-105	IIB31	34.2	4.6	0.35
8-6	105-140	IIB32	48.9	5.9	0.20
8-7	140-165	IIIC1	66.4	6.7	0.21
8-8	165-185	IIIC2-1	64.9	7.0	0.13
8-9	185-235	IIIC2-2	65.3	6.9	0.10

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Table 8. (Continued)

Samples	Depth (cm)	Horizon	% Clay	CEC/ 100 g soil	% Carbon
Southeast (cont'd)					
SR-9-1	0-19	Ap	7.0	3.3	0.54
9-2	19-36	A2	9.5	2.5	0.26
9-3	36-68	B21	9.2	2.0	0.24
9-4	68-105t	B22	8.7	1.9	0.15
9-5	105-155	B23	11.0	1.9	0.08
9-6	155-210	B3	10.0	2.3	0.07
9-7	210-235	IIC1-1	10.2	1.9	0.07
9-8	235-265	IIC1-2	9.9	2.4	0.06
9-9	265-280	IIIC2	16.3	3.3	0.03
South					
SR-2-1	0-15	Ap	8.8	2.7	0.50
2-2	15-53	A2	13.1	3.9	0.26
2-3	53-67	B1	13.2	3.6	0.12
2-4	67-91	B21t	15.3	3.8	0.11
2-5	91-125	B22t	23.5	5.0	0.10
2-6	125-143	B3t	24.1	5.5	0.10
SR-3-1	0-17	A1(Ap)	9.5	4.0	0.37
3-2	17-35	A2	10.7	3.1	0.13
3-3	35-63	B1	12.6	2.8	0.11
3-4	63-89	B21t	18.1	4.4	0.10
3-5	89-120	B22t	11.1	1.9	0.03
SR-4-1	0-7	Ap1	15.5	9.4	1.22
4-2	7-13	Ap2	14.5	8.2	0.82
4-3	13-28	A2	12.5	6.6	0.55
4-4	28-41	B1	17.7	5.9	0.33
4-5	41-68	B21t	28.1	8.2	0.39
4-6	68-86	B22t	32.7	9.7	0.39
4-7	86-120	B3	34.6	9.0	0.37

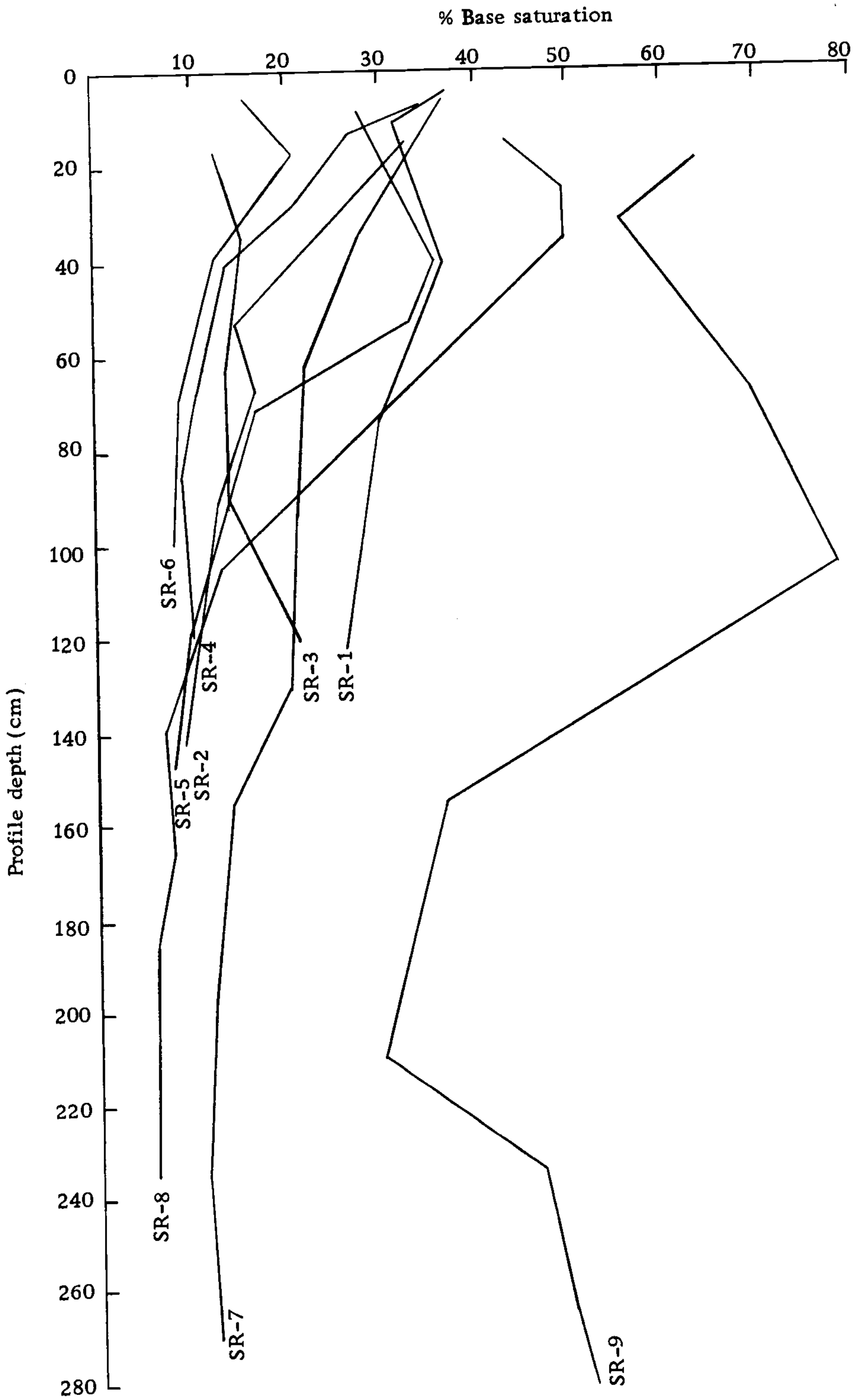


Figure 12. Relationship of base saturation with depth in the nine Gray Podzolic soils by region. North: SR-1; Northeast: SR-5, SR-6, SR-7; Southeast: SR-8, SR-9; South: SR-2, SR-3, SR-4.

studied. Profiles SR-2, SR-3 and SR-4 from the higher rainfall southern region showed relatively lower total exchangeable bases than the profiles from dryer sites further north.

C:N ratios are relatively narrow and decrease with depth, with the exception of profiles SR-8 and SR-9 which tended to increase with depth (Figure 13).

The available potassium (ammonium acetate method) and the available phosphorus (Bray's no. 2 method) were both low (Figure 14). Profiles SR-1 and SR-7 contained somewhat more available phosphorus with depth. The values for available K show more fluctuation than phosphorus. Higher values were found in profiles SR-1, SR-4, SR-7 and SR-9, with minimum values ranging from 35 to 90 ppm in subsurface horizons and increasing somewhat with depth. Other profiles range from 18 to 70 ppm at the surface and had between 10 to 40 ppm available K throughout the lower horizons.

The conductivity and free calcium carbonate values were low indicating no salinity, or levels well under the critical range for plant growth.

Clay Mineralogy

Clay samples ($<2\ \mu$), given a mild pretreatment for removal of organic matter, free carbonates and dissolved manganese dioxides, were used for the X-ray diffraction analysis. Results are summarized

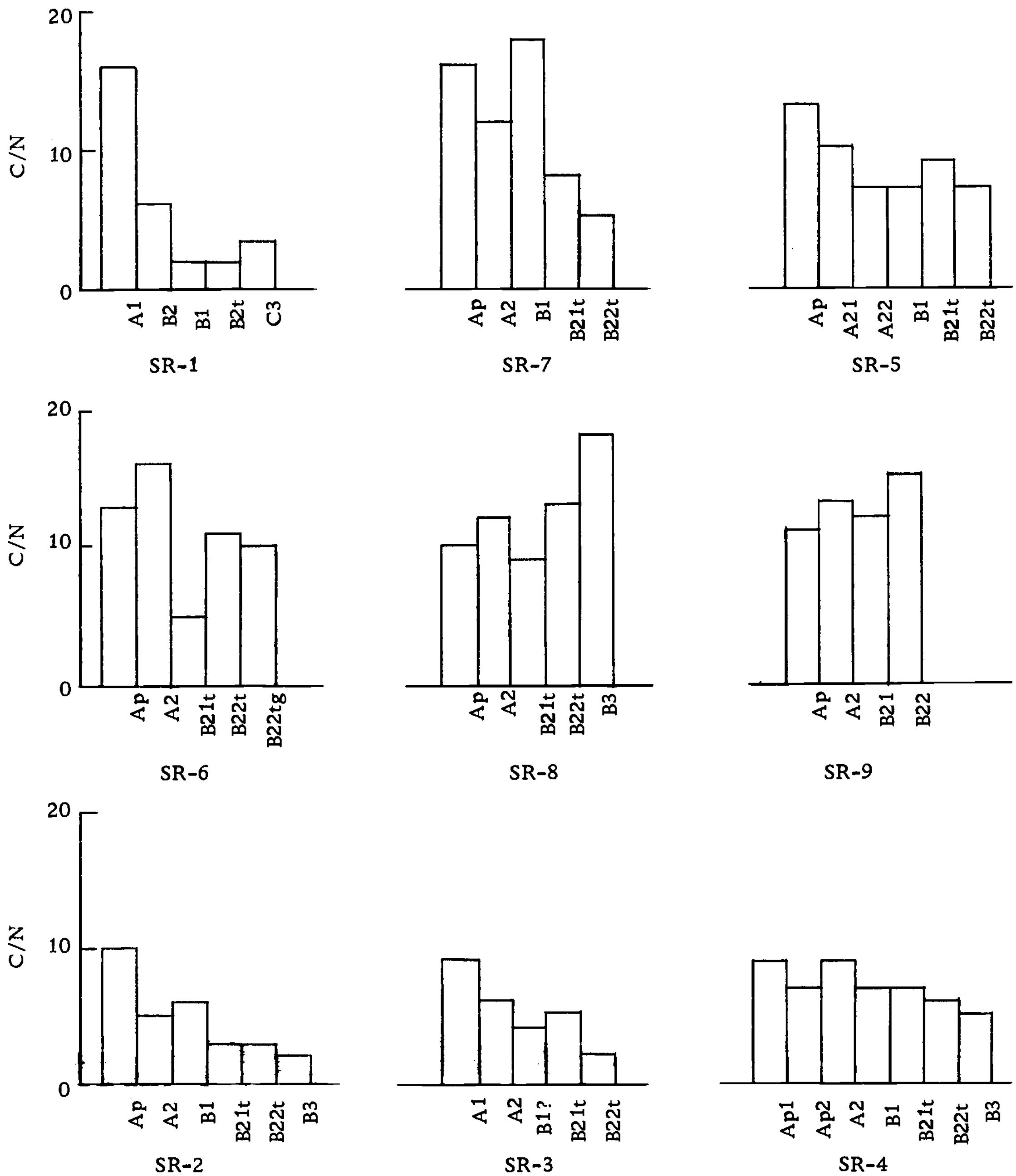
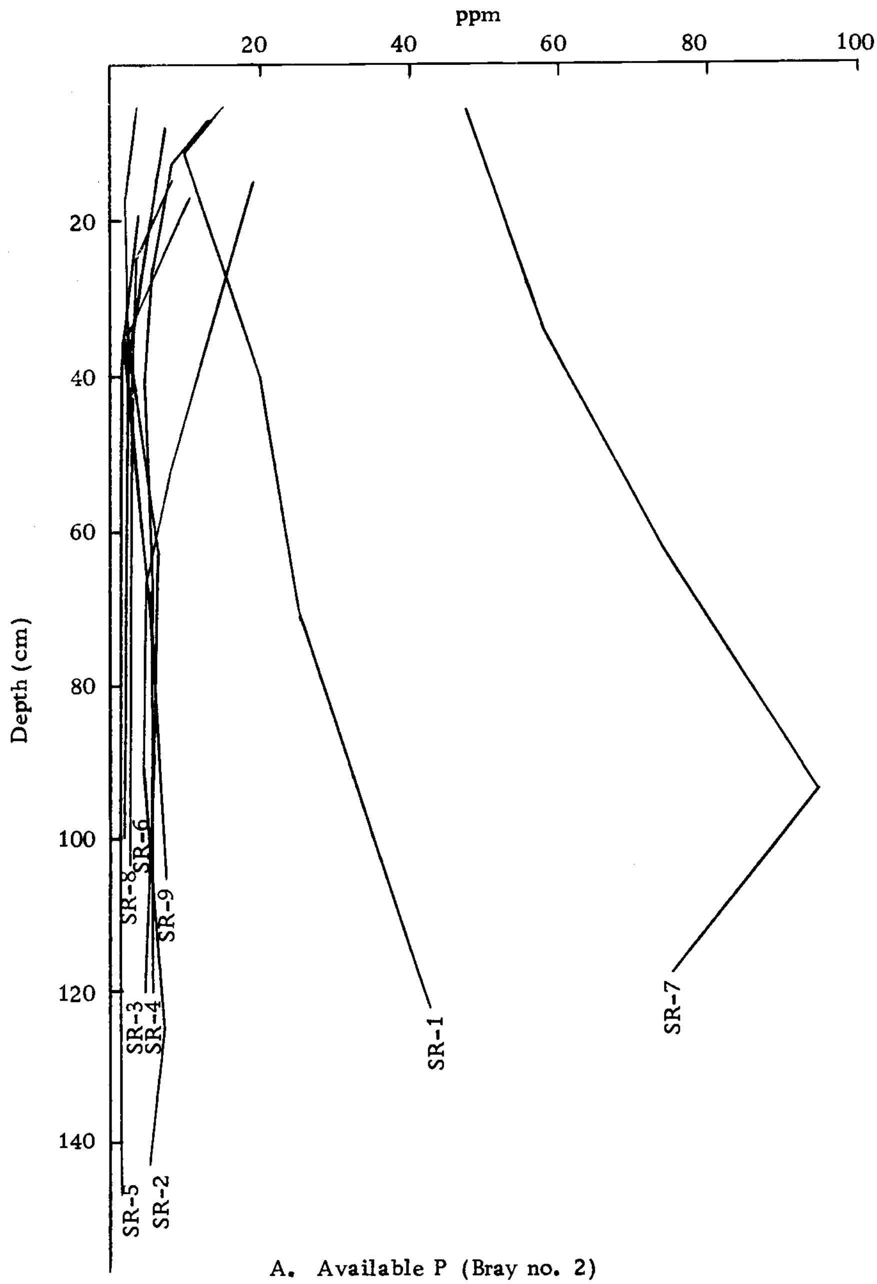
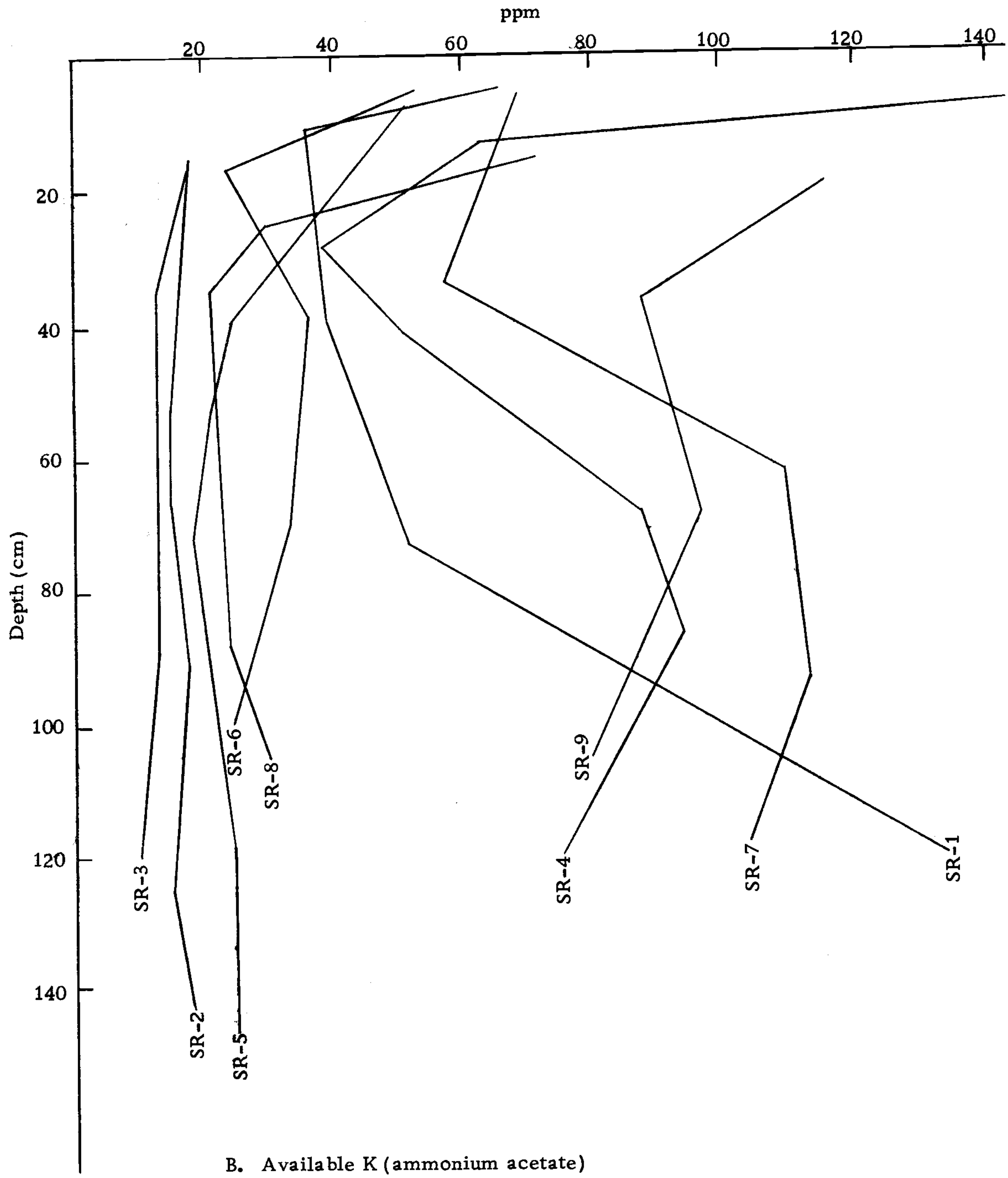


Figure 13. C/N ratio with profile depth in the nine Gray Podzolic soils by region. North: SR-1; Northeast: SR-5, SR-6, SR-7; Southeast: SR-8, SR-9; South: SR-2, SR-3, SR-4.



A. Available P (Bray no. 2)

Figure 14. Available P and K in ppm with depth of the nine Gray Podzolic soils studied.



B. Available K (ammonium acetate)

Figure 14. (Continued)

in Table 9.

The criteria for identification of the clay minerals in this study are those in use at the Department of Soils, Oregon State University (see footnote no. 8). Owing to differences in methods and interpretation of various workers, the criteria used in this study are summarized below:

Approximate 001 spacing (Å) obtained by characterization treatments:

1. Montmorillonite:

Mg-saturation; at 54% R.H.	15.3
Mg-saturation; ethylene glycol	16.9
Mg-saturation; glycerol	17.4
K-saturation; 105°C; dry air	10.3
K-saturation; rehydrated at 54% R.H.	12.1-12.4
K-saturation; 300°C; dry air	9.9-10.4
K-saturation; 500°C; dry air	9.8-10.2

2. Beidellite

Essentially the same as montmorillonite except that expansion to duo-interlayer complex does not occur with glycerol vapor and the K-saturation rehydrated to 54% R.H. treatment will show a peak at 11.6 Å.

3. Vermiculite

Mg-saturation; 54% R.H.	14.3
Mg-saturation; no expansion with either ethylene glycol or glycerol	14.1

Table 9. Clay mineral occurrence in selected horizons of the nine soil profiles.

Sample	Horizon and depth (cm)		Relative amount[1]			
			Kaolinite	Mica (illite)	2:1 component interstratified[2] amount	2:1 component interstratified[2] component
North SR-1						
1-2	A2	(5-11)	xxxx	xx	xx	V-(B)
1-4	B2t	(40-73)	xxxx	xx	x	V-(B)
1-5	B3	(73-122+)	xxxxx	xx	x	V-(B)
Northeast SR-7						
7-1	Ap	(0-6/10)	xxxxx	xx	x	V-B
7-3	B1	(34-62)	xxxx	xx	x	V-B
7-5	B22t	(94-130)	xxxx	xx	x	V-B
7-7	B3	(155-198)	xxxx	xx	x	V-(B)
7-9	IIC	(235-270)	xxxx	xx	x	V-(B)
Northeast SR-5						
5-2	A21	(8/12-40)	xxxx	xx	xxx	V-(C ?)[3]
5-4	B1	(53-72)	xxxx	xx	xxx	V-(C ?)[3]
5-6	B22t	(119-147)	xxxxx	xx	xxx	V-B
Northeast SR-6						
6-1	Ap	(0-5/7)	xxxx	xxx	xx	V-B[3]
6-3	B21t	(17-39)	xxxx	xxx	xx	V-B(C ?)[3]
6-4	B22t	(39-70)	xxxx	xxx	xx	V-B[3]
6-5	B23g	(70-100+)	xxxxx	xx	xx	V-B[3]
Southeast SR-8						
8-1	Ap	(0-15)	xxxxx	x	x	V-(B)
8-3	B21t	(25-53)	xxxxx	x	xx	V-B
8-4	B22t	(53-88)	xxxxx	x	xx	V-B
8-5	B3	(88-105)	xxxxx	x	x	V-B
8-7	IIIC1	(140-165)	xxxx	x	x	V
8-9	IIIC2	(185-235)	xxxx	x	x	V
Southeast SR-9						
9-1	Ap	(0-19)	xxx	xxx	xx	B-V
9-3	B21t	(36-68)	xxx	xxx	xx	B(M)-V
9-4	B22t	(68-105)	xxx	xxx	xx	B-V
9-5	B23	(105-155)	xxx	xxx	xx	B-V
9-7	IIC1	(210-235)	xxx	xxx	xx	B-V
9-9	IIIC2	(265-280)	xxx	xxx	xx	B-V

(Continued on next page)

Table 9. (Continued)

Sample	Horizon and depth (cm)		Relative amount[1]			
			Kaolinite	Mica (illite)	2:1 component interstratified[2]	
					amount	component
South SR-2						
2-1	Ap	(0-15)	xxxx	xx	xx	V-B
2-3	B1	(53-67)	xxxx	xx	xx	V-B
2-5	B22t	(91-125)	xxxx	xx	xx	V-B
2-6	B3	(125-143)	xxxx	xx	xx	V-B
South SR-3						
3-1	A1	(0-17)	xxxx	xx	xx	V-B
3-3	B1	(35-63)	xxxx	xx	xx	V-B
3-5	B22t	(89-120)	xxxx	xx	xx	V-B
South SR-4						
4-2	Ap2	(7-13)	xxx	xxx	xxx(11.2 Å)	V≡Mica[4]
4-4	B1	(28-41)	xxx	xxx	xxx	V(B)≡Mica[4]
4-6	B22t	(68-86)	xxx	xxx	xxx	V(B)≡Mica[4]
4-7	B3g	(86-120)	xxx	xxx	xxx	V(B)≡Mica[4]

[1] Expressed as relative quantities of crystalline clay based on peak area in the following order: x = present, 0-10%; xx - minor, 10-25%; xxx = intermediate, 25-50%; xxxx = major, 50-75%; xxxxx = dominant, 75-100%.

[2] The 2:1 component occurred as random interstratification between vermiculite (V) and beidellite (B), or occasionally montmorillonite (M) or chlorite (C ?). When indicated in parentheses the minerals have a minor role in interstratification. V-B = vermiculite probably dominant; B-V = beidellite probably dominant.

[3] Evidence of weak random interstratification peak at 12.2 Å between mica (10 Å) and vermiculite (14 Å).

[4] Random interstratification between vermiculite (and/or beidellite) and mica resulted in only one peak at 11.2 Å. Symbol used: V ≡ mica or V(B) ≡ mica.

K-saturation; 105°C; dry air	10.3
K-saturation; rehydrated at 54% R.H.	10.4
K-saturation; 500°C; dry air	10.0

4. Chlorite

14 Å spacing does not vary with solvation or K-saturation and heating.

5. Intergrades

Properties are intermediate between chlorite and vermiculite or smectite. The predominant feature is resistance to collapse upon K-saturation and heating. As the amount and stability of hydroxy-interlayers increase, the lattice is more difficult to collapse. Samples toward the chlorite end of the spectrum may also exhibit resistance to expansion upon solvation.

6. Mica

Presence of 9.9-10.4 Å component regardless of saturating cation, humidity or solvation.

7) Kaolin

Presence of 7.2-7.5 component regardless of saturating cation, humidity or solvation. Well crystallized kaolinite has 001 spacing of 7.15 with sharp peaks. Halloysite exhibits spacings of 7.3-7.5 which may expand slightly on hydration or solvation; the peaks are normally broader than for kaolinite.

In the presence of chloritic intergrades, identification of kaolinite is not positive due to the possible overlapping of the second order chlorite line on the kaolinite peaks.

It should be noted that identification and interpretation of the clay minerals by means of X-ray diffraction depend upon the methods and criteria as well as variations in clay size fraction, cation saturation of clay, dispersing reagents, etc. (Harward and Theisen, 1962).

In so far as diffraction intensities suggest quantities of minerals present, kaolinite was the dominant crystalline clay mineral present in all horizons of the profiles studied. Mica and 2:1 interstratified minerals (14 Å) were also always present but usually in much lower amounts than kaolinite (Figures 15 to 23).

The kaolinite peaks were sharp and consistently at 7.15 to 7.20 Å, suggesting the well crystallized nature of this component. The strongest peaks were from profile SR-8 of the southeastern region. The relatively weakest kaolinite peaks were found in most horizons of SR-4 and SR-9 soils. Relative peak intensities indicate that kaolinite represents from 60 to 90% of the total clay in most of the profiles. Representative samples of SR-7 and SR-8 were determined quantitatively by DTA to be about 70 and 90% of kaolinite, respectively.

Micaceous minerals with 10 Å peaks were always minor but

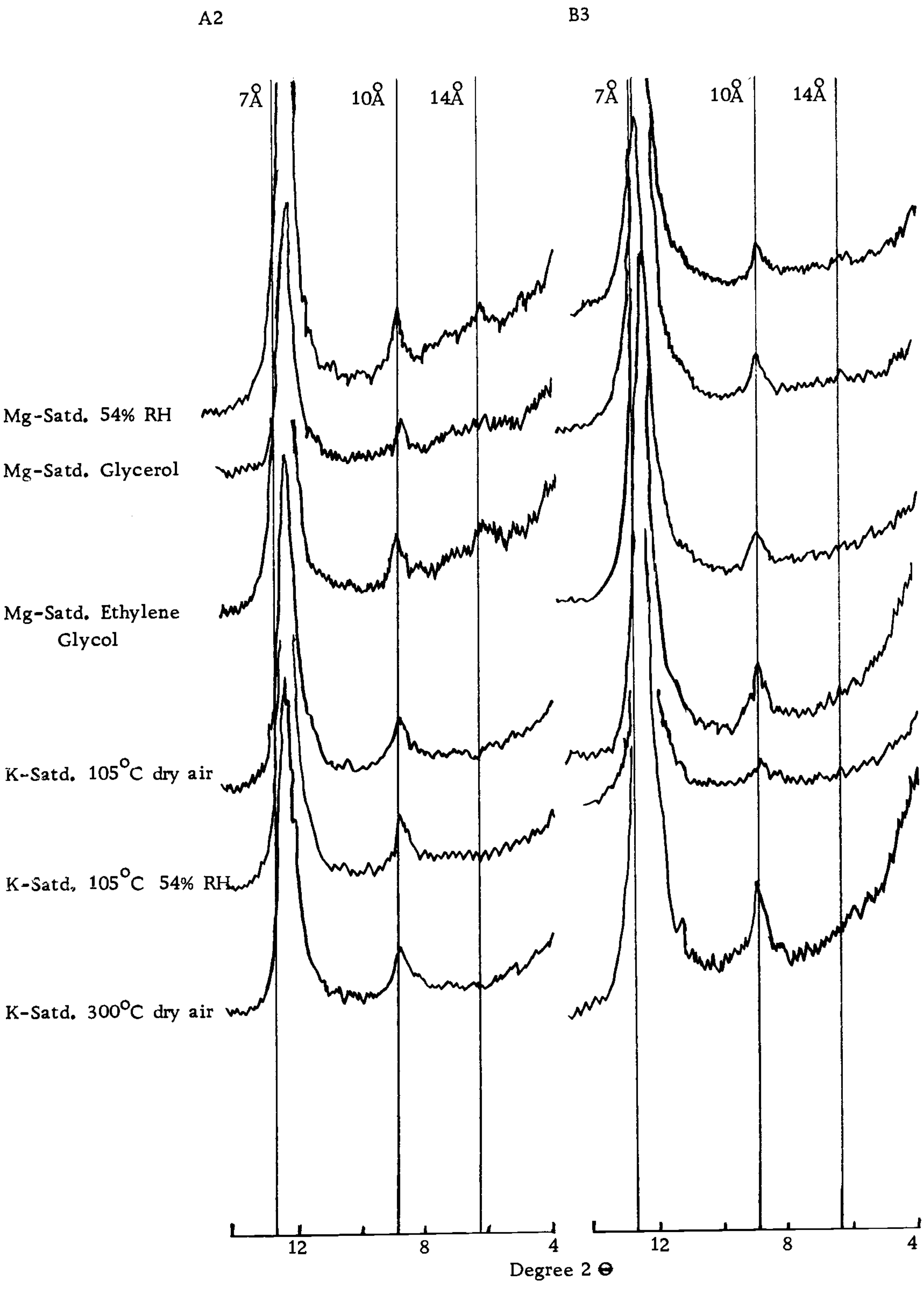


Figure 15. X-ray diffraction patterns of selected horizons in the SR-1 profile (north).

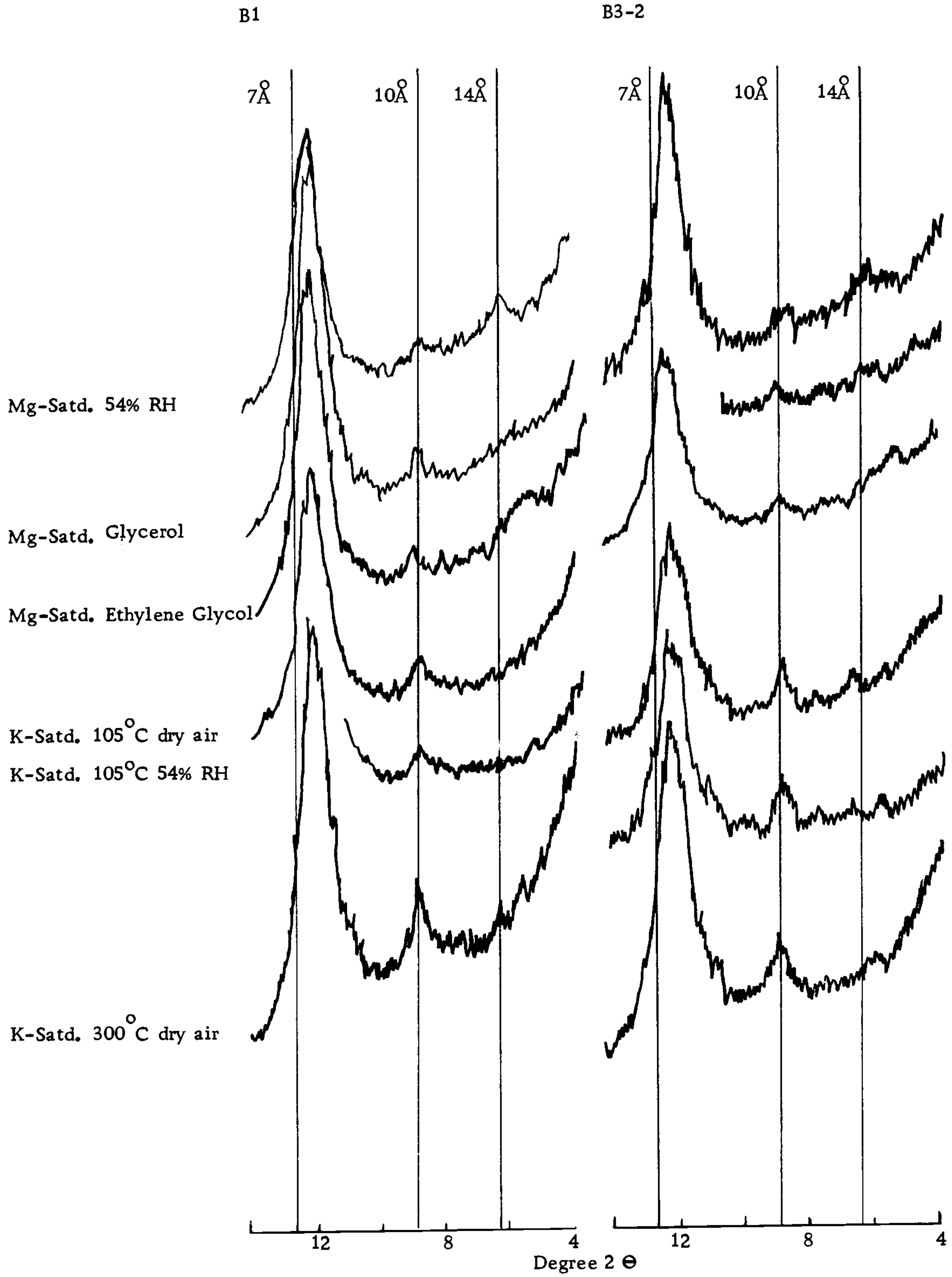


Figure 16. X-ray diffraction patterns of selected horizons in the SR-7 profile (northeast).

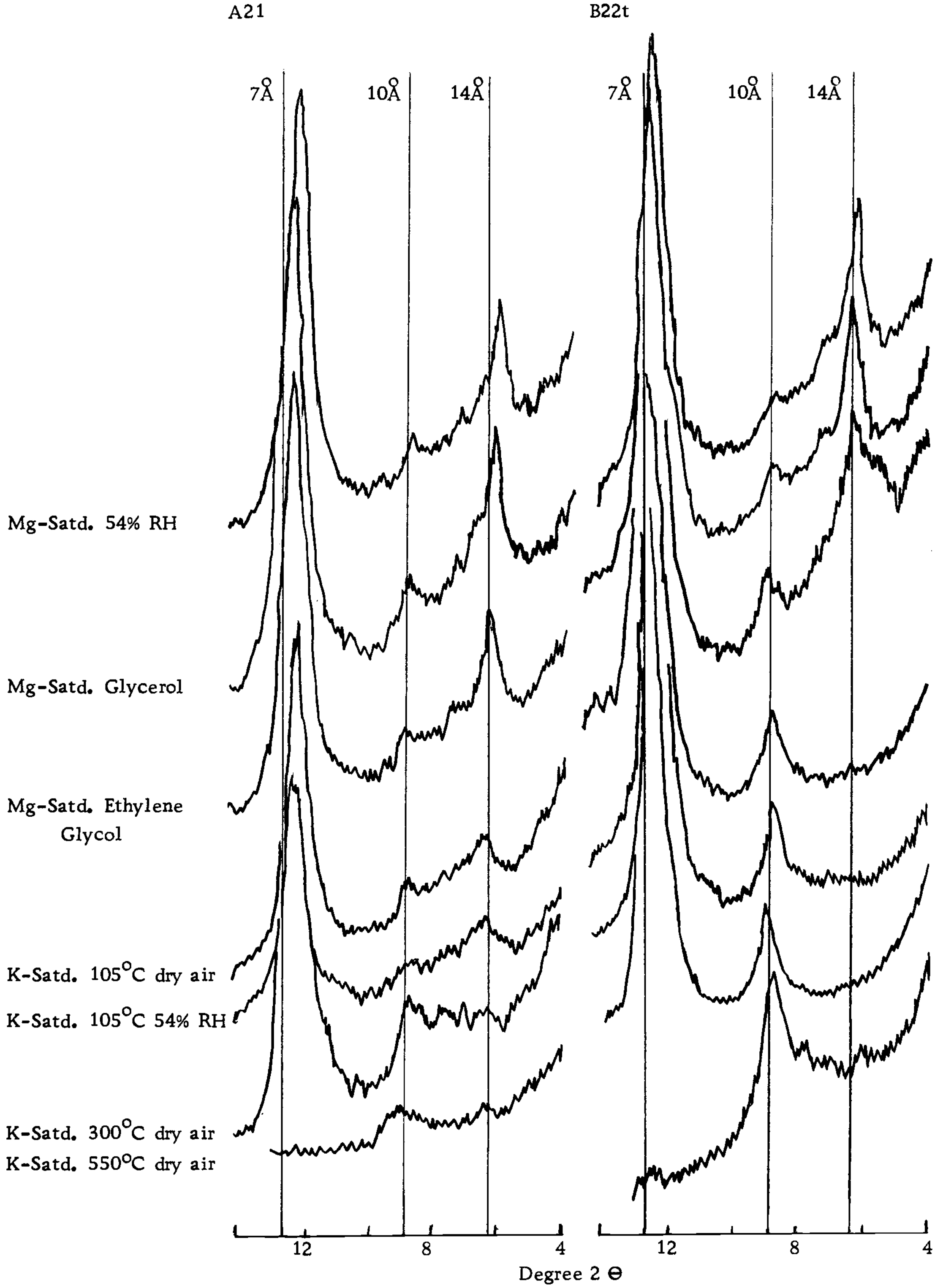


Figure 17. X-ray diffraction patterns of selected horizons in the SR-5 profile (northeast).

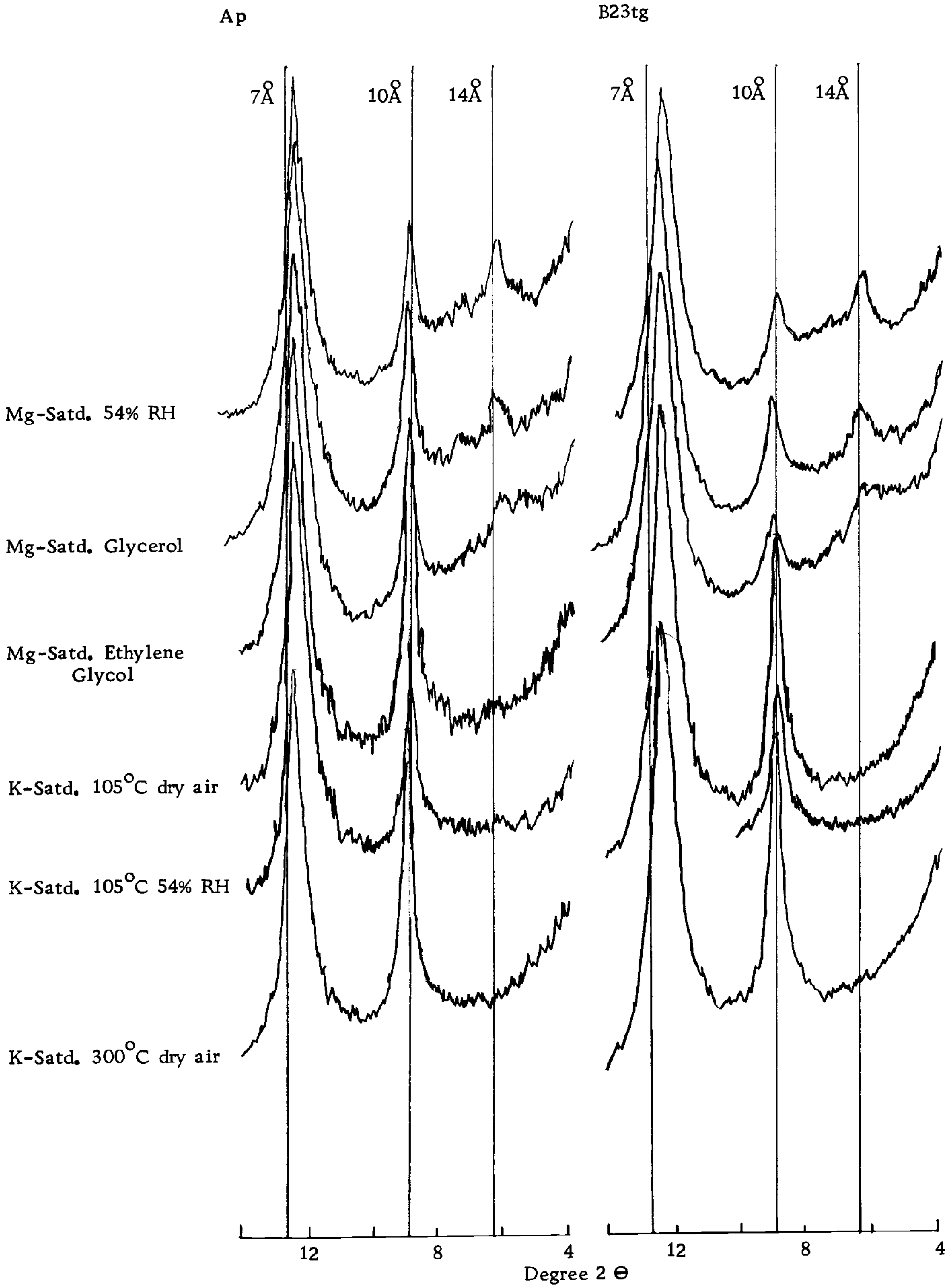


Figure 18. X-ray diffraction patterns of selected horizons in the SR-6 profile (northeast).

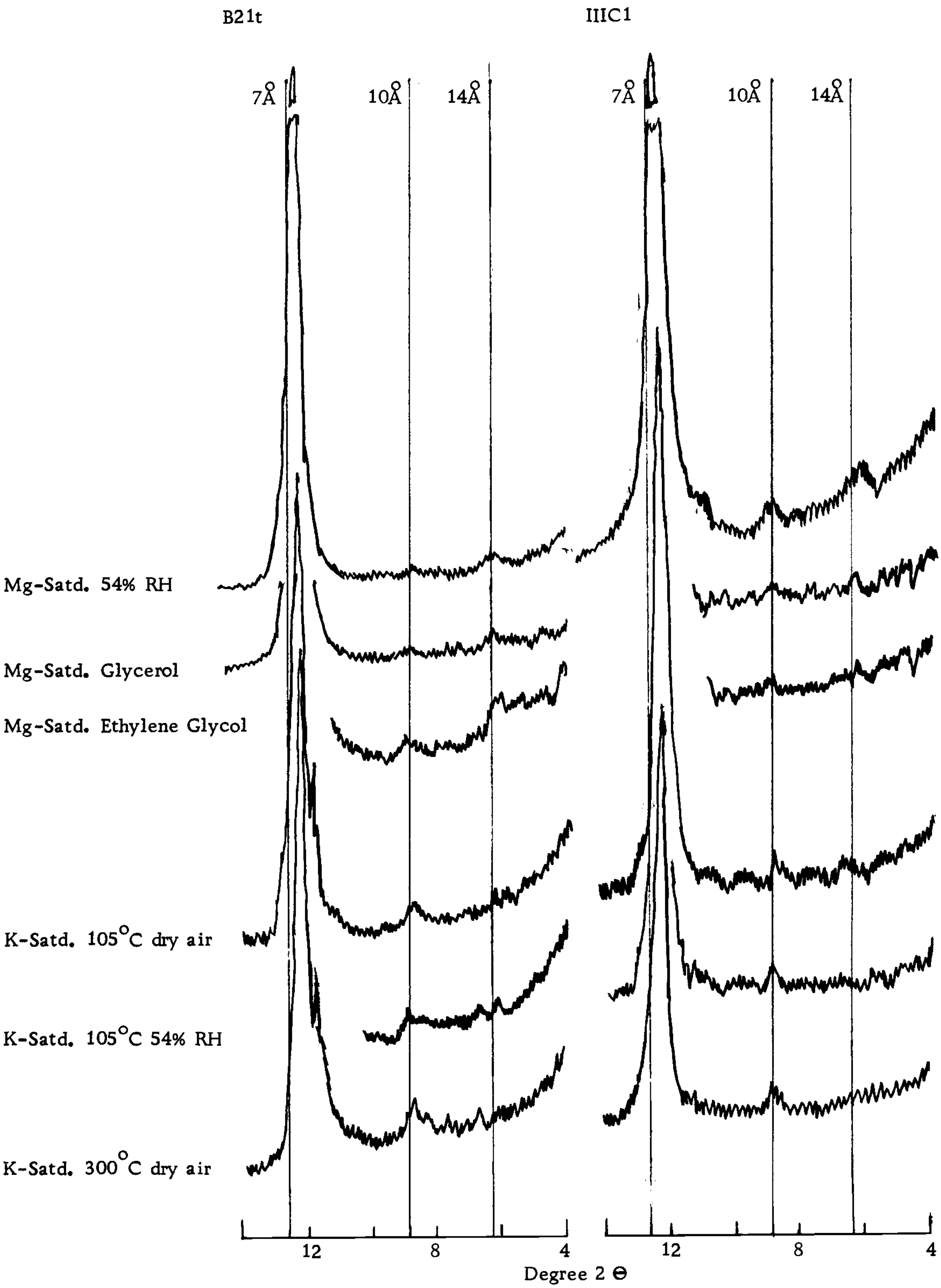


Figure 19. X-ray diffraction patterns of selected horizons in the SR-8 profile (southeast).

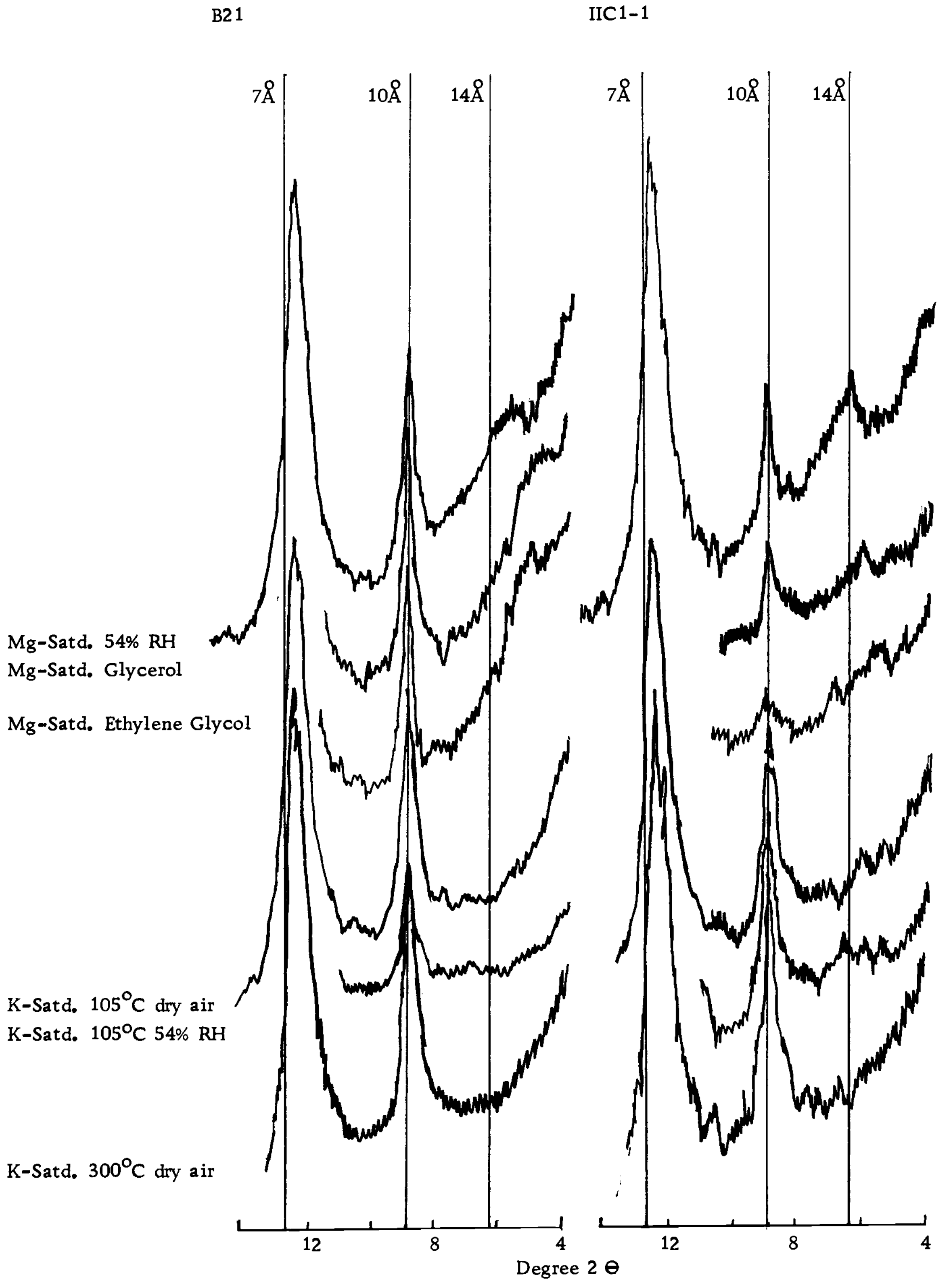


Figure 20. X-ray diffraction patterns of selected horizons in the SR-9 profile (southeast).

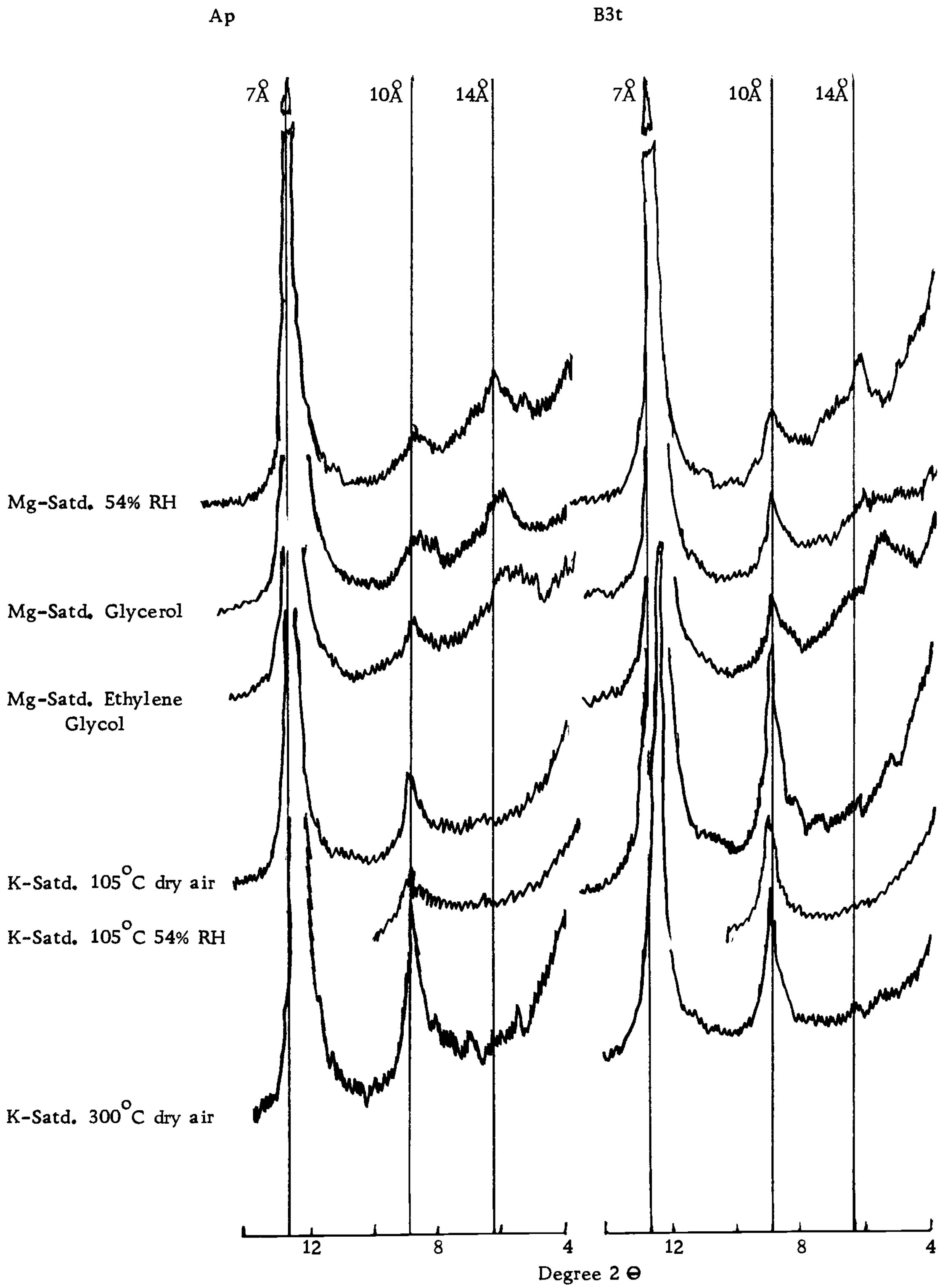


Figure 21. X-ray diffraction patterns of selected horizons in the SR-2 profile (south).

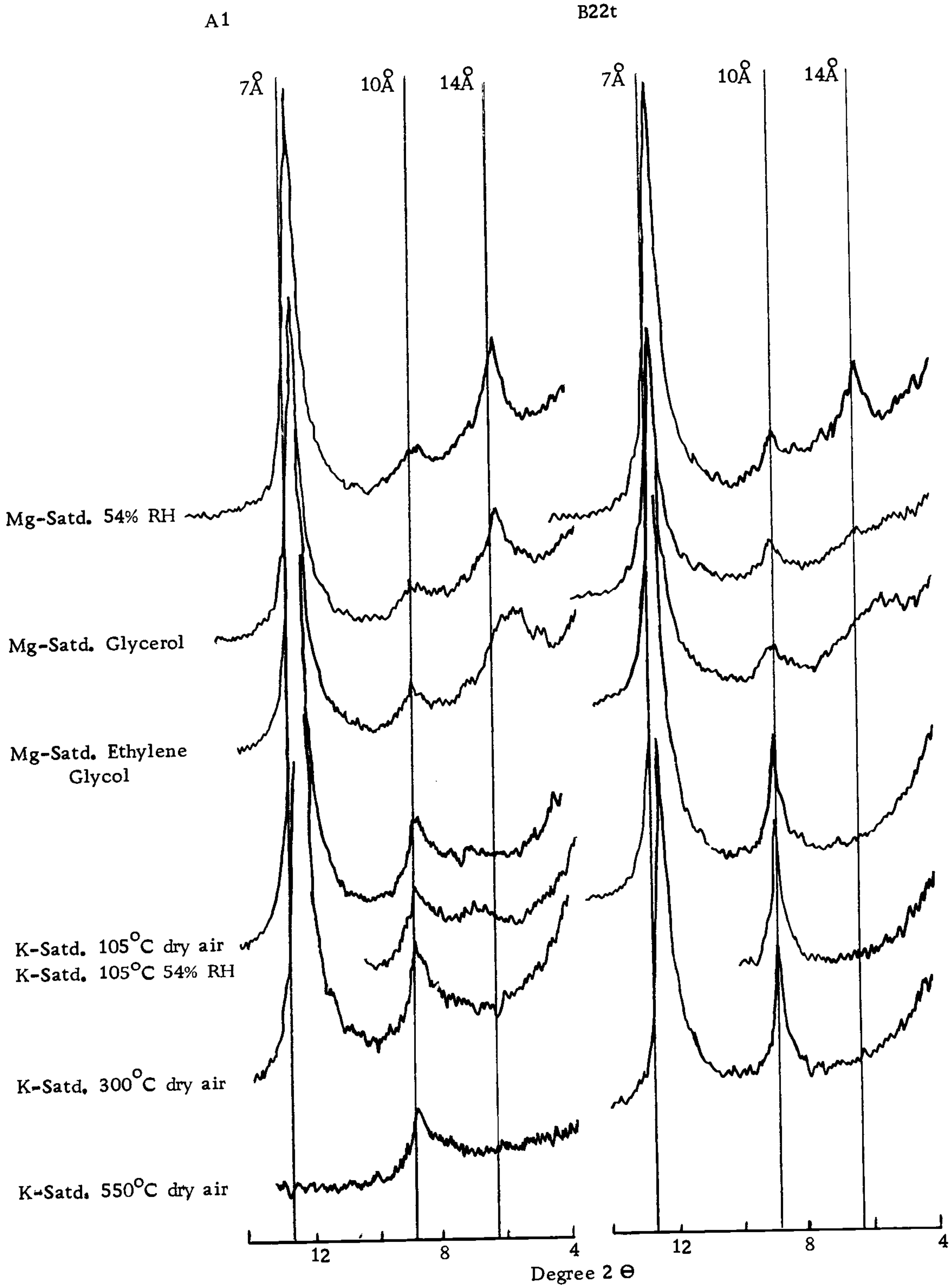


Figure 22. X-ray diffraction patterns of selected horizons in the SR-3 profile (south).

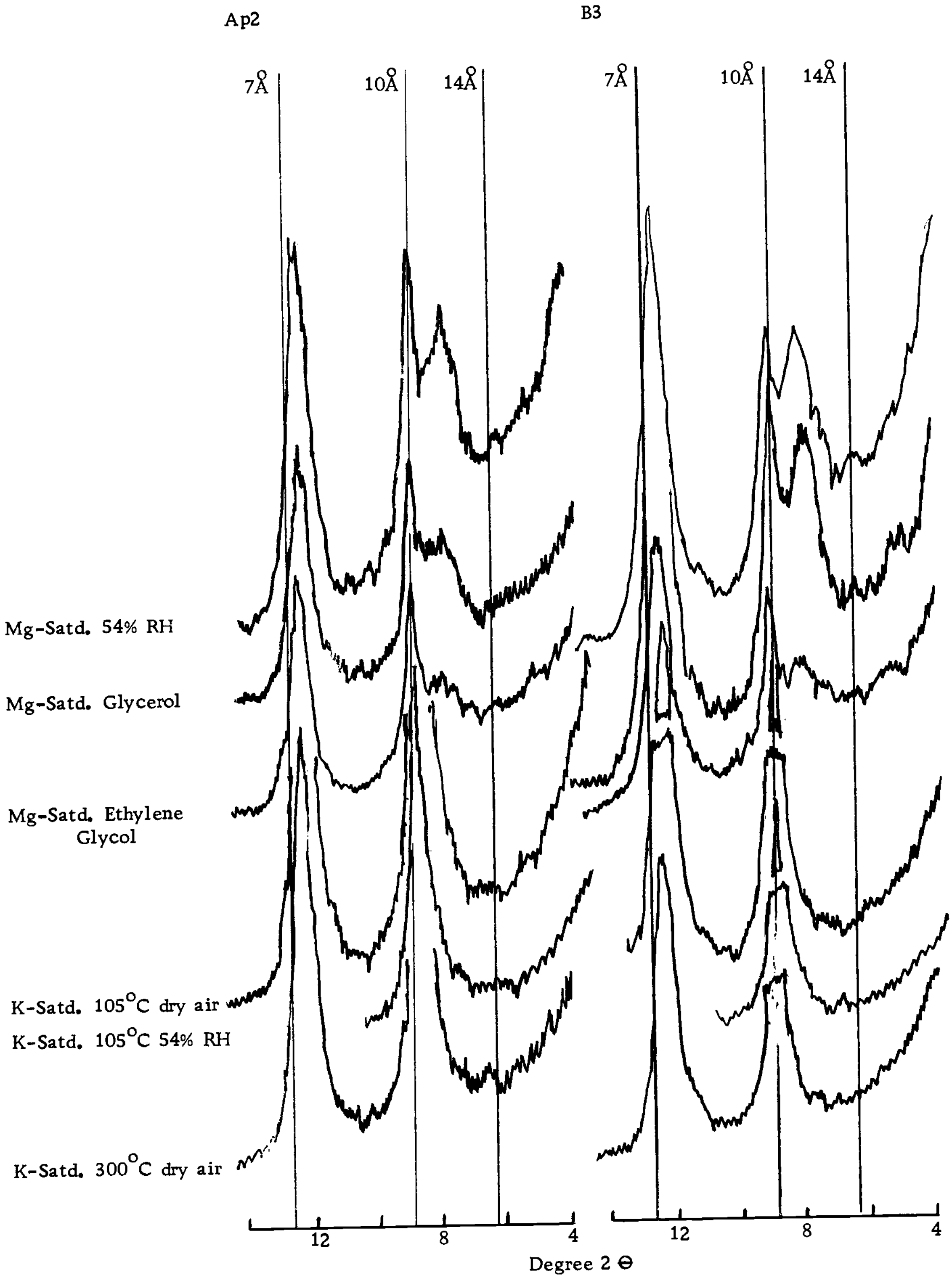


Figure 23. X-ray diffraction patterns of selected horizons in the SR-4 profile (south).

conspicuous. They attained higher intensities (minor to intermediate occurrence) in SR-4, SR-6 and SR-9 (Table 9). The micaceous clay minerals in this study show, in each assemblage, a mixture with 2:1 components. Therefore they tend to be more like "illite" as defined by Jackson (1965, p. 90), and similar to the definition of illite by Yoder (1959) who used it as a rock term.

Random interstratification between mica and the 2:1 clay mineral components, mainly vermiculite, was shown in profile SR-4 by a shoulder between 10 and 14 Å resolving into a peak at 11.2 Å. Weaker interstratification between 10 and 14 Å peaks with an additional small peak at 12.2 Å can be detected in profiles SR-5 and SR-6.

The 2:1 interstratified components with a small 14 Å peak, which persistently occurred in all horizons, showed intermediate properties between vermiculite and smectite clay minerals. These clays usually showed expansion to approximately 17 Å by forming plateaus or shoulders with ethylene glycol solvation, but not with glycerol. This has been shown to be a property of beidellitic minerals (Harward et al., 1969). On the other hand, the clays did not show 11.6 or 12 Å peaks on rehydration of K-saturation slides after heating to 105°C, but they did show broadening of the 10 Å peak somewhat. This 14 Å component, however, collapsed readily to 10 Å with K-saturation plus 105°C heat, which indicated vermiculite-like properties. In some of the horizons (SR-5-2 and SR-5-4) difficulty in collapsing the 14 Å peak occurred with K-saturation and heating at 300°C. Further heating to 550°C, however, collapsed all residual 14 Å. This indicated the possibility of some chloritic component in the 2:1 interstratified minerals. Beidellite has been identified from an earlier examination by X-ray diffraction of some Thai soils by Vacharotayan et al. (1962). The soils in that study which can be correlated with the Gray Podzolic soils in this study are the samples from Udon (Northeast Plateau) and some samples from Lampang (Northern Highland).

Chlorite as a discrete mineral seems to be absent from all the profiles studied. The 14 Å peak disappeared when the K-saturated slides were heated to 300°C. In some cases further heating to 550°C was required to collapse it completely.

Gibbsite is absent in all these assemblages. DTA analysis of a few samples confirmed the absence of gibbsite in all these soils. Quartz peaks were indicated in all profiles, the peak is high in SR-4, SR-7 and SR-9, moderate in SR-1 and SR-6 and low in SR-2, SR-3, SR -5 and SR-8.

Separate determinations of fine clay ($< 0.2\ \mu$) and coarse clay (2-$0.2\ \mu$) fractions from selected horizons show X-ray peaks of the larger clay mineral crystals (i.e., kaolinite and micaceous minerals (illite)) for coarse clay. The fine clay shows only peaks of the interstratified 2:1 minerals and smaller, broader peaks at 7 Å that can be attributed to the finer, weakly crystallized kaolinite.

The San Pathong series (SR-1) and Korat series (SR-7) from the North and Northeast contain quite similar clay mineral suites. The two profiles from further Northeast (SR-5 and SR-6), however, contain relatively higher amounts of mica and the 2:1 interstratified components. Complexity of these components was shown from the possible combination of vermiculite, beidellite and chlorite as well as weak random interstratification between the mica and vermiculite.

The SR-8 profile with high clay content from the Southeast Coast showed a very high concentration of kaolinite. It also showed the possibility of having an interstratification of vermiculite and beidellite, changing to vermiculite with depth (IIIC horizon). The SR-9 profile is sandy and appeared to have a higher proportion of beidellite than vermiculite, with some possibility of a montmorillonitic component.

The profiles from the east coast of Peninsular Thailand (SR-2 and SR-3) contain a typical combination of clay minerals for Gray Podzolic soils in this study (i. e., kaolinite dominated, followed by mica and interstratified 2:1 component with vermiculite and beidellite). The west coast profile (SR-4), however, showed composition of a different combination of clay minerals. Approximately the same amount of kaolinite, mica and random interstratification minerals were found in the SR-4 profile. The randomly interstratified mineral is composed of vermiculite (with beidellite) on one hand and micaceous clay minerals on the other. The peaks were at 11.2 Å and they appeared to drop substantially in peak height and spread somewhat when solvated with ethylene glycol.

Grain Mount Study

Study of the grain morphology and identification of the mineral assemblage was concentrated mainly in the heavy mineral fraction. The fractions under study were between 250 and 20 μ (fine sand, very fine sand and coarse silt).

Light Minerals

Study of the grain mounts and the thin sections indicated that quartz comprises nearly all of the light mineral fractions (< 2.88 specific gravity). The scarcity of feldspars was particularly noted. Only in profiles SR-1, SR-4 and SR-9 were feldspars positively identified. These are potash feldspars, either orthoclase or microcline, with a refractive index equal to, or slightly lower than, the Permount (approximately 1.52).

A series of counts in different fields of the microscope for the grain mounts of the various fractions (250-20 μ) indicated that the feldspar percentage (based on the grains which matched Permount refractive index) for the profiles with feldspars are as follow:

Profile	Depth (cm)	K-Feldspars (approx. %)
SR-1-2	5-11	14.0
SR-1-5	73-122	14.8
SR-4-1	0-7	4.4
SR-4-7	86-120	4.5
SR-9-1	0-19	12.5
SR-9-5	105-155	14.3
SR-9-9	265-280	23.6

In the light mineral fraction and particularly in the coarse silt fraction, opal phytoliths (Figure 24-B) occur throughout the soils in this study. These are probably from grasses and commonly have the shapes termed by Twiss et al. (1969) as elongate, spiny; oblong and rectangular of the Festucoid class. These opal phytoliths decrease with depth but thin section study revealed that they were present in many of the lower horizons. More detailed study is reported in the micromorphological section.

Heavy Minerals

The heavy mineral fraction of selected horizons (A, B and some C) from seven of the profiles was identified and counted with results shown in Table 10. The amounts of heavy minerals were reported on a frequency scale relative to the amount present. The frequency scale, as shown below, was used according to Evan et al. (1933) with a few additional designations. The scale simplifies comparison between samples and allows interpretation of the data in sufficient detail. The frequency numbers are in geometric progression except

Figure 24. Photomicrographs of grain mounts and thin sections of the Gray Podzolic soils (all under crossed nicols unless specified).

Grain Mount:

A. Green hornblende with siliceous coating, the coating has negative relief. SR-9 IIIC2 (265-280 cm). Plain light. 125X.

B. Example showing opal phytoliths found in this study. SR-1 A2 (5-11 cm). Plain light. 125X.
rectangular (1) fan shaped grain (2)
elongate-spiny (3) colored rectangular (4)
very faint potash feldspar grains (5), R. I. equal to mounting media (Permount, R. I. = 1.52)

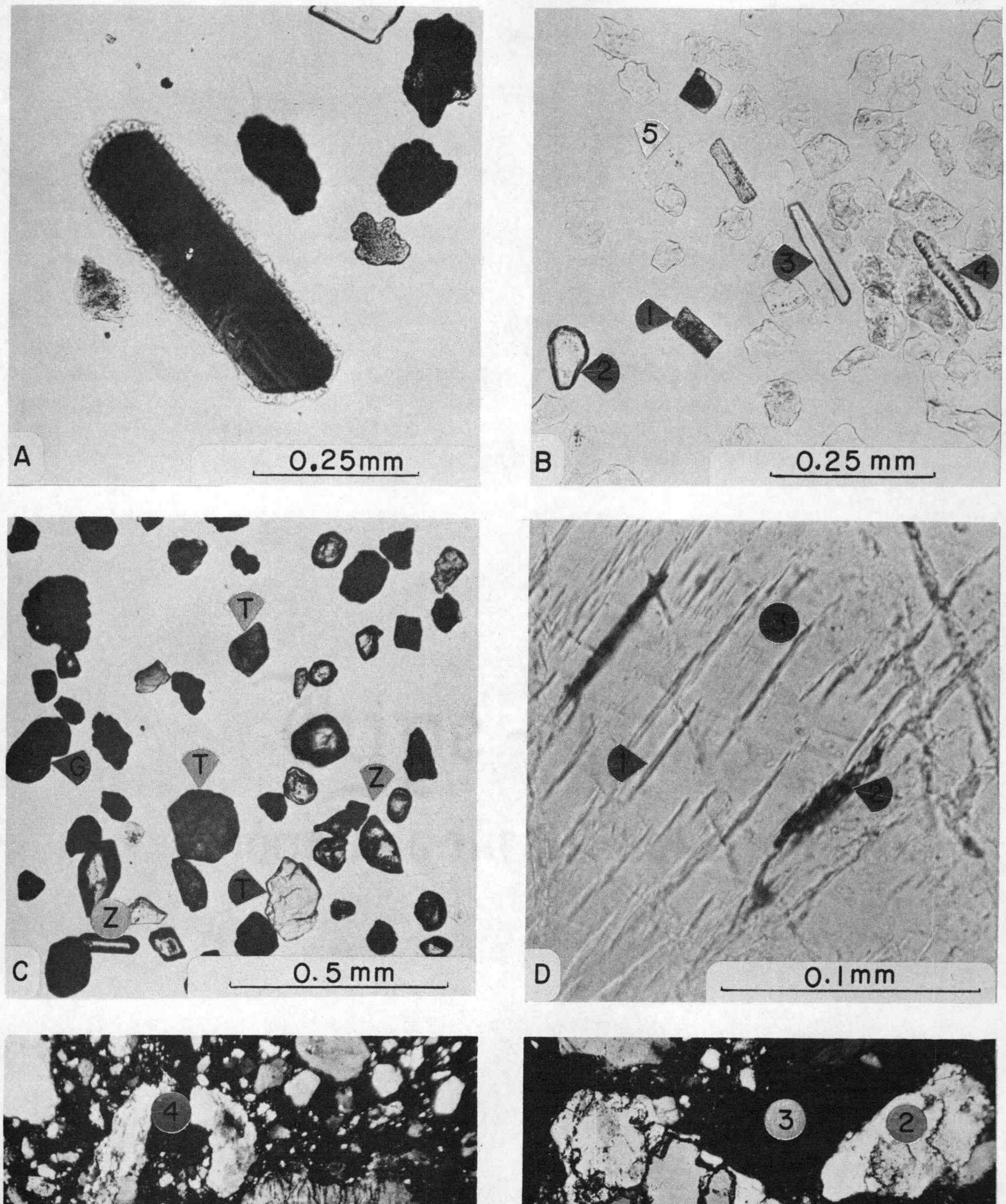
C. Typical heavy mineral assemblage in SR-5, B22t (119-147 cm). Plain light. 80X.
Tourmaline (T) Zircon (Z) Goethite-Hematite (G)

Thin Section:

D. Weathering along cleavage of potash feldspars in SR-1 A1 (0-5 cm), at 5 cm. Plain light. 500X.
High birefringence mineral along cleavage probably gibbsite (1). Iron oxides (2)
Feldspar grain (3)

E. Potash feldspars, relatively fresh (1), and weathered (2), in loose granular fabric with void (3) and quartzite grain (4) in SR-9 A2 (19-36 cm) at 25 cm. Plain light. 30X.

F. Ferruginous quartz grains (1), metamorphic (quartzite) grain (2) and void (3) in SR-1 B1 (11-40 cm) at 17 cm. 30X.


A
0.25mm
B
5
3
4
1
2
0.25 mm
C
T
G
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Z
T
Z
0.5 mm
D
1
2
0.1mm
E
4
1
2
3
1mm
F
3
2
1
1mm

Table 10. Relative frequency of the heavy minerals in selected horizons of the nine soil profiles.

Horizon	Depth (cm)	Non-iron oxide fraction[1]											Opaque minerals (mainly goethite)[2]
		Zircon	Tourmaline	Rutile	Epidote	Andalusite	Staurolite	Silimanite	Clinozoisite	Kyanite	Amphiboles	Altered minerals	
SR-1-2	5-11	7-	6+	-	5	3	3	-	3	-	3	4	6-
1-5	73-122	7	7-	-	6	4	2	-	4	2	4	4	8+
SR-7-1	0-6/10	7	7-	5	4	-	-	x	-	-	-	3	7
7-5	94-118	6+	7+	4	3	-	-	2	-	-	-	3	7+
7-9	235-270	7-	8-	3	-	-	-	2	-	-	-	2	8+
SR-5-2	8/12-40	7-	7	3	4	1	3	2	-	2	-	2	5
5-6	119-147	7-	7	3	3	-	-	2	-	3	-	3	7
SR-8-1	0-15	5	8	3	-	3	-	2	-	-	-	3	3
8-5	88-105	6+	8-	3	-	-	-	-	-	-	x	3	3
8-9	182-235	6	8	-	-	-	-	x	-	-	-	1	8+
SR-9-1	0-19	8-	6+	-	3	2	-	-	-	-	-	3	7
9-5	105-155	8-	6+	-	2	3	-	-	-	-	2	3	7
9-9	265-280	7	6+	4	2	x	-	-	-	-	5	4	8
SR-2-2	15-53	6+	7+	3	5	-	-	-	-	2	-	2	4
2-6	125-143	6+	8-	x	5	-	-	-	-	4	-	3	8
SR-4-1	0-7	4	8	2	-	-	3	-	-	-	-	4	6
4-7	86-120	5	8	3	-	2	-	-	3	-	-	4	7+

Note: Other minerals identified were brookite, apatite, sphene, monazite? and diopside.

x = present but not on counting transect; - = not present on slide

[1] Frequency numbers derived from percentage of grain count disregarding iron oxide grains.

[2] Frequency numbers derived from counts of iron oxides proportional to total heavy minerals.

for those lower than 3.

Frequency	Approximate percentage
8+	90-100
8	75-89
8-	60-74
7+	45-59
7	35-44
7-	28-34
6+	23-27
6	18-22
6-	14-17
5	7-13
4	4-6
3	2-3
2	1-2
x	present but not on the counting transect
-	not found on the slide

In all cases the non-opaque heavy minerals identified are dominantly zircon and tourmaline. A typical assemblage containing zircon and tourmaline is shown in Figure 24-C. The percentage of total heavy minerals was very small in all profiles, usually less than 1% in the upper horizons. A higher percentage (1 to 2%) of heavy minerals was found in the lower horizons from most of the profiles, due to the numerous red, iron oxide nodules of geothite or hematite in the plinthitic layers. It was found that magnetic minerals (magnetite) were almost absent in nearly all horizons studied. The small amounts observed were included in the opaque minerals.

Opaque Minerals (mainly geothite). The black or dark brown opaque grains were few except in the A horizon of SR-1 which had at least 10% of the weakly magnetic minerals. It may be maghemite. Loughnan (1969, p. 24) indicated that magnetite is unstable in a weathering environment and converted to a higher oxidized state of maghemite (black) or hematite (red). Red goethitic grains dominated throughout the profiles and increased with depth to 80-90% of the heavy mineral fraction in the lowest horizons. Their concentration is estimated through percentages of opaque grains against total heavy minerals.

Altered Minerals. Most of this group are mineral grains that are altered or covered with altering products. Positive identification was not possible.

The individual minerals identified are discussed below:

Zircon. Both fresh, euhedral and eroded, rounded grains were common. Larger grains (100-250 μ) were usually round or if elongated they had rounded ends.

Tourmaline. Prismatic and subrounded grains, strongly pleochroic, and with a variety of colors (green, brown, indigo blue) were present. Both clear grains and grains with strong parting were common.

Rutile. Generally prismatic to euhedral grains, deep yellow or reddish brown in color. This mineral is probably present in all horizons in a very small amount. Although in some slides its presence was not observed.

Amphiboles. Large, green relatively fresh tabular grains of hornblende that were in profiles SR-9, SR-1, and also in horizon SR-8-5 (88-105 cm), may have originated from different sources. In SR-9, the hornblende may have been derived directly from the metamorphic bedrock beneath the alluvium (at 280 cm). It may also have originated from more distant sources and been incorporated into the alluvial parent materials prior to deposition. Most of these large green hornblendes are coated with white vitreous material with somewhat low birefringence. A photomicrograph of a hornblende grain with coating is shown in Figure 24-A.

The metamorphic suites of epidote, andulusite, staurolite, silimanite, kyanite, clinozoisite and garnet are minerals associated with metamorphism of different rank and intensity. These minerals were distributed throughout all the profiles. The relative amounts appear to relate to the presence of metamorphic rocks in the areas (i.e., SR-1, SR-7, SR-5, SR-9 and SR-2).

Thin Section Study

Micromorphological study and descriptions were made of thin sections from oriented samples of seven to eight selected depths of profiles SR-1, SR-2, SR-3, SR-4, SR-5 and SR-6. For profiles SR-7, SR-8 and SR-9, thin sections were studied of at least 10 to 11 selected depths throughout the profiles. One aspect emphasized was the variability and weathering of the "skeleton" grains and the "matrix" or plasma (Kubiena, 1938, 1953, 1970; Brewer, 1960). Brewer (1964, p. 147) later proposed the term "s-matrix" to signify a matrix including skeleton grains to avoid confusion with terminology used in sedimentary petrology. Other aspects studied were the arrangement of soil fabric (Brewer and Sleeman, 1960; Brewer, 1964, p. 129) and pedological features leading to the understanding of the genesis of these soils.

The terms used in the descriptions are those of Brewer (1964). A glossary of terms used appeared in Stace et al. (1968, p. 15-22). Brief explanations of those terms used in this study are given in Appendix C for quick reference.

The format used for micromorphologic descriptions is shown below. The first horizon of each profile is fully described. Each subsequent horizon is then described with reference to characteristics of the first.

Profile:

Horizon - designation and depth

- nature and distribution of skeleton grains, plasma and voids
- plasmic fabric
- biogenic form
- pedological features (the presence of cutans, glaebules, pedotubules, and inherited features)

Notes: Overall trend and interpretation of profile features

North: SR-1 (San Pathong series)

A1 horizon (0-5 cm)

Skeleton grains. At 5 cm, dominantly very fine sand to fine sand quartz grains were observed throughout the profile. Most of the grains were angular and showed evidence of cracking into smaller grain size. About 5% of the grains were coarse to very coarse sand (0.5 to 2.0 mm) made up either of ferruginous quartz aggregates or quartzite (metamorphic) fragments with little or no iron cementation (Figure 24-F). Significant occurrence was noted of approximately 8 to 10% potash feldspars (coarse to medium sand), the grains were both relatively fresh and weathered (Figure 24-E). Occasional small (very fine sand) grains of zircon and tourmaline were found.

Plasma and Voids. General color of the plasma was yellowish brown. Overall packing was loose with numerous simple and compound packing voids and vughs. Orthovughs were common with some grain plucking type of voids due to the loose binding of the components. The plasma was generally composed largely of silt and fine sand size materials, randomly oriented, with low birefringence.

Plasmic Fabric. Intertextic with some areas of granular fabric (Figure 25-A).

Biogenic Form. Abundant opal phytoliths representative

Figure 25. Photomicrographs of thin sections showing fabric of the Gray Podzolic soils. (All under crossed nicols unless specified.)

A. Example of granular fabric in SR-1 (0-5 mm) at 5 cm showing void (1), K-feldspar grains (2), quartzite grain (3). 80X.

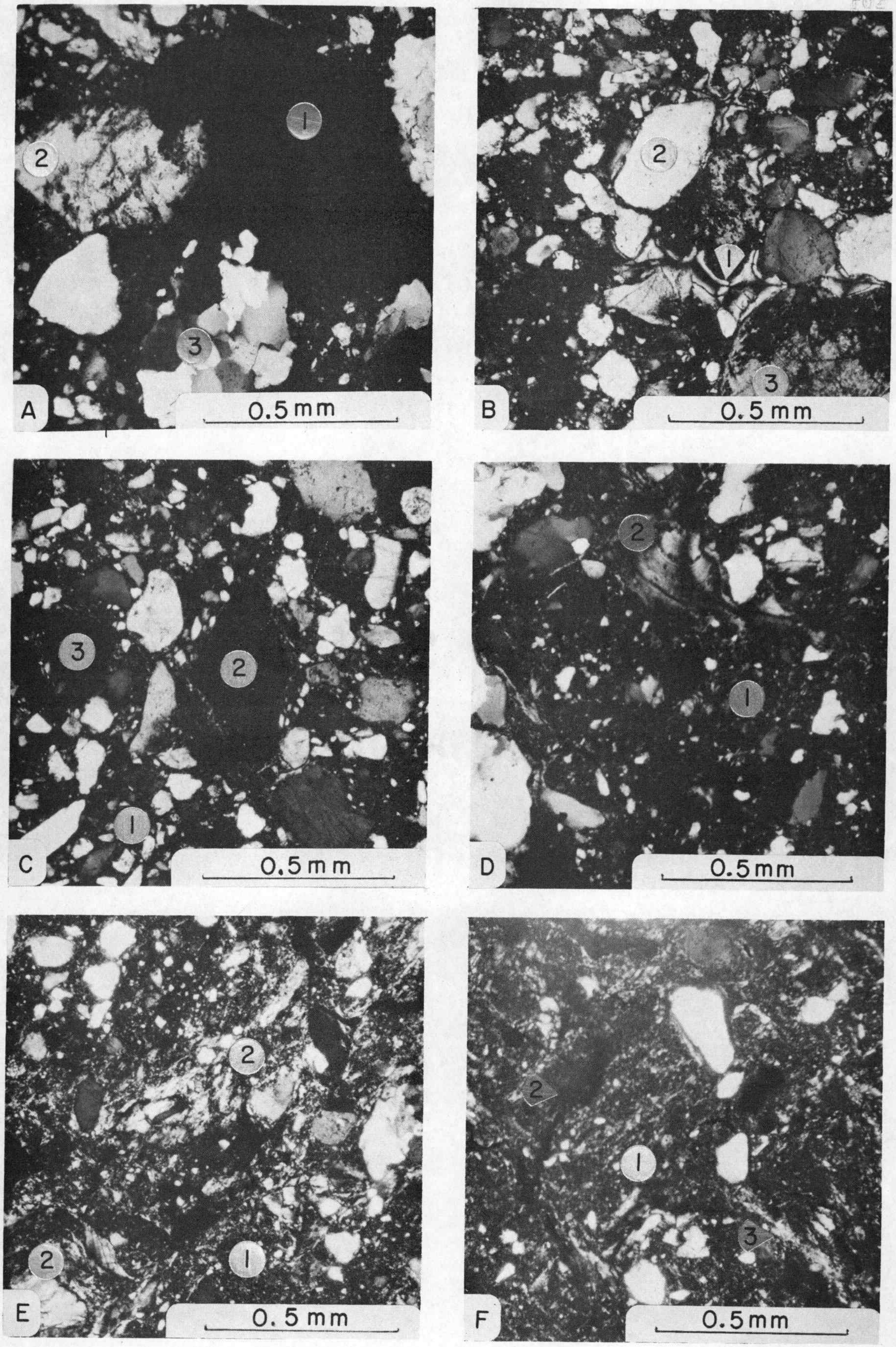
B. Example of intertextic (lower left) to silasepic prophyroskelic fabric (overall field) in SR-9 IIIC2 (265-280 cm) at 280 cm showing void ferri-argillan (1), quartz grain (2), iron oxide coated large grain (3). 80X.

C. Weak skelsepic in argilla-selasepic (3) plasmic fabric in SR-5 A22-B1 (10-53 and 53-72 cm). Skelsepic fabric is around quartz grain at extinction (1) and void (2). 80X.

D. Skel-vo-ma-insepic prophyroskelic plasmic fabric (1) with alternate bands of yellowish brown argillan and reddish brown ferri-argillan (2) in SR-1 B3 (72-112 cm) at 112 cm. 80X.

E. Ma-skel-vo-mosepic porphyroskelic plasmic fabric (1) with many neoferri-argillans mixed in with neo-argillans (2) in SR-7 IIC2 (235-270 cm) at 270 cm. 80X.

F. Masepic to omnisepic fabric (1) with iron oxides staining all pores and channels (2), stress argillan (3) in SR-8 IIIC2-1 (165-185 cm) at 185 cm. 80X.


1
2
3
A
0.5 mm
2
1
3
B
0.5 mm
3
2
1
C
0.5 mm
2
1
D
0.5 mm
2
2
1
E
0.5 mm
2
1
3
F
0.5 mm

common forms are shown in Figure 24-B. Common small specks of humified organic matter. Most of the large relatively fresh plant remains (largely roots) were somewhat humified and occurred outside (i.e., separated from the s-matrix).

Pedological Features. Loose packing of the matrix throughout. Only a few lithorelict fragments of shale or phyllite and lithopedorelict grains of ferruginous quartz were found. Feldspars showed parallel lines of slight weathering along cleavage traces, with the formation of greenish colored mineral which was probably gibbsite. Presence of iron oxides (goethite) or hematite was also indicated in the same manner (Figure 24-D).

B1 horizon (11-40 cm)

At 17 cm, the components were similar to the above horizon but with less voids (vughs). Plasmic fabric showed more orientation and increase in proportion of plasma with less voids (i.e., intertextic with increasing areas of argilla-silasepic fabric).

Opal phytoliths were still abundant, more signs of cracking of quartzite grains and clearly showed stronger weathering along cleavage of feldspar. Some void argillans of low birefringence.

At 28 cm, more compact arrangement with ortho and metavughs, still abundant opal phytoliths. Grayish brown colored plasma was weakly oriented with a few clusters of sepic fabric with low birefringence. Plasmic fabric changed to silasepic with some areas of vo-skelsepic porphyroskelic fabric. Organic matter was mostly humified. Common void argillans throughout.

B2t horizon (40-73 cm)

At 59 cm, essentially the same components as above, but more porous with numerous voids, ortho and metavughs and channels. Increase in the percentage of larger quartz grains (metamorphic quartzite type). Cracking of these quartzite grains was common. Feldspar grains were strongly weathered. Argillans were mainly void or channel linings with some observed on grains.

At 69 cm, similar as above but voids were obviously reduced. Much physical breaking of large composite grains to small size. These broken grains together with argillans appeared to have filled most of vughs and voids. Some of argillans were stained with sesquioxides producing ferri-argillans with redder color. Plasmic fabric was silasepic to in-vo-skelsepic porphyroskelic.

B3 horizon (73-122+ cm)

At 112 cm, skeleton grains were mainly large quartzite fragments with less cracking. Silt and clay which resulted from earlier breaking of skeleton grains, together with argillans or ferri-argillans, made up the dominant plasma components in this horizon. Much filling of voids, vughs, channels and craze planes by argillans was indicated. Red stained spots of mottled clay or sesquioxidic nodules with somewhat diffuse boundaries increased with depth. Papules and humified plant remains were common. Argillans always had low birefringence unless mixed with iron oxides to form reddish brown neoferri-argillans. Banding of neoferri-argillan and plain argillans are shown in Figure 25-D.

Notes. Throughout the profile, proportions of skeletons and voids are important down to the B3 horizon. Relatively more compact layers (less simple and compound packing voids) are found in the B1 horizon with vugh type of pore spaces. At the top of the B2, porosity increases somewhat with skelsepic fabric and skeletans (embedded grains) and with some papules. This horizon therefore, shows some degradation which may be similar to what Bullock (1968) described in New York soils as the deterioration of the top of the B horizon by clay removal rather than clay destruction. Less argillans were visible in this layer and activity of organisms is shown by many smoothed metavughs and some mamillated vughs.

In the lower B horizons, there is more evidence of cracking and forming of plasma *in situ*, with smaller particles of very fine sand, silt and clay. Porosity is decreased with prominent filling of pores, vughs and channels attaining its highest degree in the B3 horizon. Formation of plinthite is also strongly evident in this lower part of the profile conforming with the fluctuation of the water table.

Throughout the profile, angularity of the quartz grains indicates that they were broken in situ by pedogenic processes. The presence of ferruginous quartz grains (Panichapong, 1965; Ketudat, 1966) suggest either a derivation from a previously existing soil with iron accumulation as a laterite-like formation, or weathering from rocks with high iron content. Thus the origin may be pedo- or lithorelict.

The increase of sepic and porphyroskelic fabric in the lower horizons indicates the formation of the clay in situ plus evidence of illuviation from horizons above to form an argillic horizon. It also shows the increase of plasma with depth together with filling of vughs and channels formed by plant remains (roots), and activity of organisms, such as worms, termites, ants, etc.

Northeast: SR-7 (Korat series)

Ap horizon (0-6/10 cm)

Skeleton grains. At 11 cm, skeleton grains were mainly quartz of very fine sand and fine sand. Quartz grains were mostly angular and clean, but there were some with cloudy specks of iron oxides and some with strained extinction (metamorphosed).

Plasma and Voids. Yellowish brown colored plasma of very fine sand and silt usually concentrated around skeleton grains with weak plasma separation. Voids were mostly simple packing voids with many vughs, including the "pluck grains" type.

Plasmic Fabric. Intertextic to silasepic porphyroskelic.

Biogenic Form. Non-humified plant remains, mainly twigs and roots, occurred outside of the s-matrix. The humified plant remains were made up of small reddish specks throughout the plasma. Opal phytoliths were common throughout.

Pedological Features. A few sesquioxidic nodules occurred as diffuse clumps associated with the humified organic matter. Some shale or phyllite grains together with a few chert grains were considered lithorelicts.

A2 horizon (6 /10-34 cm)

At 15 cm, similar to above but with more argilla-silasepic plasmic fabric together with some areas of weak skelsepic porphyroskelic. Plant remains were mostly humified. Voids were mostly of vugh type, occurring as irregular, random and some interconnected vughs forming channels. Cutans with low birefringence appeared in the lower part of the horizon mainly as void and channel argillans. Some chert and phyllite fragments and a few papules were found.

At 34 cm, approximately 60% of the quartz grains were very fine sand to fine sand size. Voids were numerous (30-40%) mostly as interconnected vughs. Plasmic fabric was skel-vo-insepic porphyroskelic with some areas of silasepic fabric. Low birefringence argillans were common in pores and channels and as ped or grain coatings, and increased with depth. Some colloform coatings with positive relief showing weak birefringence occurred in voids and εs. Those coatings also occurred in other profiles (usually in the B horizon), and may be a kind of chalcedony or even a precursor of some kind of clay minerals (Figure 26-D).

B1 horizon (34-62 cm)

At 52 cm, similar to the above horizon but with a marked increase in compaction of the plasma. Less simple packing voids were observed together with an increase of argillans. Porosity in this horizon was mainly due to ortho and metavughs (smoothed). Opal phytoliths were still quite common. Plasmic fabric was sila-sepic to vo-insepic porphyroskelic.

At 62 cm, more common neoferri - argillans, mainly in pores, vughs and channels. Common indications of colloform coating in vugh interiors.

B21t horizon (62-94 cm)

At 89 cm, general appearance was more porous than above horizon, with less quartz grains larger than very fine sand. Vugh-type voids were dominate. Neo-argillan and neoferri-argillans increased, filling up channels, planes and vughs. Sila-argillasepic fabric occurred in some areas but the fabric was mostly skel-vo-insepic porphyroskelic. A few opal phytoliths and iron stained quartz grains were present.

Figure 26. Photomicrographs of thin sections showing fabric and other features of the Gray Podzolic soils. (All under crossed nicols unless specified.)

A. Compact A2 horizon with silasepic to skelsepic porphyroskelic fabric. Notice the majority of finer grains. In SR-4 A2 (13-28 cm) at 26 cm. 80X.

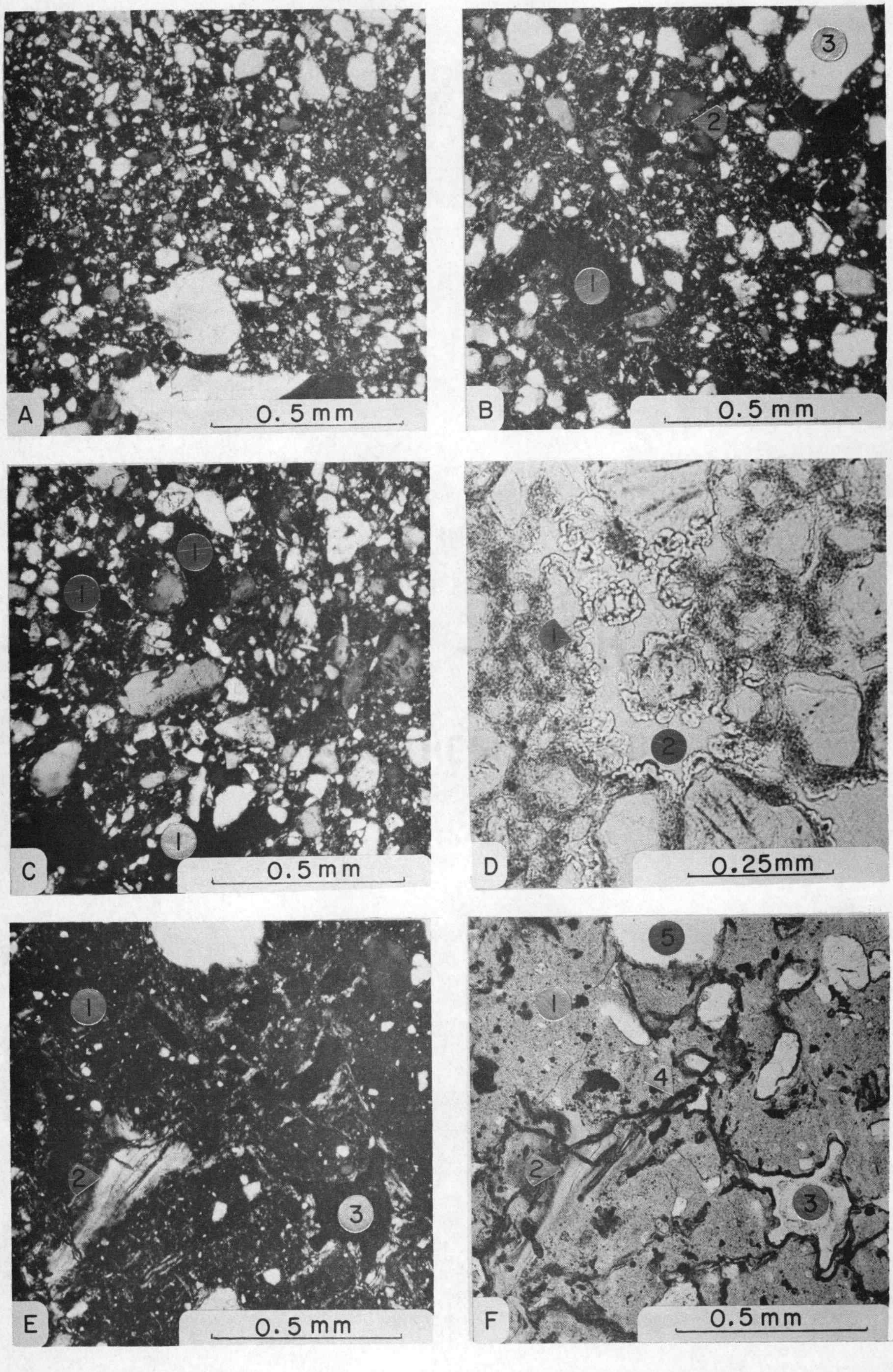
B. Less compact B horizon with increase in vughs (1), in bright yellow plasma of vo-skel-mosepic plasmic fabric. In SR-4 B21t (41-68 cm) at 50 cm. Skelsepic plasmic (2) and quartz grain (3) are indicated. 80X.

C. Example of metavughs (1) dominant in sila-argillasepic skelsepic porphyroskelic fabric. In SR-6 B22t (39-70 cm) at 44 cm. Plain light.

D. Colloform coating (1) lining vughs (2), probably with chalcedony composition (positive relief). In SR-2 B1 (53-67 cm) at 63 cm. Plain light. 125X.

E. Plinthitic layer with almost inundulic ground mass (1). The neoferri-argillan coating (2) of void (3). Redder coating of ferran (4) is indicated. In SR-8 IIIC1 (140-165 cm) at 165 cm. 80X.

F. Similar to E but with plain light. Identified are dark area of coating ferran (4), brown plasma of clay minerals (1), laminated argillan (2) and void (3). 80X.



A
0.5 mm
B
1
2
3
0.5 mm
C
1
1
1
0.5 mm
D
1
2
0.25 mm
E
1
2
3
0.5 mm
F
1
2
3
4
5
0.5 mm

B3 horizon (130-198 cm)

At 155 cm, similar with above, but with more mottled spots or sesquioxidic nodules with diffuse boundaries. The amount of argillans increased. The plasmic fabric was argilla-silasepic to mo-vo-skel-insepic porphyroskelic.

At 197 cm, similar to above, but there were more iron oxide stains. Sesquioxidic nodules and papules were common. Some of the skeleton grains were less angular with embedded grain argillans.

IIC horizon (198-270 cm)

At 235 cm, increased content of iron oxides as clumps of sesquioxidic nodules or "mottled spots." The cutans were mostly reddish brown ferri-argillans and yellowish brown argillans, with some reddish ferrans. Papules were common and there were some vughs but much less voids due to increased proportion of plasma. A few opal phytoliths and zircon, tourmaline and chert grains were present. The plasmic fabric was ma-skel-vo-mosepic porphyroskelic.

At 270 cm, similar to above and overall color was still yellowish brown. Segregation of sesquioxidic nodules were moderately strong. Skeleton grains were much less common and most were very fine sand and coarse silt. Colloform coatings were present in vughs and channels, and papules were common at this depth. An example of plasmic fabric with sesquioxidic coatings is shown in Figure 25-E.

Notes. Throughout the profile, skeleton grains and voids dominate down to the lower B horizon (94-130 cm) where plasma, together with argillans and color mottling (sesquioxidic nodules with diffuse boundary) becomes dominant. A compact layer occurs in the B1 (52 cm) where the loose packing with intertextic and simple to compound packing voids of the A change to irregular and smooth metavughs. The top of the B2 is more porous with mostly a vugh type of pore spaces. The upper B2 thus may be the most intensely weathered and degraded portion of the B horizon. The lower B2t and B3 horizons show a concentration of plasma (in situ clay and illuviated clay). The abrupt increase of clay content, and much lower porosity in materials at 235 cm, otherwise similar in general organization, suggest stratification of the old alluvial deposit.

The upper horizons with a low proportion of plasma strongly displayed intertextic fabric. Gradual increase of clay domains (Aylmore and Quirk, 1959) in asepic fabric with depth indicates the increase in reorganization of clay by differential movement of porphyroskelic fabric and changing of the plasma separation to the more oriented sepic fabric type in the Bt horizons. The formation of sepic fabric suggests reorganization of clay domains by differential movement due to irregular wetting and drying (Brewer, 1964; Brewer and Sleeman, 1969). Sesquioxidic nodules and argillans are more prominent in the B3 and C horizons.

Northeast: SR-5 (Korat series)

A2 horizon (8/12-40 cm)

Skeleton grains. At 20 cm, quartz dominated, with angular, clean grains of very fine sand to fine sand. Few small zircon and tourmaline grains and a few large ferruginous quartz grains also present.

Plasma and Voids. Yellowish brown plasma with frequent spots of organic matter remains. Abundant simple and compound packing voids.

Plasmic Fabric. Intertextic to sila-argillasepic.

Biogenic Form. Most small organic materials were humified into reddish spots, with some charcoal and plant remains of roots and twigs. Abundant opal phytoliths.

Pedological Features. Presence of a few ferruginous quartz grains.

B1 horizon (53-72 cm)

At 55 cm (also covering boundary of A22 and B1 at 53 cm), similar to above but with argilla-silasepic to weak skelesepic porphyroskelic fabric (Figure 25-C). Large quartz grains were subrounded and usually ferruginous. Very few threads of muscovite. Some papules and a few argillans in pores and channels. At the A22/B1 horizon boundary, the A22 was more dense.

At 61 cm, similar to above but with more cutans, and a stronger skelsepic fabric. The cutans were mainly embedded grain argillans and stress argillans.

B21t horizon (72-119 cm)

At 89 cm, less porous and an increase of meta and irregular to interconnected vughs. Colloform coatings present on vugh walls and argillans in voids (vughs) and channels.

At 98 cm, the arrangement of the s-matrix became denser (i.e., appeared to have less vughs). Most of the skeleton grains were very fine sand. Opal phytoliths were still common. Vo-skelsepic porphyroskelic fabric still dominated but with an increase of sila-argillasepic fabric, particularly in the denser areas. Papules, sesquioxidic nodules and shale or phyllite fragments increased.

B22t horizon (119-147 cm)

At 128 cm, as dense as the above horizon, but with more plasma separation and vo-skel-insepic porphyroskelic plasmic fabric. Low birefringence plasma was dominant, with brighter birefringence only in areas where sesquioxide mottled spots were present.

At 138 cm, porosity increased mostly from more ortho and metavughs, approximately 40% of them interconnected and irregular. Plasma separation was still insepic with many embedded grain cutans. Most of the fabric was mo-vo-skel-insepic porphyroskelic. Opal phytoliths were still present. Many small chunks of sesquioxides and a few large sesquioxidic nodules were observed.

Notes. The micromorphological characteristics of this soil are somewhat similar to profiles earlier discussed (SR-7 and SR-1). Plant opal persists deep in the profile, at least to the B3 or C horizons. It does, however, decrease sharply below the surface horizon. Skeletons and voids again constitute most of the upper horizons. Clay and silt components of plasma increases below 89 cm in the B21t. Argillans are sparse in the B horizons. This may be a reflection of higher rainfall in this area as compared to SR-7 and may indicate degradation of argillic horizon as stated by Bullock (1968).

A compact zone is present at about 100-128 cm between the upper and lower zones of loose and porous s-matrix. The compact zone is indicated by the silasepic vo-skelsepic fabric, as opposed to strong plasma separation of the lower horizons (mo-vo-skel-insepic fabric). The presence of ferruginous quartz grains in this profile again may be pedo-relict evidence for sedimentary origin of iron rich formations in this soil.

Northeast: SR-6 (Renu series)

Ap horizon (0-5/7 cm)

Skeleton grains. At 7 cm, quartz grains were very fine sand

and coarse silt (i. e., finer grained than other profiles) with a high silt content (40 to 45%). Quartz grains were mostly angular and mostly stained with iron oxides.

Plasma and Voids. Yellowish colored plasma of silt and clay with specks of iron oxide and organic matter. Voids were simple packing voids with many smoothed, elongate metavughs formed around organic remains.

Plasmic Fabric. Argilla-silasepic to intertextic.

Biogenic Form. Many fresh roots and twigs, etc. Abundant opal phytoliths with various shapes in addition to simple rectangular ones.

Pedological Features. Some chert and shale fragments were observed but no cutans.

A2 horizon (5 /7-17 cm)

At 14 cm, abundant opal phytoliths; much less organic remains; sesquioxidic nodules with diffuse boundaries (i. e., mottling spots) increased with depth. Fabric was intertextic to silaseptic with simple packing voids and ortho and metavughs that were mostly smoothed. Cutans were common in pores and channels and were usually reddish brown (ferri-argillans).

B21t horizon (17-39 cm)

At 20 cm, essentially similar to above, but skelsepic and vo-sepic plasmic fabric increased with less intertextic fabric. The fabric tended toward weak porphyroskelic. Colloform coatings were common throughout in vughs and channels. Reddish brown ferri-argillans with embedded grains occurred throughout. Organic matter was more humified and occurred as reddish, sesquioxidic nodules throughout the s-matrix.

At 31 cm, similar to above but with more diffuse mottled spots and more vughs and vugh argillans.

B22t horizon (39-70 cm)

At 44 cm, the plasmic fabric was sila-argillasepic skelsepic porphyroskelic. Increased mottles or nodules, largely of goethite.

At 53 cm, more colloform coatings. The plasmic fabric was more skelsepic and vo-sepic, in areas where plasma predominated over voids, some insepic fabric was indicated.

Notes. The SR-6 profile is very similar to profile SR-5. Since it occupied a lower position in the landscape, and is less well drained, sesquioxidic nodules occurred higher in the profile and were more abundant. SR-6 also has a higher concentration of silt. The formation of this soil is therefore similar to SR-5. The higher concentration of organic matter in the upper horizons is reflected in a high CEC per 100 g clay (82.6 vs 44.2 me/100 g clay of SR-5).

The soil is not so porous as SR-5 and smooth metavughs dominate throughout, especially in the B horizon (Figure 26-C).

Southeast: SR-8 (Huai Pong series)

Ap horizon (0 - 15 cm)

Skeleton grains. At 8 cm, quartz grains were larger than in other profiles studied, mainly coarse sand and very coarse sand, and in most of these grains were clear (a reflection of granitic rocks with large quartz grains in the area). A few of these large grains were streaked with iron oxides, probably as coatings. These ferruginous grains differ from those in SR-1, since the grains were not like quartzite fragments. Common small tourmaline and zircon grains were indicated throughout.

Plasma and Voids. Yellowish brown, low birefringence plasma of silt and clay with moderate orientation and plasma separation (stronger than in other profiles in this study). Voids were mainly simple with a few compound packing voids and a few orthovughs and smoothed metavughs.

Plasmic Fabric. Ma-vo-skel-insepic with some argillasepic.

Biogenic Form. Abundant plant remains, mainly roots and twigs, these somewhat humified remains were reddish and still showed plant structure clearly. Common phytoliths throughout.

Pedological Features. Few red, diffuse nodules of humified organic remains and ferruginous quartz grains and stronger separation of plasma, as earlier stated.

A2 horizon (15-25 cm) and B21t horizon (25-53 cm

At the boundary between the A2 and B21t (23 to 26 cm), the A2 (upper portion of the thin section) appeared similar to the above horizon, but with fewer plant remains. In the upper B2 horizon (lower portion of the thin section) plant remains were less and the plasmic fabric was better oriented, with clay skins in pores and channels. Voids also were fewer than in the A2 horizon. The plasmic fabric, in some parts, was better arranged and tended toward mosepic, but in the main bulk of the low birefringence plasma, argillasepic fabric was still common. The basic components, in order of dominance, were skeleton, plasma, voids and organic remains. Low birefringent argillans lining the voids, vughs and channels, with some embedded grain (skeletans) were common throughout the B2 horizon.

At 39 and 48 cm, the plasmic fabric was ma-skel-vo-mosepic porphyroskelic. Colloform coatings occurred occasionally in vughs and channels. At 48 cm, the appearance was more porous due to the increase of vughs, and there were more reddish brown ferri-argillans.

B22t horizon (53-88 cm)

At 76 cm, similar to above horizon but distribution of the matrix was more cutanic, and plasma was more homogenous and more oriented, forming skel-vo-ma mosepic porphyroskelic fabric. Abundant argillans and ferri-argillans as well as many papules. Locally, plasma and cutans dominated over skeleton grains.

IIB31 horizon (88-105 cm) and B32 horizon (105-140 cm)

At 130 cm, intensified distribution of sesquioxides with reddish spots of goethite (or hematite) everywhere. Colorless colloform coatings present in voids and vughs. The number of voids was less than above and many were filled by ferri-argillans, as well as localized in situ weathered clay and iron oxide impregnated clay. Papules and sesquioxidic nodules with diffuse boundaries were common throughout (weak plinthite layer).

IIIC1 horizon (140-165 cm)

At 160 cm, all channels, pores and planes were lined with or filled with sesquioxidic clay and therefore, strongly indicated the plinthite layer. Figure 26-E and F indicate such a plinthitic layer. Fabric was skel-vo-clino-bimasepic porphyroskelic. Birefringence was very low to almost inundulic (isotropic) due to the high percentage of kaolinitic clay and sesquioxidic materials. Birefringence increased only within the oriented parts of the ferri-argillans. Phytoliths were few to absent.

IIIC2 horizon (165-235 cm)

At 185 cm, there were stronger indications of the plinthite layer as found in above horizons. Masepic fabric was prominent throughout (Figure 25-F), some areas fit the description of omnisepic fabric. In the parts not affected by iron stains, the very low birefringent clay could be distinguished as pore argillans and grain cutans, or as papules. The ferri-argillans (or sesquans) because of their reddish brown color were more clearly shown. The plasmic fabric and cutanic condition were difficult to determine in areas completely stained red by the sesquioxides.

At 235 cm, the size and amount of red stained portions increased and argillans and sesquans filling channels and pores were more common. Density was similar to the above horizon with only a few unfilled vughs and channels.

Notes. The skeleton grains and voids dominate in the upper horizons above the B21t (25-53 cm). Plasma with strong separation of plasmic fabric dominated in the lower horizons. Plasma is significant down to the plinthite layer at about 160 cm. The ferruginous quartz grains, though different in morphology, probably had a similar pedogenic origin from earlier, iron oxide rich formations, as the ferruginous grains of profiles SR-1 and SR-5. Illuviation of the clay in the argillic horizon was quite distinct. In the lower portion of the profiles, where sesquioxidic components dominate, cutans and other pore filling materials, oxide diffusion may be active as well as illuviation (Brewer, 1964, p. 231).

The concentration of clay with low birefringence bears out the estimated 90% content of kaolinite in this profile as determined by D. T. A. and X-ray analyses.

Southeast: SR-9 (Sattahip series)

Ap horizon (0-19 cm)

Skeleton grains. At 13 cm, medium to fine sand size quartz dominated with some very coarse sand quartzite grains. Abundant silt size opal phytoliths and a few zircon and tourmaline grains were observed. Medium sand size potash feldspars (approximately 8 to 10%) were also noted. Many quartz grains were shattered. A few chert, shale or phyllite fragments were also present.

Plasma and Voids. Very porous yellowish plasma of silt and very fine sand was loosely packed in the s-matrix. Voids were of simple packing types with a few metavughs. Common skeletons of various sizes were throughout the matrix.

Plasmic Fabric. Intertextic to silasepic porphyroskelic.

Biogenic Form. Common organic remains, largely roots. The numerous sesquioxidic specks may have originated in connection with humified materials. There were abundant opal phytoliths in this horizon.

Pedological Features. A few shale or phyllite fragments and sesquioxidic nodules occurred in this horizon. Feldspar grains were both fresh and weathered (Figure 24-E). Cleavage weathering of feldspar, probably to gibbsite and some goethite, is shown in Figure 24-D.

A2 horizon (12-36 cm)

At 25 cm, similar to above, slightly redder with about 8 to 10% feldspar and many cloudy, reddish grains of phyllite fragments. Plasmic fabric was intertextic to weak vo-silasepic porphyroskelic.

B21t horizon (36-68 cm)

At 46 cm, similar to above but with an overall increase in reddish colored plasma. Fabric was mostly silasepic porphyroskelic with some areas of weak vo-skelsepic fabric. Few cutans in pores and channels.

B22t horizon (68-105 cm)

At 80 cm, similar to above but more porous; probably due to the increase of micropeds with compound packing voids. The plasmic fabric was intertextic to porphyroskelic.

At 84 cm, similar to above.

B23 horizon (105-155 cm)

At 130 cm, similar to above but with more large skeleton grains of quartzite fragments. Feldspar grains appeared to be strongly weathered with cracked grains. The plasmic fabric was intertextic to weak skel-vosepic porphyroskelic.

B3 horizon (155-210 cm)

At 175 cm, better plasma separation so that plasmic fabric was weak silasepic to vo-skel-insepic porphyroskelic. More common sesquans (or goethans ?). Feldspar grains were mostly cracked and small. Opal phytoliths were absent; a few rounded sesquioxidic nodules.

IIC1 horizon (210-265 cm)

At 225 cm, a gravelly horizon, mostly with skeleton grains of quartzite fragments coated with plasma of silasepic materials (i. e., intertextic) with skelsepic porphyroskelic fabric. Cutans were probably absent, only few embedded grain argillans occurred.

At 265 cm, similar to above.

IIIC2 horizon (265-280 cm)

At 280 cm, this horizon was not gravelly as above but was similar to the B3 horizon (155-210 cm). Common sesquans in voids and channels with many filled channels. Fabric was intertextic to weak silasepic porphyroskelic (Figure 25-B). The oriented argillans, when not mixed with sesquans, show very low birefringence.

Notes. The basic structure of this soil shows a dominance of skeleton grains throughout the profile. At 210-265 cm (IIC1), a gravelly horizon, largely of quartzite fragments, signifies the stratification of this alluvial deposit. Locally, some insepic fabric may be found, most of the plasma separation is asepic to intertextic. Argillans or sesquans do not occur consistently throughout B horizons and are important only in the lowest horizon studied, the IIC2 (265-280 cm). Feldspars appeared cracked and weathered in the B horizons. The soil color was redder than others in this study but there was no plinthite layer in the lower part of the profile.

South: SR-2 (Kho Hong series)

Ap horizon (0-15 cm)

Skeleton grains. At 9 cm, the majority of quartz grains were very fine sand and fine sand. Skeleton grains were dominant in the horizon and occurred close together, giving the impression of no or very little plasma. Quartz grains were always cracked and mostly angular.

Plasma and Voids. Grayish plasma of loosely packed fine sand, very fine sand and silt. Numerous normal simple and compound packing voids.

Plasmic Fabric. Intertextic to silasepic porphyroskelic; granular in some areas.

Biogenic Form. An abundance of opal phytoliths and many non-humified plant remains outside of the s-matrix.

Pedological Features. A few shale or phyllite fragments. Many of the quartz grains were stained with iron oxides and similar to the ferruginous grains in profile SR-8.

A2 horizon (15-53 cm)

At 21 cm. similar to above horizon; a few faecal pellets were observed.

B1 horizon (53-67 cm)

At 63 cm, more vughs but still retained the crowded effect on plasmic fabric. Argillans and/or sesquans were in pores and channels. Plasmic fabric was sila-argillasepic to weak vo-skelsepic porphyroskelic. Abundant opal phytoliths, zircon and tourmaline were also present. Colloform coatings of colorless, positive relief materials (chalcedony?) were observed in vughs, voids and channels.

B2t horizon (67-91 cm)

At 81 cm, similar to above but appeared to have more voids and vughs.

At 92 cm, similar to above, but more porous, due to increasing of vughs, many of the metavughs may be from grain plucking. A few argillans or sesquans occurred in voids and channels. Some large ferruginous quartz grains were also present. More skeletans in the lower part of the horizon.

B22t horizon (91-125 cm)

At 114 cm, this horizon had a reddish color throughout. Skeletons of angular, mostly clean quartz grains were crowded together. Argillans were important throughout and had low birefringence, unless mixed with oxides to form ferri-argillans or sesquans. Plasmic fabric was silasepic to weak skel-vosepic. This horizon resembled a weak plinthite layer.

At 120 cm, similar to above, but appeared to have more sesquioxidic nodules with diffuse boundaries. Large vughs were filled with ferri-argillans and most of the grains were coated with sesquans and indicated as part of the skelesepic plasmic fabric. The plasmic fabric was silasepic to vo-skelsepic porphyroskelic. A few opal phytoliths were observed. The sesquioxidic nodules, showing as spots of red and yellow throughout the horizon, indicated characteristics of a phinthite layer.

Notes. The cracking and abundance of fractured quartz of all sizes is notable in this profile. Skeleton grains of fine sand are associated with a mixed ("dirty" looking) plasma of very fine sand, silt and clay. Opal phytoliths decrease with depth, but are still observable in the lower part of the profile (120 cm). The presence of many sesquioxidic nodules with diffuse boundaries in the lowest horizon (91-125 cm) is similar to plinthite layers in profiles SR-1 and SR-8.

South: SR-3 (Nam Krachai series)

Ap horizon (0-17 cm)

Skeleton grains. At 15 cm, grain size, shape and fracturing of quartz grains were similar to SR-2. Most of quartz grains were clean (i. e., not ferruginous).

Plasma and Voids. Loose packing of dark gray plasma mixed with fine sand and silt size quartz grains. Numerous simple packing voids, ortho and metavughs.

Plasmic Fabric. Intertextic to weak silasepic fabric.

Biogenic Form. Abundant plant remains with large roots outside of s-matrix and smaller roots in the s-matrix, humified throughout the horizon. Opal phytoliths were quite abundant.

Pedological Features. Some rounded nodules, possibly of iron or manganese oxide. Many of these nodules were black in reflected light.

A2 horizon (17-35 cm)

At 20 cm, similar to above horizon.

B1 horizon (35-63 cm)

At 63 cm, similar to above, but with intertextic grading to skelsepic porphyroskelic plasmic fabric. Colloform coatings in vughs and channels. Argillans in channels and vughs as well as coating grains.

At 71 cm, similar to above, but with a more compact appearance, probably due to the increase of vughs instead of simple packing voids. Low birefringence argillans clearly indicated on vugh surfaces and around skeleton grains. Plasmic fabric was silasepic to vo-in-skelsepic porphyroskelic.

B22t horizon (89-120 cm)

At 104 and 112 cm, an increase in sesquioxidic nodules with diffuse boundaries typical of a plinthite layer. Portions of yellow and red sesquioxide stained plasma throughout the entire horizon. Fine and very fine sand and silt size grains were still dominant in the plasma. Low birefringence argillans filled most of pores and vughs, particularly in the yellow colored portions. Argillans had a somewhat higher birefringence and redder color in the red, iron stained portion. No other differences were observable in the components of the red and yellow portions.

Notes. This profile is very similar to the SR-2 profile above, but less well drained and with somewhat higher silt content. This relationship is similar to that between profiles SR-5 and SR-6. Skeleton grains mixed with a very fine sand, fine sand and silt matrix were important throughout. Although the fluctuation of the water table left its mark higher in this profile, the position of mottled clay or the plinthite layer is still at about the same level of approximately 1 m as in the SR-2 profile.

South: SR-4 (Kho Hong series)

A2 horizon (13-28 cm)

Skeleton grains. At 16 cm, large, very coarse to coarse sand size quartz grains were found, these quartz grains were mainly quartzite fragments. Most of the skeleton grains, however, were very fine sand size. Feldspar grains of medium sand size and finer were present in this profile (approximately 4 to 5%). Occasional zircon, tourmaline and some very small muscovite grains were found throughout.

Plasma and Voids. Yellowish brown plasma with a strong concentration of silt and very fine sand. Simple packing voids dominated with a few channels and smoothed vughs.

Plasma Fabric. Silasepic porphyroskelic.

Biogenic Form. Opal phytoliths were frequent. Few large fragments of plant remains but common small humified dark brown specks throughout the horizon.

Pedological Features. Cutans were found in spots on peds and mainly as pore linings. Ferruginous quartz grains also were found.

At 26 cm, an increase of vughs, and more compact than above (Figure 26-A). In some of the smoothed vughs remnants of the plant roots were still visible. Argillans increased and became largely ferri-argillans (reddish brown in color). Plasmic fabric was silasepic to moderately strong skelsepic porphyroskelic.

At 29 cm, similar to above, and vughs nearly always had void ferri-argillans. Some of these filled, smoothed vughs were probably pedotubules (earthworm tubes or other voids formed around organic remains).

B1 horizon (28-41 cm)

At 40 cm, similar to above with increased ferri-argillans or sesquioxidic impregnated plasma. Plasmic fabric was weak to moderate skel-vo-insepic porphyroskelic. A few feldspar grains were still observed. Neoferri-argillans filled most of vughs and channels and coated grains.

B21t horizon (41-68 cm)

At 50 cm, neoferri-argillans were observed throughout the horizon, and it was difficult to differentiate plasmic separation and cutanic characteristics. Figure 26-B indicates the condition described and it also shows more vughs as compared to the compact A2 at 26 cm. The plasmic fabric was vo-skel-mosepic porphyroskelic; few parts may have fitted the lattisepic description. Elongate channels (the presence of earthworms was noted during soil sampling), opal phytoliths, tourmaline, epidote, zircon and stress ferri-argillans were also observed.

B3 horizon (86-120 cm)

At 104 cm, similar to above but had more vughs with smoothed walls (probably earthworm channels) and a weak lattisepic to vo-skel-mosepic prophyroskelic fabric.

Notes. This profile indicates a departure from the skeleton domination of other profiles studied. The combination of very fine sand and silt together with the increasing of clay content with depth contribute to the importance of plasma throughout the profile. Ferruginous quartzite fragments indicates probability of an iron rich formation in the parent material sources. The active impregnation of sesquioxides in this profile indicated dispersal of iron oxides instead of being concentrated into a plinthite layer. This may be due to the better drained nature of the profile and active nature of the finer fractions (silt and clay). The presence of earthworm activity instead of termites, and the higher CEC than the rest of the soils in this study seems to indicate that this soil is more fertile than the rest.

DISCUSSION

Genesis

The study of pedogenesis involves consideration of the origin and nature of parent materials and environmental influences controlling the processes of soil formation over time. In the following discussion the geomorphic occurrence of the study sites and their climate, vegetation and topography are considered first in relation to morphology of the profiles. Evidences from mineralogic study of the nature of parent materials and the degree of weathering are then discussed; followed by consideration of specific pedogenic processes, as evidenced by the analytical results.

Pedo-geomorphic and Climatic Relationships

Gray Podzolic soils consistently occupy the higher topography of the low terrace formation in all of the physiographic regions in Thailand (Table 11). Specific geomorphic relationship of the terraces have unfortunately not been studied so general observations must be relied on for this study. Riverine low alluvial terraces of the north and northeast and the low marine terraces of the south and southeast differ distinctly in elevation (150-315 m as compared to 7-45 m) (Table 6). These two broad groups of terraces may differ somewhat in age, but overall these low terraces and the soils formed on them in

Table 11. General relationship of geomorphic positions and occurrence of Gray Podzolic and related soils in Thailand.

Physiographic region	Recent alluvial terrace	Semirecent terrace	Low terrace: Lower position	Low terrace: Higher position	Middle terrace	High terrace
North and West Continental Highland		←-------→ (LHG)	←------→ (LHG)	GP ←→ (RYP)	←-----------------→ (RYP)(RBLtr)	?
Northeast Plateau		←-------------→ (LHG)		GP ←→ (LHG)	GP ←→ (RYP + LHG)	←------→ (RYL)
Central Plain		←--------→ (LHG)	←------→ (LHG)	GP ←→	←-----------------→ (RYP) ? Peneplain ←-------------→ (RYP)(RBLtr)(RBE)	
Central Highlands	Lakebed Lacustrine ←---------------------→ (G)	←--------→ (LHG)	GP ←————→ (LHG)(RYP)		Marl & limestone alluvium ←-----------------→ (RZ)(RBE) Peneplain ←-------------→ (RBE)(RZ)(RYP)	

(Continued on next page)

Table 11. (Continued)

Physiographic region	Recent alluvial terrace	Semirecent terrace	Low terrace: Lower position	Low terrace: Higher position	Middle terrace	High terrace
Southeast Coast		← GP (LHG)	GP (LHG) →			
			← GP (RYP)	GP (RYP) →		
				←-- Peneplain (RYP)(RBLtr)	Peneplain (RYP)(RBLtr) --→	
Peninsular Thailand		← GP (LHG)(RYL)	GP (LHG)(RYL)	GP (LHG)(RYL) →	←-- Peneplain (RYP)(RBLtr) --→	?

GP = Gray Podzolic soils
RYP = Red Yellow Podzolic soils
LHG = Low Humic Gley soils
RBE = Red Brown Earths
TBLtr= Reddish Brown Lateritic
RYL = Red-Yellow Latosols
G = Grumusols
Rz = Rendzinas

all regions are similar in occurrence and characteristics. They can be correlated to one another with only minor differences. On the Southeast Coast, marine terraces grade progressively into riverine terraces further inland. In the south, such grading is not so clearly indicated because most of the valleys are small and narrow with strath terraces or higher terraces predominating. These higher terraces are usually of mixed origin and gravelly in composition. Gravelly to bouldery higher terraces are strongly expressed in the northern regions, commonly forming low hills. Stable low terraces with Gray Podzolic soils are found primarily in broader valleys throughout all of the study regions. Greater erosion due to a steeper gradient toward the south, hilly terrain and relatively less stable landscape of the northern valleys has resulted in fewer stable low terrace remnants than in other areas of the Kingdom. They are restricted to the border valleys of Chiang Mai, Lampang and Prae provinces. In the western portion of the much broader Chao Praya river valley of the Central Plain, larger areas of Gray Podzolic soils on low terraces are found.

In the Northeast Plateau, the generally broad, flat terrain resulting from late Tertiary (?) uplift has preserved vast, flat alluvial terraces of various levels broadly assigned to high, medium and low terrace groups. The low terraces are most extensive but remnants of old, high terraces with reddish colored Latosols are also more widespread than in any of the study regions. Low Humic Gley soils on the lower terrain of the low terrace occur intricately intermingled with Gray Podzolic soils throughout the area. Separation of the wetter soils of the low terrace is difficult under actual survey conditions. Two of the profiles in this study (SR-3 and SR-6) are clearly formed under wetter conditions in relation to their counterparts with better drainage on slightly higher positions (i. e., SR-2 and SR-5, respectively). In both cases the mottled zone is closer to the surface, they have a higher percentage of silt or finer materials ($< 50\ \mu$) and are more compact than the associated higher and better drained members. Such concentrations of mottles appear to fit the definition of plinthite and are comparable with the genesis of soils with laterite forming under fluctuation of the water table, as observed elsewhere. These soils are similar to Ground Water Laterite soils as described by Kellogg and Davol (1949) and Sombroek (1966, p. 95). In Thailand, Pendleton (1936, 1941a) had earlier suggested this particular process of laterite formation.

The morphology of the Gray Podzolic soil profiles in this study suggests that they formed from similar alluvial material, although profiles from the northeast are formed on terraces that may be of greater age than for the other soils studied. Characteristics of the profiles conform generally with the concepts that have evolved for the soil group. Two profiles, SR-4 and SR-9, contain characteristics quite marginal for the central concept of the Gray Podzolic group. These two profiles indicate the necessity of flat to gentle undulating relief and resultant slow surface drainage. The SR-4 profile site shows evidence that erosion has had a significant influence on genesis of this soil. The site of profile SR-9 has a slope of 4 to 5% indicating more rapid surface runoff. It should be mentioned that other characteristics of these two soils may also be significant. These include the very sandy nature of the SR-9 profile, and the conditions of slightly greater fertility and higher, more reliable rainfall distribution for the SR-4 soil. The sandy texture and very low clay content (usually less than 10%) of Gray Podzolic soils in the northeast poses questions regarding both classification and fertility that will be discussed later in more detail.

Lithologic discontinuities are commonly present as indicated by the deep samples of profiles SR-7, SR-8 and SR-9. Variations in clay percentages and other factors such as the difference in percentage of sand size fractions, chemical variation and micromorphological data, of these samples, signify the layering of the alluvium.

Influences exerted through climate can and usually produce a relatively marked effect on the soil. Average annual rainfall in the study regions (Table 3) and at the sample sites (Table 6) indicate significant variations in the regional and local climates. Average annual rainfall of 2000 mm or above are found at locations of five profiles, SR-2, SR-3, SR-4, SR-5 and SR-6. The other locations (profiles SR-1, SR-7, SR-8 and SR-9) have rainfall of 1200 to 1300 mm. Latitude difference of 19°N to 7°N (SR-1 at the extreme north and SR-2 at the extreme south), topography and vegetation all vary somewhat in their influence on the processes operating in these soils. Temperature is fairly uniform with little fluctuation and therefore fits the isothermic temperature regime in classification (USDA, Soil Survey Staff, 1970).

The central concept of Gray Podzolic soils was evolved for the soils formed on old, reworked alluvium of the lower Mekong River basin, applicable mostly in the Northeast Plateau region (Dudal and Moormann, 1964). The climate of this region is characterized by the unreliable rainfall distribution and the long dry period (usually four to five months).

The following comparison shows wide variation in the average annual number of rainy days for soils from the various locations in this study. Three profile sites with a high average annual rainfall (2163 mm for SR-5 and SR-6, and 2415 mm for SR-4) still have a fairly low average number of rainy days.

North and Northeast	Average annual rainy days	Southeast	Average annual rainy days	South	Average annual rainy days
SR-1	108.5	SR-8	121.7	SR-2	162.9
SR-7	86.9		(Sattahip)	SR-3	162.9
SR-5	81.8		47.7	SR-4	84.4
SR-6	81.8		(Rayong)		
		SR-9	89.4		

In general, Gray Podzolic soils of the north (SR-1) and the northeast (SR-5, SR-6, SR-7) have Dry Deciduous (Dwarf Dipterocarp) forest. As rainfall increases, the forest grades toward the Moist Deciduous forests, such as found in the southeastern area (SR-8 and SR-9). In this region, rainfall is higher toward the easternmost section and Evergreen Forest dominates in that portion. The southern Gray Podzolic soils represented by profiles SR-2, SR-3 and SR-4 are situated in the high rainfall tropics with vegetation of the Tropical Rain Forest type. The soils of the southern region have been classified as an intergrade soil group toward Yellow Latosols. In Malaysia, the Holyrood series developed on old alluvium under very high rainfall (Panton, 1964) has been correlated with the Kho Hong series (Moormann et al., 1964b) represented by profiles SR-2 and SR-4. The macro and micromorphology as well as analytical data of soils in this study from the wet tropics do not indicate any strong departure from the central concept of Gray Podzolic soils. Profile SR-4, in fact, contains a small amount of the more easily weathered potash feldspars, similar to profiles SR-1 and SR-9 from other climatic zones.

Despite the indicated variations in position, stratification of parent materials, possible age differences, and quite different original forest types and climatic conditions, these nine profiles have a great deal of morphological similarity.

Mineral Stability and Origin of Parent Materials

Stability tables of the minerals have been proposed by various workers (Goldich, 1938; Pettijohn, 1941; Jackson and Sherman, 1953; etc.). Brewer (1964, p. 90) listed comparative mineral stability tables from various authors and concluded that the discrepancies in orders of stability resulted from judgement based on different environments of weathering and, in some cases, different assemblages of associated minerals. Based on the broad groupings generally agreed upon by most workers for average environmental conditions, mineral assemblages in this study are of a stable to very stable type. The main heavy mineral group is, in fact, ubiquitous in occurrence.

Using mainly Pettijohn's (1941) stability list of the mineral species, the heavy minerals in this study are grouped into the four broad classes shown below. In addition to the heavy minerals, feldspars and the secondary minerals, mainly of clay size, have been placed according to the weathering indices of Jackson and Sherman (1953) as modified by Jackson (1968). These are shown in parentheses in the list.

High stability: Zircon, tourmaline, rutile (goethite, gibbsite).

Moderate stability: Garnet, magnetite, staurolite, kyanite (kaolinite, smectite, interstratified 2:1 layer, vermiculite).

Low stability: Epidote, hornblende, andalusite clinozoisite, silimanite (illite, quartz, potash feldspar).

Unstable: Olivine, actinolite, hypersthene (olivine is the least stable mineral).

From the heavy mineral frequencies (Table 10) and the proposed mineral stability classes, it can be seen that minerals of high stability, goethite, zircon, tourmaline and rutile, dominated the whole heavy mineral fraction. It should be noted that all of the less stable minerals in this study were in the low stability class, of which the least stable members are still considered rather high in the stability scale (Pettijohn, 1941). No discernible trend in weathering with depth in the profiles can be established. In the lowest horizons of SR-7, SR-8 and SR-9 which correspond to IIC, IIIC2 and IIIC3 horizons, the heavy minerals, zircon in particular, have distinctly different proportions than in horizons above, and thus support the designation of lithologic discontinuities. The higher concentrations of tourmaline correlate with profiles in the areas of granitic rocks (i. e., SR-2, SR-4 and SR-8).

The presence of large, relatively fresh, green hornblende in the profile, particularly when the amount is increasing with depth as in profile SR-9, seems to indicate its origin from substrata material containing such mineral, or relatively fresh additions of the mineral incorporated into old reworked alluvium. This type of hornblende is also found in upper and lower horizons of SR-1 and identified in one horizon of the SR-8 profile. Gneissic granite or gneiss and schist areas are in the vicinity of these three locations where "fresh" green hornblende was found. Horizon SR-9-9 (265-280 cm) is, in fact, indicated in the profile description as resembling weathered crystalline rock, possibly granitic gneiss. The frequency number of hornblende is also higher in that horizon.

It is interesting to note that hornblende, as seen in the grain mount slides, is coated with thin, low birefringence, colorless material with negative relief. In Oregon, this type of opaline coating has been identified as volcanic glass coatings on mineral grains of pyroclastic deposits. Fresh, large, euhedral grains of hypersthene and hornblende have been found in the upper horizons of many soil series throughout Oregon, and they have been correlated with the widespread, recent ash deposit in this part of the country (Norgren, 1962; Rojanasoonthon, 1963; Paeth, 1970).

If the hornblende minerals have a pyroclastic origin, they must have deposited in the parent materials long before the formation of the soils in this study. There is no record of any recent strong volcanic activity in Thailand, apart from Tertiary basalt, andesite and rhyolite flows, dikes and plugs (Brown et al, 1951). It is doubtful that hornblende would remain stable and quite fresh that long. Scrivenor (1930) indicated the presence of rhyolite ash with sponge-spicules and diatoms in Malaya and suggested Lake Toba of North Sumatra as the source of the ash. In comparing many of Scrivenor's ash and sponge-spicule photos and descriptions to some of the studies on plant opal (Kanno and Arimura, 1958; Parry and Smithson, 1964; Parfenova and Yarilova, 1965; Twiss et al., 1969), it was found that most of the ash and sponge-spicules he identified could have been opal phytoliths. Many of the forms shown by Scrivenor are similar to the opal phytoliths identified in this study.

In support of the hornblende having originated from granite or gneissic rocks, potash feldspars were identified in thin sections and grain mounts of SR-1, SR-4 and SR-9 profiles. Metamorphic quartz grains (quartzite) were also dominant in these soils.

The presence of andalusite at these three sites, particularly at SR-1 and SR-9, indicates the possibility of a pelitic amphibolite facies of hornfelses (William et al., 1954). This type of bedrock could have resulted from a reaction between granite and the prevailing country rocks of sandstone-shale, or their metamorphic equivalents of quartzite-phyllite, in the Kanchanaburi (geological) group.

The presence of amphiboles and potash feldspars indicates either the addition of younger materials or relatively younger parent materials for profiles SR-1, SR-4 and SR-9 than for other profiles in this study.

The complexity of the bedrock in catchment areas is probably responsible for the greater variety of the heavy mineral suites in profiles of the north and northeast (SR-1, SR-5 and probably SR-6). In the northeast profiles (SR-5 and SR-6), sediments carried by Mekong River which is in the proximity of the sample sites have influenced the composition of the old alluvial deposits.

Clay mineral analysis indicates a predominance of the relatively stable kaolinite group, and the amount was interpreted as being 50 to 90% of the total clay in most of the profiles (slightly lower in SR-4 and SR-9). The higher concentration of micaceous clay minerals in profiles SR-4, SR-6 and SR-9 indicates somewhat younger soil parent materials or later addition of those minerals in the profiles. The concentration of illite in SR-6 profile can be attributed to its relatively lower position subject to additions of micaceous minerals found rather widespread in the general area adjacent to the Mekong River drainage. Concentrations in SR-4 and SR-9 (and to a lesser extent in SR-1) are probably due to rock sources in the catchment area rich in micaceous minerals.

Kaolinite and the interstratified 2:1 clay minerals of this study are classified as having moderate stability in the broad stability classes indicated earlier. Illite is in the low stability group with quartz, potash feldspar and hornblende.

Of the nine profiles, SR-8 shows the highest concentration of kaolinite and least mixing of other components. The silt to clay ratio (Table 12) of Van Wambeke (1962) is about 0.15 or less in the B

Table 12. Silt to clay ratios of the nine Gray Podzolic soil profiles (arranged by geographical occurrence from north to south).

SR-1		SR-7		SR-5	
A1	3.23	Ap	2.93	Ap	2.17
A2	3.62	A2	1.82	A21	1.73
B1	2.35	B1	1.24	A22	1.55
B2t	1.89	B21t	1.15	B1	1.17
B3	0.61	B22t	0.99	B21t	1.32
		B3-1	0.83	B22t	1.23
		B3-2	0.71		
		IIC-1	0.48		
		IIC-2	0.38		

SR-6		SR-8		SR-9	
Ap	6.08	Ap	0.34	Ap	3.45
A2	5.46	A2	0.25	A2	2.42
B21t	2.43	B21t	0.14	B2t	2.72
B22t	1.82	B22t	0.14	B22t	2.76
B22tg	1.89	B31	0.17	B23	1.91
		IIB32	0.14	B3	1.56
		IIIC1	0.09	IIC1-1	0.96
		IIIC2-1	0.14	IIC-2	1.31
		IIIC2-2	0.16	IIIC2	1.56

SR-2		SR-3		SR-4	
Ap	2.87	A1	3.26	Ap1	2.99
A2	1.99	A2	3.04	Ap2	3.14
B1	1.97	B1	2.54	A2	3.73
B21	1.73	B21t	1.72	B1	2.61
B22t	1.02	B22t	2.79	B21t	1.48
B3	1.02			B22t	1.23
				B3	1.16

Table 13. Classification of Gray Podzolic soils in this study (arranged by geographical occurrence from north to south).

Region and sample no.	Series and location	USDA Soil Taxonomy (Soil Survey Staff, 1970)	Note
North			
SR-1	San Pathong series Chiang Mai	Ustoxic Plinthustult (coarse-loamy, siliceous, isohyperthermic)	Feldspars 10-14% Plinthic Haplustult (if no plinthite)
Northeast			
SR-7	Korat series Khon Kaen	Ustoxic Paleustult (fine-loamy, siliceous, isohyperthermic)	
SR-5	Korat series Nakhon Panom	Ustoxic Paleustult (fine-loamy, siliceous, isohyperthermic)	
SR-6	Renu series Nakhon Panom	Aeric Oxic Plinthaquult (fine-loamy, siliceous, isohyperthermic)	Plinthic Paleaquult (if no plinthite)
Southeast			
SR-8	Huai Pong series Rayong	Plinthic Ustoxic Peleustult (clayey, kaolinitic, isohyperthermic)	Plinthite at 1.5 m
SR-9	Sattahip series Chon Buri	Oxic Ustropept (coarse-loamy, siliceous, isohyperthermic)	
South			
SR-2 (east coast)	Kho Hong series Hat Yai	Orthoxic Plinthudult (fine-loamy, siliceous, isohyperthermic)	Plinthic Paleudult (if no plinthite)
SR-3	Nam Krachai series Hat Yai	Aeric Oxic Plinthaquult (fine-loamy, siliceous, isohyperthermic)	Plinthic Orthoxic Tropudult (if no plinthite)
SR-4 (west coast)	Kho Hong series Satun	Typic Paleudult (fine-loamy, siliceous, isohyperthermic)	

horizon of SR-8. Van Wambeke considered a ratio of this magnitude in the Congo as indicative of old highly weathered parent materials (i.e., as old or older than Pleistocene). He regarded silt content to be closely related to the actual amount of weatherable minerals. Many qualifications, however, were required for application of the silt to clay ratio. Some of these are the restriction to use only in well drained soils, with dominantly kaolinite clay minerals, and profiles with a textural B but with clay content not much higher than overlying and underlying horizon. Profile SR-8 can be interpreted from the ratio as the most weathered, if possible, parent material and age differences are discounted. Profiles SR-7, SR-1, SR-2, SR-3 and SR-5 have moderately stable clay minerals on the basis of Jackson's index that interstratified 2:1 minerals are more stable than illite. Profile SR-7 is very close to SR-8 in the ratio of silt to clay, followed by SR-2 and SR-5. However, profiles SR-1 and SR-3 do not seem to show a good correlation between mineral stability and silt to clay ratio. Profiles SR-4, SR-6 and SR-9 comprises a mineralogically less stable group of soils. The presence of micaceous clay minerals and the amount of silt in profiles SR-3, SR-4, SR-6, SR-9 and somewhat in SR-1, however, indicated a rather good correlation of less weathering with a high silt to clay ratio in the upper horizons.

Khalifa and Buol (1968) reported weakly crystallized 7 Å kaolinite peaks for the fine clay in illuviated clay skins of kaolinite-dominated old soils of the Southern Atlantic Coastal Plain. A similar occurrence of weakly crystallized kaolinite in the fine clay of the clay skins is noted in this study. The morphology and mineralogy of some of these soils classified as Red Yellow Podzolic or Paleudults and Hapludults in the Southeast United States (Cady and Daniels, 1968) are quite similar to the Gray Podzolic soils of this study. The major differences are probably the drier moisture regime and the absence of gibbsite in the Gray Podzolic soils.

The presence of 9.2 Å peaks in the fine clay fraction (<0.2 μ) of certain horizons in profiles SR-1 (B2t), SR-2 (B3), SR-4 (A2) and SR-5 (B22t) is not fully understood and cannot be correlated to any known clay minerals in this study. It cannot be a variety of mica since it is thermosensitive and the peak disappears with K-saturation plus heat at 105°C or 300°C. A 9.2 Å peak that is thermosensitive at 300°C has been identified as zeolites[9] in the water samples derived from volcanic areas in Oregon. Zeolites are highly unstable and are among the most common authigenic silicate minerals in sedimentary rocks (Hay, 1966). It is most unlikely that zeolitic minerals are present in the samples of this study. Further work is needed to determine definitely the validity and identity of the 9.2 Å peak.

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[9] Dr. Dhanpat Rai, Department of Soil Science, Oregon State University, Corvallis. Personal communication.

Pedogenic Processes

It has been noted earlier that quartz grains are the dominant skeleton grains in all profiles in this study. All are angular and most of them are small (very fine sand and fine sand). Evidence from thin sections indicated that quartz grains were cracking in situ (i. e., breaking down within the profile). Many of the metamorphic quartzite grains displayed abrupt fracturing, particularly in the upper horizons and appear to be the major component with such cracking, at least in profiles SR-1, SR-2, SR-3, SR-4 and SR-8, where quartzite sand grains were positively identified. Furthermore, a decrease in amount of the very fine and fine sand fractions with depth has been observed in most of the soils studied. At the same time the silt content remains somewhat the same while clay content increases. Therefore there has been a relative increase of silt size over sand size components.

Flach et al. (1968) proposed the term pedoplasmation for the formation of the soil plasma. The process is primarily a physical process that affects the transformation of weathered rock (saprolite) to soil B horizons. In this study, although there is no saprolite to be related directly since the parent materials were old alluvium, pedoplasmation is still operating and it may explain the cracking of the sand grains. This process is primarily through mechanical disturbance, notably shrinking and swelling through wetting and drying, root action and soil fauna. These are likely agents of pedoplasmation *in situ*. The concentration of broken down materials has progressively contributed to plasmic fabric formation of the asepic type. Commonly the plasmic fabric is sila-argillasepic with a domination of the fine sand and very fine sand skeleton grains in a silt and/or clay matrix. The effect of pedoplasmation on increasing the dispersibility of clay, water retention, and shrink-swell capacity toward the soil surface has been demonstrated by Flach *et al.* (1968). They also indicated that other rheological properties are also affected. It is a contributing process in the formation of many argillic horizons. Commonly, argillans are a small proportion of the clay in the Bt horizon (Knox *et al.*, 1965; Brewer, 1968). Brewer and Sleeman (1969) suggested that the main bulk of clay in the matrix has gone through stages of being initially unoriented to becoming more oriented, depending on age of the soil; but is influenced as well by type of clay minerals, degree of wetting and drying and many other factors. The evidence for transfer of clay down the profile by illuviation is clearly indicated by thin section study in all of the profiles (Figures 25 and 26).

The generally highly porous nature of these soils has been indicated from the micromorphological study showing that an intertextic to argilla-silasepic plasmic fabric is quite common. In the surface horizons where skeleton grains are dominant, the plasma separation is weakly expressed, and the s-matrix is loosely held with common simple and compound packing voids. In the B horizons plasma has increased and there has been reorganization of clay domains. The porosity is then dependent on vughs and most of these vughs appear to be biogenic in origin since they are mostly metavughs with smoothed walls. Estimation of the pore space in the soils of this study indicated that most of the B horizons have porosity (by thin section methods) between 10 to 20%. Bennema et al. (1970) used a point count method to indicate the difference of pore space between representative Ultisols and Oxisols of Brazil. They found 17 to 23% porosity in Oxisols and approximately 13 to 18% in Ultisols. Most of the soils in this study have porosity tending toward the higher percentage of Oxisols.

The cation exchange capacity of all the profiles studied is very low, usually less than 10 me per 100 g. This is a reflection of the dominance of the 1:1 kaolinitic clay type as well as relatively low clay and organic matter contents. Under the strong leaching conditions of the tropical climate any cations released by weathering or added to the soil will tend to be quickly removed and retention of cations will be at a minimum. The CEC per 100 g of clay indicated somewhat higher values in the surface horizons due to organic matter. In the B horizons, however, these CEC values drop to about 24 me or lower. Thus the clay showed a tendency to have low activity somewhat intergrading to the type of clay found in Oxisols.

Base saturation of the profiles decreased with depth, somewhat parallel with the pH values which are mostly 5.5 to 6.0 in the surface and drop to 5.0 or 5.5 in lower horizons. The variation of base saturation levels in the B horizons poses some problems in classification. In all profiles except SR-9 the base saturation dropped below 30%, usually at a depth of 1 m or more. In the case of the sandy SR-9 profile with less than 10% clay, the base saturation is quite high. The significance of this is questionable. The precise determination of base saturation or CEC becomes quite critical in very sandy soils and any error would be amplified on a percentage basis. Furthermore, contamination in the field by termites, salt infusion, etc., at the different times of sampling may yield different results for base saturation.

All plant nutrients in these soils are very low and this may stem from a combination of factors. It has been shown that most of these profiles have very few if any easily weatherable minerals and are dominated by low exchange capacity kaolinitic clay minerals. These profiles have been subjected to rather strong weathering and leaching. Profiles SR-1 and SR-7 appear to have more available phosphorus with depth while all others remain very low. The reason for the higher phosphorus levels is not known. The C:N ratio is relatively narrow and indicates a high level of nitrogen mineralization, generally increasing with depth. The increase in available P with depth in profile SR-1 could be due to greater organic P availability related to the narrower C:N ratio of the organic matter (Walker and Adams, 1958). In general organic P is at least two-thirds to one-sixth of the amount present in inorganic form (Schuffelen and Koenigs, 1962). In profile SR-7, however, the C:N ratio is not as low as in SR-1 and the high level of available P in the soil must be due to other factors. High available K in certain horizons of SR-1, SR-4, SR-7 and SR-9 seems to correlate with areas where rocks rich in mica or potash minerals are in the immediate drainage basin. These rock sources include micaceous shale (SR-7), mica gneiss and phyllite (SR-1, SR-9 and SR-4).

Organic remains in the humid tropics are quickly mineralized and only a small part is synthesized by bacterial action to form relatively stable humus. In the thin sections, dark brown to reddish brown spots of humus thoroughly incorporated in the s-matrix are quite common, particularly in the surface horizons of all the soils in this study. One important form of plant remains which persists in soils are the plant opals or opal phytoliths. The majority of plant opal is from grasses and the most common weed in Thailand is a grass (Imperata cylindrica). Some opal forms found in this study correlate well with studies elsewhere, particularly from Japan (Kanno and Arimura, 1958). Although plant opal content found in this study decreases sharply from the surface downward, the micromorphological study indicates their presence as far down as the B3 and C, suggesting that the parent materials may already have opal phytoliths mixed in before deposition. Witty (1962) cited references from many workers in different countries indicating the stability of opal phytoliths by their presence in many paleosols. Wilding (1967), in his study of phytoliths from Brunizem soils in Ohio using radio carbon dating methods, reported the age of carbon occluded within opal phytoliths to be 13, 300 $\pm$ 450 years before present. He concluded that biogenic opal is stable for relatively long periods. The presence of opal phytoliths throughout the profiles in this study, therefore, is compatible with high stability of the heavy mineral suites and evidently they could be quite old. Another inference that can be drawn from the indication that opal phytoliths were in the parent materials of the Gray Podzolic soils is that the source areas of the alluvium were possibly cleared for shifting cultivation and remained for a period under savanna at least once prior to deposition of the old alluvium. This could have contributed to the infertile condition of Gray Podzolic soils.

The importance of forest or other vegetative cover on Gray Podzolic soils in the humid tropical climate needs to be emphasized. Crocker (1960) stated that vegetation, forest in particular, affects most directly and rapidly the organic carbon, total nitrogen, pH and bulk density. The recycling or "nutrient pumping" by forest vegetation is almost the sole source of nutrients to maintain and replenish fertility of these soils. Shifting cultivation in the past and similar practices at the present time have operated to deplete their fertility.

Another important aspect which has a strong bearing on the genesis of Gray Podzolic soils is the mixing of the soils by physical, chemical or biological means, called pedoturbation by Hole (1961) Termites and other fauna such as ants, insects and soil dwellers exert a very direct and important influence on Gray Podzolic soils (and most of the soils in the humid tropics). It has been reported by Pendleton (1941b, 1942) that termites in Thailand, in addition to mixing the soils, also accumulate lime in their nests.

Evidences of soil fauna, particularly termite mounds, are widespread in Gray Podzolic soil areas in this study (Figure 9-B). Such conditions are indicated in connection with the profile descriptions. The sites of soil profiles in this study were selected to avoid the direct influence of termites as much as possible. However, the high content of exchangeable calcium with subsequent higher base saturation and higher pH in the upper horizons of SR-4, SR-5 and SR-8 are probably due to termite influences. Numerous profiles studied in the past have shown stronger indications of termite influence than indicated in the samples in this study.

The occasional presence of lime from termites in these infertile and leached Gray Podzolic soils is quite significant. The reason for the lime accumulation is not completely known. Harris (1964) discussed various conflicting reports of lime producing and non-lime producing termites in Africa and Asia. Hesse (1955) studied the origin of lime in termite mounds of East Africa and concluded that the termites themselves do not produce or secrete lime. He indicated that all the lime containing termite mounds were in poorly drained or waterlogged areas and suggested that the lime was derived by termites from calcium charged ground water. The source of lime in termite mounds in Thailand is still unknown. Although there are important limestone areas in Thailand, widespread availability of lime charged water leading to selective accumulation in termite mounds is most unlikely. In Thailand, to the author's knowledge based on extensive survey work in the country, lime is always found in termite mounds. However, no detailed study of this condition has been made. Lime from abundant occurrence of termites in the Gray Podzolic soil areas definitely has some significance in improving the soils locally. It usually increases the base saturation in Gray Podzolic soils, particularly in the very sandy soils, to the extent that it has some significance in classification.

A condition pertaining only to the Northeast Plateau is the problem of excess salt from geological deposits. A salt formation in the upper member of the Korat Group (Thailand, Department of

Mineral Resources, 1969) is widespread throughout the northeast region. In some areas salt is brought to the surface by capillary action and accumulates in the soils. Most of the salt spots, however, are in the lower areas associated with Low Humic Gley soils. The Gray Podzolic soils in this study show low conductivity values and are well under the critical range for plant growth.

One of the major processes in the Gray Podzolic soils is the formation of a plinthite layer in the lower part of the profile. It is not the purpose of this study to cover the genesis of laterite which has been treated at length in recent years by many workers (Alexander and Cady, 1962; Sivarajasingham _et al._, 1962; Maignien, 1966). The type of laterite formation in this study is plinthite (Buchanan's laterite), associated with fluctuation of the water table. The occurrence of plinthite is usually deep and not as dense or shallow as in the wetter Gray Podzolic soils (SR-3 and SR-6) or the associated Low Humic Gley soils.

In the early stages of the soil formation sesquioxides occur ubiquitously as ultramicroscopic grains intimately mixed with other constituents of the plasma (Brewer and Sleeman, 1969). Variations in concentration and hydration of sesquioxides cause color mottling. The so-called sesquioxidic nodules with diffuse boundaries (undifferentiated fabric) occur in the horizons that periodically become wetter than those where nodules with sharp boundaries occur.

Optically, the aluminum oxides are difficult to identify, thus only iron oxides and hydroxides can be studied in thin sections. It has been shown by Deshpande *et al*. (1968) and Flach *et al*. (1969) that hydrated aluminum oxide rather than iron oxide is the probable cementing agent in the formation of certain soil aggregates or nodules. Greenland *et al*. (1968) have presented some evidence that iron oxides are present as small rounded particles, primarily on the edges of halloysite and kaolinite particles, and they behaved as negatively charged particles. They could find no evidence that the iron oxides form coatings on the clay. Flach *et al*. (1969) believe that attention has been focused too much on iron oxides and manganese and the role of aluminum oxides as a cementing agent should be explored further.

The formation of plinthite involves primarily segregation of iron within the soil profile under the influence of a fluctuating water table creating alternate oxidizing and reducing conditions. The sesquioxides first form soft red mottles that do not harden irreversibly on drying. The nodules from the soil samples in this study are still soft and still redisperse in water. Presumably they are really dry only after excavation and therefore fit the plinthite definition. As shown by micromorphological study (Figure 18-E and -F), a set of cracks or channels (Figure 17-F) appeared to be similar to what Stoops (1968) called contraction planes. He indicated further that the planes were formed due to leaching (i. e., a decrease of volume), or shrinking leading to the formation of neosesquans. The result is cellular-like features consisting of bleached grayish areas of unoriented, almost isotropic clay minerals surrounded by a deep brown or red zone of iron concentration (Figure 18-E). Stoops (1968) indicated that the contraction voids between these units may be closed or filled with illuviated argillans or ferri-argillans and, as the process continues, the areas of grayish plasma are reduced through leaching and the iron oxide cutans increase and become better crystallized. The final form will be a network of crystals knitted together to form a more rigid framework as part of the hardening process indicated by Frei (1964), Hamilton (1964), Schmidt-Lorenz (1964), Stoops (1968), and Flach et al. (1969).

In this study, the features indicating repeated concentration of iron oxide cutans and the hardening process had not been observed. However, it is considered probable that the condition of the plinthite layers represents an early stage of the process.

Classification

The Gray Podzolic soils in this study can be classified according to the USDA Soil Taxonomy (USDA, Soil Survey Staff, 1970). The results of such placement are shown in Table 13. Terms and definitions used in the following are of the USDA Soil Taxonomy with amendments.

Order

Placement into the Ultisol order of the USDA Soil Taxonomy for eight of these nine soil profiles indicates the presence of an argillic horizon in these soils. It was found that all profiles except SR-9 complied with the specific clay increase in the B horizons required for argillic horizons (Appendix A, Table 1). The upper limits of the argillic horizons coincide with the B horizons in the profile descriptions, except for SR-2, where the argillic horizon starts a lower depth with the B22t (91-125 cm).

In profile SR-9 the clay content remains less than 10% throughout, except in the IIIC2 horizon. The clay increase does not meet the criteria for the argillic horizon, and the evidence of oriented clay does not consistently meet the requirement of 1% or more of the cross section. This soil has a cambic horizon and is classified as an Inceptisol.

The base saturation (by sum of cations) of all the Gray Podzolic soils in this study except SR-9 is lower than 35% within the depth limit specified for Ultisols (1.8 m from surface or 1.2 m from the top of argillic horizon). The base saturation of profile SR-9 remains high throughout down to 2.8 m.

Suborder

Two of the Gray Podzolic soils (SR-3 and SR-6) in lower topographic positions qualify to be in Aquult subgroups. Climatic data indicate that the north, northeast and southeast (except for the easternmost portion) have an ustic moisture regime. The south, except for the northernmost of the Peninsular Thailand, has an udic moisture regime. Soil moisture data at Hat Yai, Peninsular Thailand (Kennedy et al., 1967) were used for the determination of the udic moisture regime. Profiles SR-1, SR-5, SR-7 and SR-8 are, therefore, in Ustult subgroups while profiles SR-2 and SR-4 are in Udult subgroups. SR-9 with an isothermic temperature regime, ochric epipedon and cambic horizon fits the Tropept subgroup.

Great Groups

The presence of plinthite in profiles SR-1, SR-2, SR-3 and SR-6, which appears to constitute more than half of the volume of the lower B horizon (B22 or B3) indicates that they are probably Plinthustults (SR-1), Plinthudults (SR-2) and Plinthaquults (SR-3 and SR-6). If, however, the plinthite did not meet the requirement for Plinthic groups, SR-1 would be a Haplustult (more than 10% weatherable minerals), SR-2 would be a Paleudult, SR-3 a Tropudult (having a clay bulge that drops more than 20% of the maximum amount) and SR-6, a Paleaquult.

The ustic moisture regime and the base saturation of more than 50% places the SR-9 in the Ustropept great group.

The remaining profiles have less than 10% weatherable minerals in the 20 to 250 μ fraction and a clay bulge that does not drop more than 20% of its maximum amount. Therefore, SR-5, SR-7 and SR-8 are classified as Paleustults and SR-4 as a Paleudult.

Subgroups

At the subgroup level it was found that the CEC per 100 g clay of all these soils, with the exception of SR-4, drops to or below 24 me in the major part of the argillic horizon. Thus Ustoxic is the dominant designated subgroup in association with Paleustult or Plinthustult. Profile SR-4 with CEC per 100 g clay of more than 24 me qualifies as a Typic Paleudult. The wetter profiles SR-3 and SR-6 are classed as Aeric Oxic Plinthaquults and SR-2 is an Orthoxic Plinthuduult. There is no separate subgroup for Ustropepts with a low CEC and Oxic Ustropept is probably appropriate for such soils as SR-9. Plinthite occurs in the lower part of SR-8 and therefore it is classed as a Plinthic Ustoxic Paleustult.

Family

The family grouping reflects strong similarity between these profiles. Family textures are fine-loamy, except profiles SR-1 and SR-9 which are coarse-loamy, and SR-8 which is clayey. All are siliceous except SR-8 which is in the kaolinitic mineralogy family group. The temperature regime of all profile sites is isohyperthermic.

Questions arise concerning the validity of the high base saturation in the so-called Regosolic Gray Podzolic soils and also in some more developed Gray Podzolic soils with high base status. It has been previously stated that some Gray Podzolic soils, particularly the Korat series of the Northeast Plateau, have been classified as Alfisols. It has been found in this study that when the soils are very sandy and low in clay (e.g., SR-9) the base saturation fluctuates widely within the profile. This condition is found in the Northeast Plateau under the ustic moisture regime. Moncharoen[10] (1970) determined the frequency distribution of the base saturation and other properties from 37 Gray Podzolic profiles and 51 Red Yellow Podzolic profiles (Figure 27). The B horizon designation represents the subsurface horizons of very sandy Gray Podzolic soils without textural B (Bt) horizons. A trend toward higher base saturation percentage is indicated for the B horizons in Figure 27. Lower base saturations predominate for the profiles with Bt horizons. D. L. Gallop[11] found similar relationships from his study of many Gray

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[10] L. Moncharoen. Personal communication. Frequency distribution of some physico-chemical properties of Gray Podzolic and Red Yellow Podzolic soils in Thailand. Unpublished data, Land Development Department, Thailand.

[11] D. L. Gallup, State Soil Scientist, Boise, Idaho. Formerly Soil Specialist, USAID, Thailand. Personal communication.

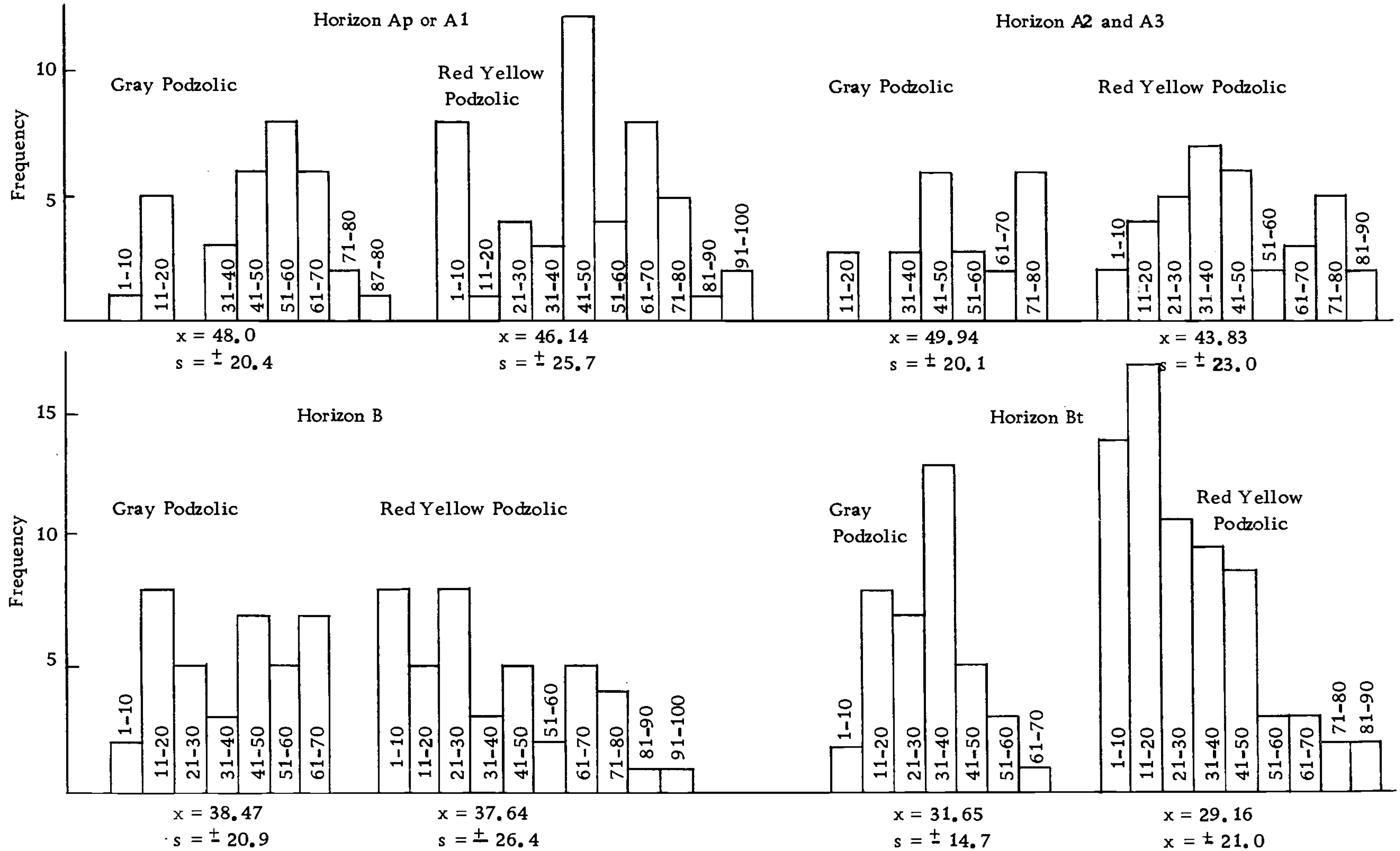

Figure 27. Frequency distribution of base saturations (by sum) of 37 profiles of Gray Podzolic soils and 51 Red Yellow Podzolic soil profiles in Thailand (after Lek Moncharoen, unpublished date, Land Development Department, Thailand).

Podzolic soils of the Korat series in the Khon Kaen area, Northeastern Thailand.

It is quite true that high base saturation will be more common under the ustic moisture regime than the udic regime. The low buffering capacity of these soils and other factors such as fire and termite activity can easily produce high base saturation in these soils. Unless these profiles with high base saturation lack argillic horizons, Alfisols and Ultisols will occur side by side throughout the Northeast Plateau of Thailand. It is proposed here that the low CEC per 100 g clay be given precedence at the order level regardless of the base saturation. Thus, these soils with both high and low base saturations and argillic horizon would only be in Ultisols.[12]

Correlation of Gray Podzolic Soils in This Study to Other Areas and Other Classification Systems

Dudal (1968) indicated the possible correlation of Southeast Asian Gray Podzolic soils to other areas in the world. The Sols Ferrugineux Tropicaux Lessivés (Sols beigés as it sometimes is called) have characteristics somewhat comparable to the Gray Podzolic soils in this study. Using the description of the SPI (Service Pedologiqué Interafricain), Leached Ferruginous Tropical soils have

[12] Dr. F. R. Moormann, Senior Soil Scientist, International Institute of Tropical Agriculture. Ibadan, Nigeria. Personal communication. The idea proposed is also shared by him.

the following characteristics similar to the Gray Podzolic soils of Thailand: Yellow colors, textural B horizon (argillic horizon); dominated by kaolinite and small amounts of micaceous clay minerals (illite) and absence of gibbsite; very few weatherable minerals; may or may not contain soft laterite (plinthite) or lateritic concretions.

Moormann has identified Gray Podzolic soils in Nigeria, Ghana and Senegal, with almost identical morphologic features and geomorphic location as Southeast Asian Gray Podzolic soils (i.e., on lower river terraces of major rivers. The extent of these soils in West Africa is, however, much less than in Southeast Asia because of the rather narrow primary valleys of most rivers.

The Ferruginous Tropical soils have been correlated by most workers with Alfisols (Maignien, 1966; Dudal, 1968; Sys, 1969b). Insufficient data on base saturation and CEC of the Leached Ferruginous Tropical soils makes comparison to the Gray Podzolic soils difficult. Leached Ferruginous Tropical soils had been divided into subgroups with concretions, without concretions and with ironstone. It appears that only the subgroup without concretions can be used for comparison, since in Thailand soils with abundant concretions had been classified into another great soil group (Red Yellow Podzolic). Fauck (1963) indicated high base saturation throughout for the Leached Ferruginous soils with hard concretions. Maignien (1961) described Leached Ferruginous Tropical soils without concretions but did not give data for comparison. However, he indicated high base saturation with depth for the group. Sys (1969b) grouped the Leached Ferruginous Tropical soils (called Fersiallitic soils by the Portuguese and Xeroferrisols in the Congo classification) in the Alfisols and indicated that they had base saturation above 35% in the argillic horizon. According to the base saturation these soils in Africa differ from the Gray Podzolic soils. The higher base saturation appears to be due to exchangeable Ca and Mg.

Lateritic Podzolic soils in Australia have been shown to be similar to Gray Podzolic soils (Dudal, 1968). Stace et al. (1968) reported some profile descriptions (with micromorphological data) and analyses for Lateritic Podzolic soils in Australia. The majority of Lateritic Podzolic soils contain a considerable amount of lateritic concretions in the profiles and appear to be slightly redder (5YR) than Gray Podzolic soils in this study. Rainfall is very much lower (about 460 mm) in Western Australia than in Thailand and the base saturation remains high in the B horizon. One of the profiles described is from Darwin, Northern Territory with a more humid climate and rainfall of 1320 mm. The base saturation drops to 20 or 25% in the lower horizons. The profile, however, is described with hard laterite and ferruginous concretions which appear to be part of the transported materials (Stace et al., 1968, p. 354).

Clay minerals of the Australian Lateritic Podzolic soils are quite similar to Thailand Gray Podzolic soils in having dominantly kaolinite with minor components of illite and some interstratified minerals.

Micromorphological descriptions are rather similar in having intertextic or argillasepic porphyroskelic fabric in the surface horizons, sepic fabric in the lower horizons and diffuse sesquioxidic nodules, particularly in the humid northern part of Australia. The climate here is sufficiently humid, so that plinthite formation may be continuing at present. Elsewhere, particularly in southwestern Australia, most of Lateritic Podzolic soils are associated with much older relict formations. Lateritic Podzolic soils in northern Australia without or low in lateritic concretions, and the Australian Yellow Podzolic soils appear similar to the Gray Podzolic soils in Thailand.

In South America, particularly in the Amazon Basin, there may be similar soils formed on old reworked low terrace deposits. From limited data of Bennema (1963), Sombroek (1966), and Bennema et al. (1970), it appears there may be soils comparable with Gray Podzolic soils in Thailand. Bennema (1963) correlated Red Yellow Podzolic soils of medium to high base saturation with Sols Ferrugineux Tropicaux of Africa.

Red Yellow Podzolic soils with high base saturation, as indicated by Bennema (1963), Dudal (1968) and Sombroek (1966) do not appear to be similar to the soils in this study. From Sombroek's data the kaolinitic Yellow Latosols intergrading to Red Yellow Podzolic soils appear to have more characteristics common to the Gray Podzolic soils in this study (i.e., low base saturation, low CEC, gradual horizon transitions and yellowish color). Possible gradation to Ground Water Laterite soils is indicated in the same study. Using the USDA soil classification (Soil Survey Staff, 1960, 1967), Bennema et al. (1970) indicated many Paleustalfs, Paleustults and Haplustults which may be similar to the soils in this study (particularly the Typic Paleustult profile at Araras).

The legend for the soil map of the world (Dudal, 1968, 1969) listed Gray Podzolic soils in Luvisols (ferric-, plinthic-, or gleyic-) on the basis of presumed high base saturation. If the group is shown to typically have low base saturation, they should have been classed as Acrisols (helvic-, plinthic-, or gleyic-). In later supplements (Dudal, 1969), the Gray Podzolic soils in this study may fit the proposed new soil group of Dystric Nitosols.

Management and Fertility Implications

This study is not designed to solve the problems of agriculture on Gray Podzolic soils in Thailand. However, one purpose is to clarify relationships between soil characteristics and management problems pertaining to these soils and to point the way to probable appropriate solutions or adjustments. It has been established that Gray Podzolic soils are very infertile and have increasing problems of use and management under cultivation. The major factors favoring their use are probably the gentle undulating topography and the vast areal extent in the Northeast Plateau. If choice of other soils is not limited, Gray Podzolic soils have been used only sparingly, particularly in the northeast. However, under the pressure of population and other factors these soils have been opened up and used under shifting cultivation with adverse effects on their stability and fertility. An example of shifting cultivation with a kenaf field growing in open secondary forest in the northeast is shown in Figure 9-C. Once used for a few years, these soils are abandoned for an indefinite period and mostly, no definite cultivation-fallow rotation seems to exist. Continuous cultivation of Gray Podzolic soils in northeastern Thailand occurs only rarely.

The unproductive quality of Gray Podzolic soils relates directly to the nature of the alluvial terrace deposits and the resulting soils which are quartz rich and very low in weatherable minerals. Potential for nutrients from weathering is almost nonexistent and the only major source of nutrients is from the small amount of organic matter in the surface horizon. Recycling of nutrients by vegetation appears to be an effective process operating in undistributed forest conditions on Gray Podzolic soils. Once the deciduous forest has been removed the close recycling relationship between plant and soil is broken and usually the original forest vegetation cannot reestablish itself.

Gray Podzolic soils lack the quality of good soil tilth for cultivation. Addition of organic matter or better retention of organic matter in the soils will help considerably to ease the management and fertility problems. Organic matter can be acquired by maintaining a plant cover. This will protect the soils from erosion as well as produce additional organic matter. Crops therefore need to be selected to meet the requirements of a sound soil management program as well as a favorable price and market.

In addition to their extremely low natural fertility, Gray Podzolic soils have poor physical properties. Due to their sandy texture and highly porous nature, as indicated in the thin sections and by the dominantly kaolinitic clay, these soils have low water holding capacity. Because of low organic matter and the weak structure in the surface horizons, Gray Podzolic soils have a strong potential for erosion when tilled. The characteristic "shifting" or splash effect, common on sandy soils, is especially important in Gray Podzolic soils. The impact of rain weakens the bond between the organic and mineral components of the surface soil. Partial loss of loose organic matter and fine particles occurs through micro-erosion, especially of cultivated soils, when bare of vegetation. A resulting micro pattern of separate loose sand and compacted more clayey patches is a typical surface phenomena of these soils (Figure 9-A). In some slight depressions, ponding of water on the surface may last for a few days after heavy rain due to the accumulation of the detached finer particles and organic matter. The presence of plinthite layers in the upper part of some profiles may create perched water tables. The plinthite layer in Gray Podzolic soils usually indicates the ground water level and restricted drainage.

Bond et al. (1966), in their report on Thailand's fertilizer situation and potential use, show a table of fertilizer use and crop response information compiled from various sources based on both actual and potential fertilizer use for the major crops grown in Thailand. They indicated that many estimations were necessary where specific information was not available. Much research and experimental data are still needed for the suitable crops and the response on Gray Podzolic soils under permanent cultivation. From the soil characteristics found in this study, the need for a high level of fertilizers is indicated since the analyses show very low levels of all major plant nutrients, and probably minor nutrients also are deficient. The sandy nature and low CEC of these soils and the usually long dry season indicate that time and method of application are crucial for effective fertilization. Irrigation and careful cultural practices are equally essential for improved results with any kind of crops on the Gray Podzolic soils.

Specific management implications are indicated for Gray Podzolic soils in each particular region since there are many factors influencing different cultivation practices and kinds of crops.

The San Pathong series in Northern Thailand, including the upper portion of the Central Plain, are slightly more productive due to more reliable precipitation and better though small reserves of weatherable minerals. Gray Podzolic soils in this area are subjected to the general gradation of the landscape and narrower valleys. Irrigation potential is better than other areas but poor water retention, excessive leaching and severe erosion when cultivated are common problems similar to other regions. Crops such as tobacco, cotton, beans, peanuts and fruit trees are successfully grown on the lower Alluvial soils of the valley. With more efficient irrigation practices and higher fertilizer levels these crops may also be grown on Gray Podzolic soils of the northern regions.

In the Southeast Coast and the lower portion of the Central Plain, Gray Podzolic soils are similar in productivity to those in the north. Precipitation is more reliable and is higher toward the east. Cassava is the dominant crop on the sandy soils (Sattahip series) of the western portion and rubber on the more clayey soils (Huai Pong series) in the eastern portion. Cassava is suitable for the sandy soil (Sattahip series) and has been in cultivation almost permanently. A need for somewhat higher levels of fertilizer use on the crop has been indicated by Bond *et al.* (1966). Erosion potential is quite severe when cultivated and some types of cover crops are needed with the cassava field. In lower areas, sugar cane is grown with moderate success. Grain and forage sorghum also may have some prospect on this sandy soil. Irrigation is impractical in this area due to the lack of water. Further east in the region with more clayey soils (Huai Pong series) and with increasing rainfall, there is a better potential for cultivation. Rubber plantations are grown mainly where rainfall is more than 1500 mm. Orchards such as citrus, pomelo, tangerine, durian, lambutan and mango have been increasingly grown in the eastern high rainfall portion. Fertilizer recommendations available in the area are mainly for the more suitable soils under better management than the Gray Podzolic soils. Thus some adaptation in fertilization and specific management skills are needed for the latter soils, particularly during the early period of orchard establishment.

The southern region has quite similar conditions to the high rainfall area of the Southeast Coast. In the south, however, rubber plantations have been established and are quite extensive. Orchards and rubber plantations are suitable crops for the Gray Podzolic soils which can reinstate or maintain fertility and reduce hazards due to poor physical properties and erosion.

The Northeastern Gray Podzolic soils have all of the severe problems in management mentioned earlier. Large areas are dominated by the very sandy Yang Talat and Nam Pong series. Erratic distribution of the rainfall and flooding are common in the southern portion of the Plateau in the Moon River Basin. Permanent or semi-permanent agriculture cannot be established without some kind of water control and irrigation together with specific soil management practices. Chu (1968, p. 21-22) gives a vivid, non-technical description of the Northeast Plateau as follows:

> East of Central Thailand is the Korat Plateau, a slightly tilted tableland that comprises one-third of the country's area. This Northeast section is an infertile region of scrubby savanna, with a scattering of low hills and patches of scrawny jungle. During the rainy season it is a collection of transient lakes and swamps; when the monsoon shifts it becomes a dustbowl of swirling laterite, a fine red soil containing iron oxide, or rust. At some spots the iron content is so high that no grass or other plants will grow. These patches of dark ground are called talat phi, or "marketplace of the ghosts.
>
> On the Korat Plateau, scaly anteaters forage among 10-foot-tall nests built by vast armies of termites. The farmers of this region grow rice, tobacco and pokaeo, or kenaf, a jute-like plant producting fibres which are used for making gunny sacks.

Adverse soil conditions are prevalent on Gray Podzolic soils in the northeast including the "shifting" surface or splash effect of rain and high susceptibility to erosion on cultivated fields when bare of vegetation, low water retention capacity, infertility and strong leaching and high susceptibility to erosion. Kenaf has been an important crop for the northeastern Gray Podzolic soils since it was introduced a few decades ago. This crop has good potential since it has the ability to thrive well under shifting cultivation but these practices leave the soil depleted of nutrients and susceptible to erosion. Improved cultural and soil conservation practices are urgently needed. Grain and forage sorghum is another crop which is well adapted to the northeast conditions and compliments the highly significant potential for cattle production.

Improvements are needed in many aspects of management and levels of the industry in order to establish permanent agriculture in the northeastern region and prevent further depletion and deterioration of the Gray Podzolic soils due to shifting cultivation. Fertilizer applications are necessary to improve agricultural production on these soils. It should be pointed out that increasing fertilizer use can encounter other limiting problems since a low level equilibrium exists on these soils for the potential agricultural production. Responsiveness to fertilization as well as improved management at all levels should be carefully studied. Present indications are that the economic return to fertilizer may be quite low under limited improved management and irrigation. Work on many other production factors essential for development of agriculture on these soils is needed. Some of these are the level of macro and micro nutrients needed in relation to higher production levels, crops and improved varieties suitable for the soils, the disease and insect control, level of the farmers' management skill, etc.

CONCLUSION

Gray Podzolic soils from different physiographic regions of Thailand are similar in general characteristics and they occupy comparable low terrace levels. These terraces appear quite similar; however, they may vary somewhat in age in the different regions. Gray Podzolic soils in lower topographic positions show a gradual transition in wetness, depth and intensity of mottling and other characteristics toward the closely associated Low Humic Gley soils.

Profiles from the different regions show only slight variation in characteristics indicative of differences in pedogenic factors such as climate and vegetation. The original concept of the Gray Podzolic great soil group originated in the northeast where these soils are most extensive. The rainfall distribution in the northeastern region is somewhat irregular with a pronounced dry season, and Dry Deciduous Forest predominates. The presence of Gray Podzolic soils under Evergreen Forest in the south, with a wet tropical climate and less distinct dry season, signifies a significant departure from the earlier concepts of a climatically oriented soil group. The analyses of profiles from the south indicate little differences physically, chemically and mineralogically from the Gray Podzolic soils in dryer areas further north except slightly lower base saturations and variations due to lithological differences of the country rocks.

The two most important factors influencing the genesis of Gray

Podzolic soils are the nature of the parent materials and the topography. Flat to gently undulating topography and resultant slow surface drainage appear essential for the formation of these soils. Mineralogical assemblages in the soils and underlying strata indicate that the alluvial parent materials were probably preweathered sediments. These profiles are quartz rich, with very few if any weatherable minerals and ubiquitous, highly stable heavy minerals, and with dominantly kaolinitic clay. These old alluvial deposits originated from predominantly acidic rock types in the catchment areas. Ferruginous fragments (litho-pedorelict) deep in the profiles and some easily weathered, relatively fresh minerals in association with otherwise stable mineral assemblages of some profiles are indications that the alluvium was dominantly preweathered before deposition. Highly weathered alluvium is to be expected in these tropical regions with deeply weathered upland soils. Reworking of older terraces to form the present low terrace levels could also have contributed highly preweathered alluvium.

The relative amount of *in situ* weathering during formation of the soils as compared to preweathering of the parent materials is conjectural. The terraces apparently are relatively old, although their absolute age is not known, and the climate is conducive of strong weathering processes. Thus, considerable weathering could have taken place since deposition. However, indications of *in situ* weathering in the profiles are quite scant in the Gray Podzolic soils studied. The only indications of importance are the cracking of quartz grains, particularly of quartzite, and common etching and engulfing of the grains. Feldspars when present suggest pre-depositional differences since they are both fresh and weathered. There are, however, some more weathered feldspar grains showing signs of disintegration and thus indicating some weathering in situ.

The quartz-dominated materials in these sandy soils are easily leached and weathering processes could lead to depletion of sparse weatherable minerals in a relatively short period of time. The presence of small amounts of lower stability minerals in several profiles can be traced to the occurrence of some rocks rich in those minerals in the respective catchment areas. The retention of these minerals may reflect less weathering in these soils but probably results mainly from differences in parent materials.

Regardless of the alternative explanations, the soils can be ranked according to their apparent state of weathering: profiles SR-8 of the southeast and SR-7 of the northeast appear to be the most thoroughly weathered; profiles SR-2 of the south and SR-5 of the northeast are intermediate; and the other profiles (SR-1, SR-3, SR-4, SR-6 and SR-9) appear less completely weathered. Since climatic variations are not consistent with these weathering stages and differences in age of the soils are probably not great, differences in mineral composition and preweathering of parent materials most logically account for the relatively minor weathering differences among these soils.

The process of clay translocation leading to formation of illuvial horizons is favored by alternate wet and dry periods and a relatively long period of time. Profile development in the Gray Podzolic soils is shown by the morphologic descriptions of eluvial A2 and illuvial Bt horizons. The presence of these horizons was confirmed by the thin sections studied.

Other interrelated soil formation processes are significant in the Gray Podzolic soils. Physical cracking of grains is a dominant part of the pedoplasmation process. This process has produced a porous matrix of loosely bound plasma with low orientation dominated by quartz grains in the upper horizons. In the lower part of the profiles, the plasma is more strongly oriented with illuviated cutans and vugh-type voids due to animal activities. The porosity is still high. Pedoturbation through the activity of termites and other soil dwellers has been significant in maintaining porosity of these soils. Termites also play an important role in reduction of surface organic litter, mixing of surface layers by mound building and accumulation of lime. Plinthite formation is an important process in some of the profiles studied and it appears to relate directly to iron mobility and accumulation at lower profile levels affected by a fluctuating water table. This process has been described as the formation of ground water laterite and, conceivably would result with time in formation of a hardened laterite layer in these soils.

The type of clay, sandy nature, and high porosity of the Gray Podzolic soil profiles together with the humid tropical climate are very conducive to strong leaching of bases which must have been initially low in supply. Depletion of the bases and organic matter is intensified when recycling of nutrients by forest vegetation has been interrupted by clearing for shifting cultivation. Exposure of the surface by cultivation promotes further leaching and depletion of nutrients. Plant opal in the alluvial parent materials suggests the possibility of at least a period of savanna when alluvium source areas were devoid of forest vegetation. Shifting cultivation practiced since prehistoric time would account for savanna periods and would have contributed to low nutrient status of the alluvium.

Eight of the nine profiles can clearly be classified as Ultisols, seven of them as Paleustults and one, SR-4, as a Paleudult. Four of the profiles are considered to have a plinthite layer as defined in the USDA system. Two of these are Plinthaquults (SR-3 and SR-6), one a Plinthustult (SR-1) and one a Plinthudult (SR-2). Profile SR-9, without an argillic horizon, fits in the Ustropept great group. The low CEC of all these soils (with placement in either the ustoxic, orthoxic and oxic subgroups) indicates the highly weathered, leached nature of

Gray Podzolic soils in Thailand and their intergrading to Oxisols.

Certain soil groups in other areas of the world show similarity to the Gray Podzolic soils of Thailand. Of these, the Leached Ferruginous Tropical soils of Africa and Lateritic Podzolic soils of Australia have characteristics most similar to the soils under this study. But, in general, they have higher base saturations. In northeastern Thailand, both high and low base saturation levels are found, with a predominance of the lower levels (Figure 27). Thus Alfisols and Ultisols may occur side by side in the major areas of the Gray Podzolic soils. The higher base saturation may be due to lime accumulation by termites and very low buffering capacity of the small amounts of kaolinitic clay and organic matter in the sandier soils.

Soil characteristics of the Gray Podzolic soils in this study indicate serious problems in their management under cultivation. In the northeast--where the rainfall is less reliable, development of adapted crops and improved varieties has lagged and the level of farmers' education, etc. are the lowest--improvements are the most difficult. With the present crops and management, the response to fertilization and irrigation on these soils is very low. Multiple improvements in other essentials of production such as improved varieties and adapted crops, pest control, increasing the level of farmers' skill, expansion of markets, etc. are also needed.

Improvements are taking place but sustained effort on all aspects of the problem is needed for effective and lasting progress. Understanding of the soil resources and their management requirements is essential to guide these developments. The Gray Podzolic soils are a significant portion of the arable soils in Thailand. This thesis is an addition to knowledge of the characteristics and genesis of those soils, giving a more accurate classification for an improved inventory of soil resources and more precise application of research results in soil management.

BIBLIOGRAPHY

Alexander, L. T. and J. G. Cady. 1962. Genesis and hardening of Laterite in soils. Soil Conservation Service, U.S. Department of Agriculture. Technical Bulletin no. 1282. 90 p.

Aubert, G. 1964. The classification of soils as used by French pedologists in tropical or arid areas. (CCTA/FAO Symposium) Leopoldville. Sols Africains. Vol. IX, no. 1. p. 107-115.

Aylmore, L. A. G. and J. P. Quirk. 1959. Swelling of clay water systems. Nature 183:1752-1753.

Bennema, J. 1963. The red and yellow soils of the tropical and sub-tropical uplands. Soil Science 95:253-257.

Bennema, J., A. Jongerius and R. C. Lemos. 1970. Micromorphology of some oxic and argillic horizons in south Brazil in relation to weathering sequences. Geoderma 4:333-355.

Bond, B. J., T. M. Kelso and R. O. Woodward. 1966. A report on the Thailand fertilizer situation and potential. (Prepared for the Agency for International Development) 164 p.

Botelho Da Costa, J. V., E. P. Cardoso Franco and R. Pinto Ricardo. 1964. Generalized soil map of Angola. (2nd Approximation) In: Transactions of the Eighth International Congress of Soil Science, Bucharest, 1964. Vol. V. p. 153-162.

Brewer, R. 1960. The petrographic approach to the study of soils. In: Transactions of the Seventh International Congress of Soil Science, Madison, Wisconsin, 1960. Vol. I. p. 1-13.

__________ 1964. Fabric and mineral analysis of soils. New York, Wiley. 470 p.

__________ 1968. Clay illuviation as a factor in particle size differentiation in soil profiles. In: Transactions of the Ninth International Congress of Soil Science, Adelaide, 1968. Vol. IV. p. 489-499.

Brewer, R. and J. R. Sleeman. 1960. Soil structure and fabric: their definition and description. Journal of Soil Science 11:172-185.

Brewer, R. and J. R. Sleeman. 1969. The arrangement of constituents in Quarternary soils. Soil Science 107(6):435-441.

Brown, G. F. et al. 1951. Geologic reconnaissance of the mineral deposits of Thailand. Geological Survey Bulletin 984. U.S. Government Printing Office. 183 p. with maps.

Brown, G. and R. Farrow. 1956. Introduction of glycerol into flake aggregates by vapor pressure. Clay Minerals Bulletin 3:44-45.

Bullock, P. 1968. The zone of degradation at the eluvial-illuvial interface of some New York soils. Ph.D. thesis. Ithaca, Cornell University. Dissertation Abstracts 29(6):1900B.

Buol, S. W. and F. D. Hole. 1961. Clay skin genesis in Wisconsin soils. Soil Science Society of America, Proceedings 25:377-379.

Cady, J. G. and R. B. Daniel. 1968. Genesis of some very old soils - The Paleudult. In: Transactions of the Ninth International Congress of Soil Science, Adelaide, 1968. Vol. IV. p. 103-112.

Charreau, C. and R. Fauck. 1970. Misc Au point sur l'utilisation Agricole des sols de la région de Séfa (Casamance). L'Agronomie Tropicale. Vol. XXV, no. 2. p. 151-191.

Chu, T. Y. and D. T. Davidson. 1953. Simplified air-jet dispersion apparatus for mechanical analysis of soils. Proceedings of the Highway Research Board 32:541-547.

Chu, V. 1968. Thailand Today. New York, Crowell. 200 p.

Crocker, R. L. 1960. The plant factor in soil formation. In: Proceedings of the Ninth Pacific Science Congress, Bangkok, 1960. Vol. 18. p. 84-90.

Desphande, T. L., D. J. Greenland and J. P. Quirk. 1968. Change in soil properties associated with removal of iron and aluminum oxides. Journal of Soil Science 19:108-122.

D'Hoore, J. 1964. La carte des sols d'Afrique au 1/5,000,000. (Colloque CCTA/FAO) Lovanium, Leopoldville. Sols Africains Vol. IX, no. 1. p. 65-73.

Dudal, R. 1960. Les sols du bassin du Mekong inférieur et leur utilization. Pedologie Vol. X. p. 24-47.

_______________ 1964. Correlation of soil classification units used in different continents. In: Transactions of the Eighth International Congress of Soil Science, Bucharest, 1964. Vol. I. p. 253-259.

_______________ 1968. Definition of soil units for the soil map of the world. World Soil Resources Report no. 33, Rome, Food and Agriculture Organization. 72 p. (with addendum, May, 4 p.).

_______________ 1969. Supplement to definitions of soil units for the soil map of the world. World Soil Resource Reports no. 37, Rome, Food and Agriculture Organization. 10 p.

Dudal, R. and F. R. Moormann. 1964. Major soils of Southeast Asia. Journal of Tropical Geography 18:54-80.

Evans, B., R. J. Hayman and M. A. Majeed. 1933. World Petroleum Congress, Proceedings 1:251-256.

Fauck, R. 1955. E'tude pedologique de la région de Sédhiou (Moyenne-Casamance). (Pedological survey of the Sedhiou region Mid-Casamance) L'Agronomie Tropicale Vol. 10, no. 6. p. 753-793.

_______________ 1963. The sub-group of Leached Ferruginous Tropical soils with concretions. Sols Africains Vol. VIII, no. 2. p. 407-429.

Flach, K. W., J. G. Cady and W. D. Nettleton. 1968. Pedogenic alteration of highly weathered parent materials. In: Transactions of the Ninth International Congress of Soil Science, Adelaide, 1968. Vol. IV. p. 343-351.

Flach, K. W., W. D. Nettleton, L. H. Gile and J. G. Cady. 1969. Pedocementation: Induration by silica, carbonates, and sesquioxides in the Quarternary. Soil Science 107(6):442-453.

Food and Agriculture Organization. 1965. Guidelines for soil profile description. Soil Survey and Fertility Branch, Land and Water Development Division, Rome. 53 p.

Frei, E. 1964. Eisenoxydkonkretionen und schlierenbildung in einigen tropenböden Equadors. (Iron oxide concretions and formation of cutans in some tropical soils of Ecuador) In: Soil Micromorphology, ed. by A. Jongerius, Amsterdam, Elsevier. p. 291-294.

Goldich, S. S. 1938. A study in rock weathering. Journal of Geology 46:17-58.

Greenland, D. J., J. M. Oades and T. W. Sherwin. 1968. Electron-microscope observations of iron ixides in some red soils. Journal of Soil Science 19:123-126.

Hamilton, R. 1964. Microscopic studies on laterite formation. In: Soil Micromorphology, ed. by A. Jongerius. Amsterdam, Elsevier. p. 269-276.

Harris, W. V. 1964. Termites -- Their recognition and controls. London, Longmans Green. 187 p.

Harward, M. E., D. D. Carstea and A. H. Sayegh. 1969. Properties of vermiculite and smectites: Expansion and collapse. Clay and Clay Minerals 16:437-447.

Harward, M. E. and A. A. Theisen. 1962. Problems in clay mineral identification by X-ray diffraction. Soil Science Society of America, Proceedings 26:335-341.

Hay, R. L. 1966. Zeolites and zeolitic reactions in sedimentary rocks. Geological Societies of America. Special paper no. 85. 130 p.

Hesse, P. R. 1955. A chemical and physical study of the soils of termite mounds in East Africa. Journal of Ecology 43:449-461.

Hole, F. D. 1961. A classification of pedoturbations and some other processes and factors of soil formation in relation to isotropism and anisotropism. Soil Science 91:375-377.

Jackson, M. L. 1956. Soil chemical analysis--advanced course. Madison, University of Wisconsin. 894 p.

____________ 1965. Chemical composition of soils. In: Chemistry of the soil, ed. by F. E. Bear. 2nd ed. New York, Reinhold. p. 71-141.

Jackson, M. L. 1968. Weathering of primary and secondary minerals in soils. In: Transactions of the Ninth International Congress of Soil Science, Adelaide, 1968. Vol. IX. p. 281-291.

Jackson, M. L. and G. D. Sherman. 1953. Chemical weathering of minerals in soils. Advances in Agronomy 5:219-318.

Kanno, I. and S. Arimura. 1958. Plant opals in Japanese soils. Soil and Plant Food (now Soil and Plant Nutrition) 4:62-67.

Karmanov, I. I. 1968. Soils of Burma. In: Geography and classification of soils of Asia, ed. by V. A. Kovda and E. V. Lobova, trans. by A. Gourevitch, Israel Program for Scientific Translations, Jerusalem. Published for U.S. Department of Agriculture, Washington, D.C. 267 p.

Kellogg, C. E. and F. D. Davol. 1949. An exploratory study of soil groups in the Belgian Congo. Institut National Pour L'Etude Agronomique du Congo Belge (INEAC), Serie Scientifique no. 46. 73 p.

Kennedy, J. G., J. G. Collins and M. H. Smith. 1967. Moisture-strength characteristics of selected soils in Thailand. U.S. Army Engineer Waterway Experiment Station, Vicksburg, Mississippi. Technical report no. 3 (in 2 vols). 51 p.

Ketudat, P. 1966. Micromorphological investigations in soils of the coastal strip of the southeast and of the eastern coastal peninsular plain of Thailand. Unpublished thesis, State University of Ghent, Belgium. 42 numb. leaves.

Khalifa, E. M. and S. W. Buol. 1968. Study of clay skins in a Cecil (Typic Hapludult) soil. I. Composition and genesis. Soil Science Society of America, Proceedings 32:857-861.

Kilmer, V. J. and L. T. Alexander. 1949. Methods of making mechanical analyses of soils. Soil Science 68:15-24.

Knox, E. G., J. F. Corliss and J. M. Williams. 1965. Dark colored, acid forest soils of western Oregon. Soil Science Society of America, Proceedings 29:732-736.

Krumbein, W. C. and F. J. Pettijohn. 1938. Manual of sedimentary petrography. New York, Appleton-Century. 549 p.

Kubiena, W. L. 1938. Micropedology. Ames, Iowa, Collegiate Press. 242 p.

____________ 1953. The soils of Europe. Issued under the auspices of Consejo Superior de Investigacionies Cientificas of Madrid. London, Murby. 317 p.

____________ 1964. The role and mission of micromorphology and microscopic biology in modern soil science. In: Soil micromorphology, ed. by A. Jongerius. Amsterdam, Elsevier. p. 1-13.

____________ 1970. Micromorphological features of soil geography. New Jersey, Rutger University Press. 254 p.

Kunze, G. W. 1955. Anomalies in the ethylene glycol solvation technique used in X-ray diffraction. Clay and clay minerals. Proceedings of the Third National Conference on Clay and Clay Minerals, Houston, 1954. p. 88-93.

Leneuf, N. and G. Riou. 1963. Red and Yellow soils of the Ivory Coast. Sols Africains Vol. VIII, no. 2, 3. p. 451-462.

Loughnan, F. C. 1969. Chemical weathering of the silicate minerals. New York, American Elsevier. 154 p.

Maignien, R. 1961. The transition from Ferrugineous Tropical soils to Ferrallitic soils in the southwest of Senegal. Sols Africains Vol. VI, no. 2, 3. p. 173-228.

____________ 1966. Review of research on laterites. Natural Resources Research IV. United Nations Educational, Scientific and Cultural Organization, Paris. 148 p.

Marshall, C. E. and C. D. Jeffrey. 1945. Mineral method in soil research. I. The correlation of soil types and parent materials with supplementary information on weathering processes. Soil Science Society of America, Proceedings 10:397-405.

Moormann, F. R. 1961. The soils of the Republic of Vietnam. Ministry of Agriculture, Saigon, Republic of Vietnam. 66 p. with map.

Moormann, F. R., S. Montrakun and S. Panichapong. 1964a. Soils of Northeastern Thailand. A key to their identification and survey.

Miscellaneous Soil Survey Report no. 9, Ministry of National Development, Bangkok. 32 p.

Moormann, F. R., W. P. Panton, G. H. Arnott, S. Rojanasoonthon and S. Panichapong. 1964b. Report on the Thai-Malayan soil correlation meeting. Soil Survey Report no. 27, Ministry of National Development, Bangkok. 47 p.

Moorman, F. R. and S. Rojanasoonthon. 1968. Soils of Thailand. Soil Survey Report no. 72, Ministry of National Development, Bangkok. 43 p. (with map showing soil conditions in Thailand).

Mulcahy, M. J. 1960. Lateritic soils in South Western Australia. Journal of Soil Science 11:206-225.

________________ 1961. Soil distribution in relation to landscape development. Zeitschrift fur Geomorpholgie (Berlin) 5:211-225.

Norgren, J. A. 1962. Thin-section micromorphology of eight Oregon soils. M.S. thesis. Corvallis, Oregon State University. 122 numb. leaves.

Nuttonson, M. Y. 1963. The physical environment and agriculture of Thailand. American Institution of Crop Ecology, Washington, D.C. 256 p.

Olcott, G. N. 1960. Preparation and use of a gelatin mounting medium for selected old impersion of minerals. American Mineralogist 45:1099-1101.

Paeth, R. C. 1970. Genetic and stability relationships of four Western Cascade soils. Ph.D. thesis. Corvallis, Oregon State University. 126 numb. leaves.

Panichapong, S. 1965. Chemical and mineralogical study of subsurface horizons of some soils of Chaingmai. Unpublished thesis, State University of Ghent, Belgium. (Reprinted in Soil Survey Reports of the Ministry of National Development, no. 42. 20 p.)

Panton, W. P. 1964. The 1962 soil map of Malaya. The Journal of Tropical Geography 18:118-124.

Parfenova, E. I. and E. A. Yarilova. 1965. Mineralogical investigation in soil science. Trans. from Russian edition 1965 by A. Gourevitch and N. Kaner of the Israel Program for Scientific

Translations, Jerusalem. Published for U.S. Department of Agriculture, Washington, D.C. 178 p.

Parry, D. W. and F. Smithson. 1964. Types of opaline silica depositions in the leaves of British grasses. Annals of Botany 28:169-185.

Pendleton, R. L. 1936. On the use of the term Laterite. American Soil Survey Association Bulletin 17:102-108.

__________ 1940. Soils of Thailand. Journal of the Thailand Research Society (The Siam Society). Natural History supplement Vol. XII, no. 2. p. 235-260.

__________ 1941a. Laterite and its structural uses in Thailand and Cambodia. Geographical Reviews 31(2):177-202.

__________ 1941b. Some results of termite activity in Thailand soils. Thai Science Bulletin 3:29-53.

__________ 1942. Importance of termites in modifying certain Thailand soils. Journal of the American Society of Agronomy 34(4):340-344.

__________ 1947. The formation, development and utilization of the soils of the Bangkok Plain. Natural History Bulletin Vol. XIV, no. 2. p. 1-40.

__________ 1953. Report to accompany the provincial map of soils and surface rocks of the Kingdom of Siam. U.S. Special Technical and Economical Mission to Thailand, Bangkok. 290 p. (Mimeographed)

__________ 1962. Thailand--Aspects of landscape and life. American Geographical Society Handbook. New York, Duell, Sloan and Pearce. 321 p.

Pendleton, R. L. and S. Montrakun. 1960. The soils of Thailand. Proceedings of the Ninth Pacific Science Congress of the Pacific Science Association, Soil and Land Classification. Vol. 18. p. 12-33 with map.

Pendleton, R. L. and S. Sharasuvana. 1942. Analysis and profile notes of some laterite soils and soils with iron concretions of Thailand. Soil Science 54(1):1-25.

Pendleton, R. L. and S. Sharasuvana. 1946. Analysis of some Thailand laterites. Soil Science 62(6):423-440.

Pettijohn, F. J. 1941. Persistence of heavy minerals and geologic age. Journal of Geology 49:610-625.

Platteborze, A. 1969. Contribution a L'etude des dépôts sablenx anciens et des podzols de basses altitudes an Cambodge. Pedologie Vol. XIX, no. 3. p. 357-386.

Prescott, J. A. and R. L. Pendleton. 1952. Laterite and lateritic soils. Commonwealth Bureau of Soil Science, England. Technical Communication no. 47. 51 p.

Rojanasoonthon, S. 1963. State of weathering of some upland soils in the Alsea Basin, Oregon. M.S. thesis. Corvallis, Oregon State University. 131 numb. leaves.

____________ 1966. Great Soil Group survey of selected study areas in Thailand. U.S. Army Engineer Waterway Experiment Station, Vicksburg, Mississippi. 32 p. in 2 vols. (Contract Report no. 3-150)

Rojanasoonthon, S. and F. R. Moormann. 1966. Final report on the Great Soil Group survey of seven selected areas in Thailand. Soil Survey Report no. 48. Ministry of National Development, Bangkok. 32 p.

Schmidt-Lorenz, R. 1964. Zur Mikromorphologic der Eisen-und Aluminumo-xydanreicherung beim Tonmineralabbau in Lateriten Keralao und Ceylons. (On the micromorphology of iron oxides and aluminum oxides accumulation by destruction of clay minerals in laterites in Kerala State and in Ceylon) In: Soil Micromorphology, ed. by A. Jongerius, Amsterdam, Elsevier. p. 279-290.

Schuffelen, A. C. and F. F. R. Koenigs. 1962. Plant nutrients in soil of different genesis. In: Transactions of Commission IV and V, International Soeicty of Soil Science, International Soil Conference, New Zealand. p. 105-120.

Scrivenor, J. B. 1930. A recent Rhyolite-ash with sponge spienles and diatoms in Malaya. Geological Magazine 67:385-393.

Simonson, R. H. 1959. Outlines of generalized theory of soil genesis. Soil Science Society of America, Proceedings 23:152-156.

Sivarajasingham, S., L. T. Alexander, J. G. Cady and M. G. Cline. 1962. Laterite. In: Advances in Agronomy 14:1-60.

Smith, H. H., D. W. Bernier, F. M. Bunge, F. C. Rintz, R. S. Shinn and S. Teleki. 1968. Area handbook for Thailand. U.S. Government Printing Office. 558 p. (DA Pam no. 550-53)

Smyth, A. J. 1963. Red and Yellow soils of western Nigeria. Sols Africains Vol. VII, no. 2. p. 463-469.

SOGREAH. 1960. Agro-pedological study of the upper Namchee Basin. Grenoble, France. 159 p. with map.

Sombroek, W. G. 1966. Amazon soils. Center for agriculture publications and documents, Wageningen. 292 p. with maps.

Stace, H. C. T. et al. 1968. A handbook of Australian soils. Glenside, South Australia, Rellim. 435 p.

Stoops, G. 1968. Micromorphology of some characteristic soils of the Lower Congo (Kinshasa). Pedologie Vol. XVIII, no. 1. p. 110-149.

Sys, C. 1969a. Soil characteristics of the experimental plots. In: Can primitive farming by modernized? ed, by F. Jurion and J. Henry from French edition 1967 by AGRA Europe (London). p. 429-455. (INEAC Hors series)

__________ 1969b. The soil of Central Africa in the American classification. Seventh Approximation. Sols Africains Vol. XIV. p. 25-44.

Sys, C. et al. 1961. La cartographie des sols au Congo et Ruanda Urundi, ses principes et ses méthodes. Institut National Pour L'Etude Agronomique du Congo (INEAC), Série Technique no. 63.

Tavernier, R. and C. Sys. 1965. Classification of the soils of the Republic of Congo (Kinshasa). Soil Classification International Symposium, Ghent, 1965. Pedologie, Special publication no. 3. p. 91-136.

Thailand. Central Statistical Office. 1962. Population census, 1960. (Changwad series: Whole kingdom) Bangkok.

Thailand, Department of Mineral Resources. 1969. Geological map of Thailand. Bangkok, Thailand. 16 p. (with explanatory notes) (Mimeographed)

Thailand, Royal Forestry Department. 1955. Type and distribution of forest in Thailand. Bangkok. 9 p.

Theisen, A. A. and M. E. Harward. 1962. A paste method for preparation of slides for clay minerals identification by X-ray diffraction. Soil Science Society of America, Proceedings 26:90-91.

Twiss, P. C., E. Suess and R. M. Smith. 1969. Morphological classification of grass phytoliths. Soil Science Society of America, Proceedings 33:109-115.

U.S. Department of Agriculture. 1951. Soil Survey Manual. Washington, D.C. 503 p. (Handbook no. 18, and 1962 supplement replacing p. 173-188)

__________ 1960. Soil Survey Staff. Soil classification - A comprehensive system. Seventh Approximation. Washington, D.C. 265 p.

__________ 1967. Soil Survey Staff. Supplement to soil classification (Seventh Approximation). Washington, D.C. 207 p.

__________ 1970. Soil Survey Staff. Selected chapters from the unedited text of the soil taxonomy of the National Cooperative Soil Survey. Soil Conservation Service. Washington, D.C.

Vacharotayan, S., S. Rojanasoonthon and M. D. Dawson. 1962. Characterization of selected Thai soils by means of X-ray diffraction chemical and mechanical analysis. Journal of the National Research Council of Thailand 3(4):207-223.

Van, N. H. 1962. Inventory and nomenclature of Vietnam soils. M.S. thesis. Ithaca, Cornell University. 134 numb. leaves with maps.

Van Wambeke, A. R. 1962. Criteria for classification of tropical soil by age. Journal of Soil Science 13(1):124-132.

Walker, T. W. and A. F. R. Adams. 1958. Studies on soil organic matter. I. Accumulations of carbon, nitrogen, sulfur and organic phosphorus in grassland soils. Soil Science 85:307-318.

Wilding, L. P. 1967. Radiocarbon dating of biogenetic opal. Science 156:66-67.

Williams, H., F. J. Turner and C. M. Gilbert. 1954. Petrography. San Francisco, Freeman. 406 p.

Witty, J. E. 1962. Grass opal in some chestnut and forested soils of Wasco County, Oregon. M.S. thesis. Corvallis, Oregon State University. 47 numb. leaves.

Yoder, H. S. 1959. Experimental studies on micas. A synthesis. Clay and Clay Minerals 2:42-60.

APPENDICES

APPENDIX A

Profile descriptions, site characteristics and photographs of sample sites arranged by geographic occurrence (SR-1, SR-7, SR-5, SR-6, SR-8, SR-9, SR-2, SR-3, and SR-4).

All color notations are from the Munsell Soil Color chart and all are moist unless otherwise specified.

The format and terms used for profile description are according to the FAO Guideline for soil profile description (1965) which followed terms and forms in the USDA Soil Survey Manual (1951) closely.

APPENDIX A

Profile: SR-1 (North and West Continental Highlands)
San Pathong Series (Sp)

Classification: Gray Podzolic soils

Described by: Santhad Rojanasoonthon
Date: December 19, 1967

I. INFORMATION ON THE SITE

Location: Amphoe Muang Chiang Mai, Changwat Chiang Mai.
The pit is along Huai Mae Yuak road, west of the highway to Fang, approximately 100 meters from the highway and close to the east-west irrigation ditch along the road. The turn off is just after passing the Army shooting range, approximately 6 kms from Chiang Mai township.
Topographic map sheet 4767 II AMS series L708 'Changwat Chiang Mai' NS coordinate 497.7 and EW coordinate 2082.0

Elevation: 315 meters

Landform:
i. Physiographic position: upper part of Lower terrace (middle terrace?)
ii. Surrounding landform: generally undulating
iii. Microtopography: nil

Slope: General direction of 1-2% E.

Land use: The area is under open (secondary) Dipterocarpus forest. The main species are Dipterocarpus tuberculatus, D. obtusiforius, Shorea obtusa, Pentacme siamensis. Sparse grasses understory with frequent bare patches.

Climate: Annual rainfall recorded at Chiang Mai is 1246 mm.[1] The normal dry season is from November to early May and quite pronounced from December to March, when a span without any rain is common.

II. GENERAL INFORMATION ON THE SOILS

a. Parent material : Old alluvium of the Ping river.
b. Drainage: Moderately well drained.
c. Moisture condition: Moist below 30 cm when described.
d. Depth of groundwater table: Unknown but almost certainly deep, at least 3 m.
e. Presence of stone and outcrop: None
f. Evidence of erosion: None at the site, but evidence of 'micro-erosion'[2] (Figure 9-A) or the phenomenon of 'shifting' on the surface is prominent.
g. Human influence: Almost nil, however the area may have been under shifting cultivation once.

III. GENERAL DESCRIPTION OF THE PROFILE

Deep, well drained, grayish to yellowish brown profile with pronounced 'micro-erosion' on the surface. Structure is moderate throughout. The profile has a light sandy loam texture and shows a moderately developed textural B, with moderately thick cutans, mainly in pores. Prominent mottles

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[1] Rainfall data from Royal Thai Meteorological Dept., Hydrometeorological Division, 1963.

[2] Micro-erosion is the condition where the material in the surface horizon is subject to separation of the fine and humus fractions from the sandy matrix when exposed to rains (splash effect).

with variegated color are strongly expressed in the lower part of the profile, resembling laterite development. Root distribution is normal with the majority of the fine roots in the top 10 cm. Larger tree roots are frequently encountered throughout the profile.

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
A1	0-5	Very dark gray (10YR3/1) and gray (10YR5/1) when dry; sandy loam; weak fine subangular blocky structure; hard, slightly sticky, slightly plastic; common very fine vesicular pores; fine to very fine animal holes in peds; many fine roots, pH 5.5; clear and wavy boundary.
A2	5-11	Brown (10YR5/3) and light gray (10YR7/2) when dry; (light) sandy loam; moderate fine subangular blocky structure; very hard, non sticky and non plastic; common fine to very fine vesicular and interstitial pores; common bleached sand grains; common fine roots; pH 5.0; gradual and smooth boundary.
B1	11-40	Light yellowish brown (10YR6/4); sandy loam; moderate medium subangular blocky structure; firm, slightly sticky and slightly plastic; common very fine vesicular and interstitial pores; thin, patchy cutans in pores; few medium roots and common fine roots; pH 5.0; gradual and wavy boundary.
B2t	40-73	Light yellowish brown (10YR6/4) matrix, with few fine distinct mottles of strong brown color (7.5YR5/6); sandy clay loam; moderate medium subangular blocky structure; friable, sticky and plastic; common very fine vesicular pores, few fine tubular pores; patchy bridging cutans with common moderately thick in pores; sparse medium roots; pH 5.0; gradual and smooth boundary.
B3g	73-122+	Light brownish gray (10YR6/2) matrix; many medium prominent mottles with variegated color of red and brown (10R4/6, 7.5YR5/6); clay; weak medium subangular blocky structure; friable, very sticky and very plastic; common very fine vesicular pores with few fine to very fine tubular pores; moderately thick, continuous cutan in pores and on peds; sparse medium roots; pH 5.5.
Remarks		The number and size of the red and brown color mottles usually increase with depth in the lower part of the profile, the pattern resembles the mottled clay layer of 'soft laterite' development.

Profile: SR-7 (Northeast Plateau)
Korat series (Kt)

Classification: Gray Podzolic soils

Described by: Santhad Rojanasoonthon and Jitti Pinthong
Date: December 28, 1967

I. INFORMATION ON THE SITE

Location: Nong Mek village, Tam bon Tha Phra, Amphoe Muang, Changwat Khon Kaen.
Along Tha Phra-Kosompisai road. About 1.5 km from railway crossing or 2 km from the Northeast highway. Directly in line and south of the horse breeding section of the Tha Phra livestock station.
AMS L708 no. 5559 I "Station Ban Hat"
NS coordinate 266.9 EW coordinate 1806.8

Elevation: Approximately 170 m.

Landform:
i. Physiographic position: low terrace (middle terrace?)
ii. Surrounding landform: gently undulating.
iii. Microtopography: nil, common termite hills.

Slope: 2% NE

Land use: Open cleared area which was once used for kenaf field, now covered with *Eupatorium odoratum*. The sparse remaining trees are *Dipterocarpus* spp., *Shorea* spp., *Pentacme* spp.

Climate: Tropical savanna climate with average rainfall of 1208 mm at Khon Kaen (10 km north of the site).

II. GENERAL INFORMATION ON THE SOILS

a. Parent material : Old river alluvium.
b. Drainage: Well drained.
c. Moisture condition: Dry when described down to about 35 cm.
d. Depth of groundwater table: Unknown but usually deep (3-5 m).
e. Presence of stone and outcrop: None.
f. Evidence of erosion: None at the site, common micro-erosion at the surface.
g. Human influence: Mainly on the surface horizon, with possibly many cycles of shifting cultivation of rice in the past and recently of kenaf.

III. GENERAL DESCRIPTION OF THE PROFILE

A well drained, deep, yellowish brown profile with moderately well developed structure. Textural B horizons are also prominent with strong mottles. Hard lateritic concretions are common in the lower part of the profile. Compaction of the subsurface, below plow layer, when the soil is dry is distinctive. Root distribution is normal. The evidence of "inverted gley"[1] can be clearly seen in the first two horizons.

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-6/10	Grayish brown (10YR5/2) and light gray (10YR7/1) when dry; many fine distinct root mottles, evidence of "inverted gley" ; (light) sandy loam;

[1]Probably once under shifting rice cultivation, since surface gleying is the direct result of temporary flooding of the field for paddy rice.

Horizon	Depth (cm)	
		weak fine granular structure; slightly hard, dry, non sticky and non plastic; common very fine vesicular pores; many fine roots; pH 5.5; clear and wavy boundary.
A2	6/10-34	Light brown (7.5YR6/4) and very pale brown (7.5YR7/3) when dry; few very fine to fine faint root mottles (inverted gley); sandy loam; weak fine subangular blocky structure; very compact pan-like, dry, hard, slightly sticky and slightly plastic; few very fine vesicular pores, common medium to large ant holes; few fine charcoals fragments; common fine roots, few medium darker dead roots; pH 5.0; gradual and smooth boundary.
B1	34-62	Light brown (7.5YR6/4) moist; sandy clay loam; weak to moderate fine subangular blocky structure; firm, sticky and plastic; common very fine vesicular and tubular pores; thin to moderately thick cutans in pores and some around peds; common fine roots; pH 4.5; gradual and smooth boundary.
B21t	62-94	Light brown (7.5YR6/4); sandy clay loam; weak to moderate medium subangular blocky structure; friable, very sticky and plastic; common very fine tubular and vesicular pores; continuous moderately thick cutans in pores and around peds, few fine roots; pH 4.5; gradual and smooth boundary.
B22t	94-130	Light brown (7.5YR6/4) few fine distinct mottles; sandy clay; weak fine to moderate subangular blocky structure; firm, very sticky and plastic; common very fine vesicular and few very fine to fine tubular pores; few medium moderately hard nodules (lateritic concretions); broken thin cutans around peds and in pores; few roots; pH 4.5; gradual and smooth boundary.
B3	130-198	Light brown (7.5YR6/4); few to common fine distinct strong brown (7.5YR5/8) mottles; sandy clay; moderate fine to medium subangular blocky structure; firm, sticky and plastic; common very fine tubular and vesicular pores; few medium moderately hard nodules (lateritic concretions); continuous thick cutans; few fine and medium roots; pH 4.5; gradual and smooth boundary.
IIC	198-270	Yellow (10YR7/6); common medium distinct strong brown (7.5YR5/8) and common medium prominent red (10R4/8) mottles; clay; strong fine and medium subangular blocky structure; firm, very sticky and plastic; few very fine vesicular pores; continuous thick cutans; very few fine and medium roots; this horizon appears to indicate that it is a weathered shale layer.

Profile: SR-5 (Northeast Plateau)
Korat series (Kt)

Classification: Gray Podzolic soils

Described by: Santhad Rojanasoonthon
Date: December 27, 1967

I. INFORMATION ON THE SITE

Location: Changwat Nakhon Phanom, Amphoe Muang.
In field crop propagation station, Department of Agriculture. Approximately 15 km south of Nakhon Phanom township along Mukdahan road. The site is at about 150 m north of the station gate.
AMS series L 708 5962 I.
NS coordinate 1909.7 EW coordinate 477.0

Elevation: 150 m (approximately).

Landform:
i. Physiographic position: low terrace? (upper part).
ii. Surrounding landform: undulating.
iii. Microtopography: nil.

Slope: General direction 0-1% SE

Land use: Land had been cleared and used for field crop experimenting mainly kenaf (Hibiscus cannabinus) and some upland rice. Sparse remaining trees are mainly Dipterocarpus species.

Climate: Part of the tropical savannah climate, but here the rainfall is higher than the rest of the plateau. Average annual rainfall at Changwat Nakhon Phanom at 2163 mm leads to better formation of forest type of mixed deciduous and dry evergreen forest. At Mukdahan (90 km south of the site) average rainfall is 1445.9 mm; at Sakon Nakhon (80 km west of the site) rainfall is 1493 mm.

II. GENERAL INFORMATION ON THE SOILS

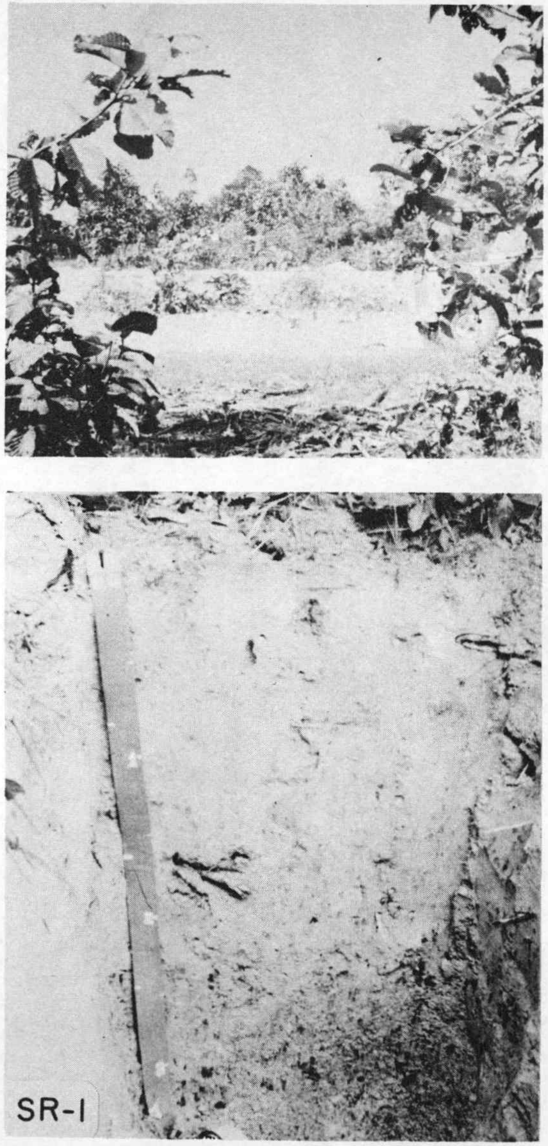
a. Parent material: Old alluvium (river).
b. Drainage: Well drained.
c. Moisture condition: Dry when described at least down to 40 cm.
d. Depth of groundwater table: Unknown but deep, at least 2-4 m.
e. Presence of stone and outcrop: None.
f. Evidence of erosion: None at the site.
g. Human influence: Confined to surface 10-30 cm.

III. GENERAL DESCRIPTION OF THE PROFILE

Deep, well drained profile with color changing from dark brown surface to yellowish red in the B horizon. Structure is weakly developed except in the B horizon where texture changed from sandy loam to sandy clay loam. Animal holes (mainly ants) are common throughout. Pan-like compactive layer is developed directly under the plow layer. Thick clay skins are found in B horiaon. Root distribution is normal. Mottled clay is common in the lower part of the profile.

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-8/12	Dark brown (10YR3/3) and light brownish gray (10YR6/2) when dry; sandy loam; moderate common fine granular structure but on the lower portion strong medium platy structure; hard, dry, particularly in plough trough; slightly sticky and slightly plastic; common very fine vesicular and interstitial pores; few fine root pores; common mixing of dark and light spots by plowing; many fine roots; clear and wavy boundary; pH 5.0.
A21	8/12-40	Dark brown (10YR4/3), grayish brown (10YR5/2) when dry; sandy loam; weak fine subangular blocky structure; firm, slightly sticky and slightly plastic; few very fine vesicular and interstitial pores, few fine root pores; common bleached sand grains; few fine roots; compact pan-like; clear and smooth boundary; pH 6.0.
A22	40-53	Strong brown (7.5YR5/6-5/8); sandy loam; weak fine subangular blocky structure; very firm, slightly sticky and plastic; patchy thin cutans in root pores; common very fine to fine vesicular and interstitial pores, few fine animal pores; few fine roots; gradual and smooth boundary; pH 4.5.
B1	53-72	Yellowish red (6YR5/6); sandy clay loam; weak medium subangular blocky structure; firm, sticky and plastic; broken thin cutans in pores and some patchy on peds; common very fine vesicular pores, few very fine to fine tubular pores; few fine roots; gradual and smooth boundary; pH 4.5.
B21t	72-119	Yellowish red (5YR5/6); few fine very faint mottles; sandy clay loam; moderate medium subangular blocky structure; friable, sticky and plastic; continuous moderately thick clay skins in larger pores; patchy thin cutans around peds; common very fine to fine tubular and vesicular pores; few fine roots; gradual and smooth boundary; pH 4.5.
B22t	119-147	Yellowish brown (10YR5/4), matrix and common fine faint mottles with strong brown (7.5YR5/6) color; sandy clay loam; weak fine subangular blocky structure; friable, sticky and plastic; clay skins similar to above horizon; common very fine to fine tubular and vesicular pores; very fine roots; gradual and smooth boundary; pH 4.5.
B23tg	147-153+	Light yellowish brown (10YR6/4), matrix, mottles color (7.5YR5/8), common fine distinct mottles; fine sandy clay; weak fine subangular blocky structure; friable, sticky and plastic; patchy thin cutans in pores and around peds; common very fine to fine tubular and vesicular pores; very few roots; pH 4.5.
	Note	From the surface to B1, there are numerous holes (4-5 cm in diameter) which are probably due to the dead roots or animal holes.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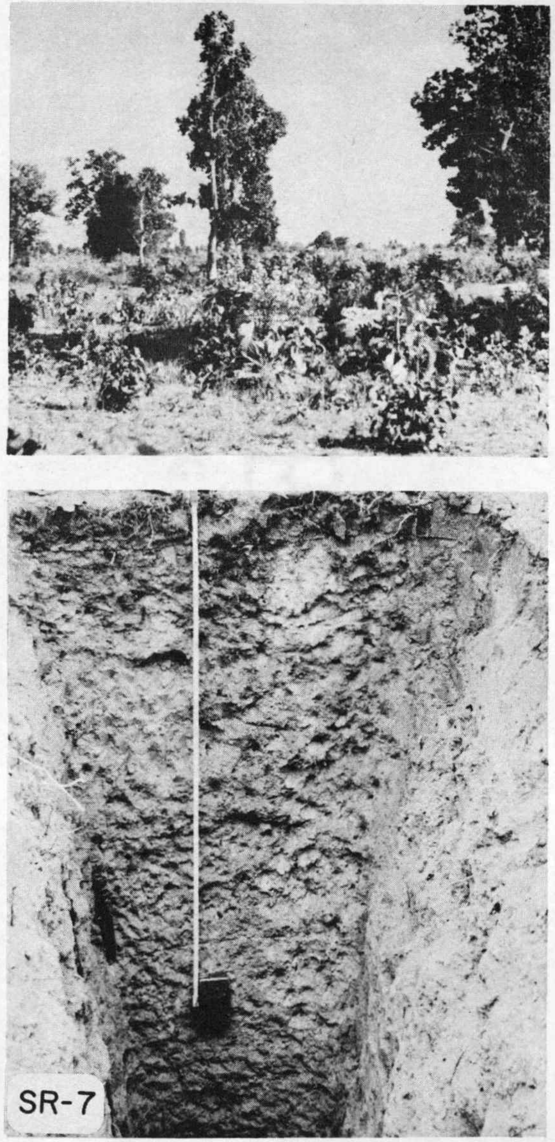
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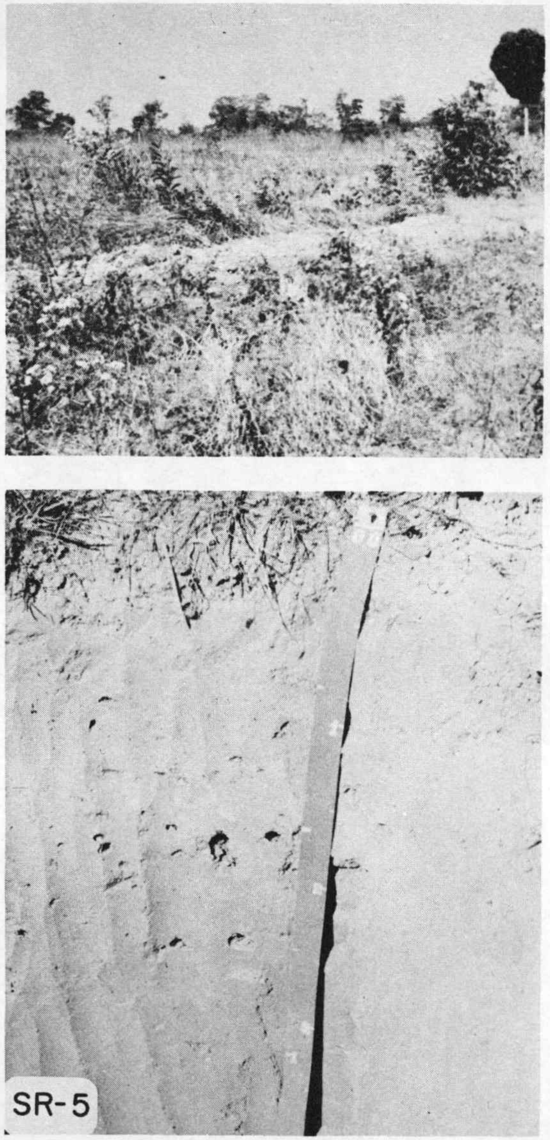

SR-5

Profile: SR-6 (Northeast Plateau)
Renu series (Rn)

Classification: Gray Podzolic- Low Humic Gley soils

Described by: Santhad Rojanasoonthon
Date: December 27, 1967

I. INFORMATION ON THE SITE

Location: Phon Thong village (Tam bon Renu), Amphoe That Phanon, Changwat Nakhon Phanom
The site is at the first north turn off along the road approaching Renu village, in the kenaf field (former rice field).
AMS L708 number 5962 III 'Ban Renu'
NS coordinate 466.5 EW coordinate 1885.2

Elevation: About 142 m.

Landform:
i. Physiographic position: low terrace, lower zone above rice field.
ii. Surrounding landform: gently undulating.
iii. Microtopography: nil, prominent termite hills in the area.

Slope: 2% E.

Land use: The area is under open secondary dipterocarp forest with recent clearing and sparse shrubs, common species are Shorea, Pentacme, bamboo, the land is cleared for kenaf planting with small patch of watermelon in the lower ground.

Climate: Part of the tropical savannah climate, but here the rainfall is higher than the rest of the plateau. Average annual rainfall at Nakhon Phanom (30 km north of the site) is 2163 mm. Forest type in this area departs somewhat from the usual dipterocarp forest to mixed deciduous and dry evergreen forest due to the higher rainfall. Sixty km south of the site at Mukdahan average rainfall is only 1445 mm. At Sakon Nakhon (70 km west of the site) rainfall is 1493 mm.

II. GENERAL INFORMATION ON THE SOILS

a. Parent material : Old alluvium.
b. Drainage: Somewhat poorly drained.
c. Moisture condition: Dry when described down to about 60 cm.
d. Depth of groundwater table: Unknown but relatively shallow in the wet season, usually at least 1.5-2 m.
e. Presence of stone and outcrop: None.
f. Evidence of erosion: None at the site.
g. Human influence: Mainly on the surface layer. Evidence of shifting cultivation in the past, an abandoned rice field.

III. GENERAL DESCRIPTION OF THE PROFILE

Variegated color of mottles is prominent throughout the profile, and increases in intensity and number in the lower part of the solum. Structure distribution is normal. The soil is somewhat poorly drained.

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-5/7	Light brownish gray (10YR6/2) and light gray (10YR7/1) when dry; sandy loam; weak fine granular structure; hard, dry, slightly sticky and slightly plastic; common very fine interstitial and vesicular pores; few small charcoal fragments; common fine roots; pH 5.0; abrupt and wavy boundary.
A2	5/7-17	Light yellowish brown (10YR6/4) matrix, few fine faint mottles (7.5YR6/8), pinkish gray (7.5YR7/2) when dry; sandy loam; weak fine subangular blocky structure; very hard dry (compact), slightly sticky, slightly plastic; few very fine vesicular pores, few very fine to fine animal holes (mainly ant); common clean bleached sand grains; few fine roots; pH 4.5; gradual and smooth boundary.
B21t	17-39	Pinkish gray (7.5YR6/2) matrix, common fine to medium distinct mottles (7.5YR5/8), pinkish gray to pink (7.5YR7/3) when dry; sandy loam; weak fine to medium subangular blocky structure; very hard dry, slightly sticky and plastic; common very fine vesicular and tubular pores; patchy thin cutans on peds, continuous thin cutans in root channels; few fine roots; pH 4.5; diffuse and smooth boundary.
B22t	39-70	Pinkish gray (7.5YR7/2) matrix, mottles as in above horizon but more distinct (7.5YR5/8 and 5YR4/8); sandy clay loam; weak fine subangular blocky structure; very hard when dry, very firm, sticky and plastic; pores similar to above horizon; continuous thin cutans on peds; few fine roots; pH 4.5; gradual and smooth boundary.
B23tg	70-100+	Pinkish gray (7.5YR6/2) matrix, many prominent fine to medium mottles (mainly 2.5YR5/8); sandy clay loam; weak fine subangular blocky structure; firm, sticky and plastic; pores and clay skins similar to above horizon; few roots; pH 4.5.

Profile: SR-8 (Southeast Coast)
Huai Pong series (Hp)

Classification: Gray Podzolic soils

Described by: Santhad Rojanasoonthon and Jitti Pinthong
Date: December 29, 1967

I. INFORMATION ON THE SITE

Location: Tambon Huai Pong, Amphoe Muang, Changwat Rayong.
In Huai Pong Agriculture Experiment Station, Sukumwit Highway near front entrance of the station.
AMS L708 no. 5249 III
NS coordinate 731.8 EW coordinate 1408.6

Elevation: 35 m.

Landform:
i. Physiographic position: higher marine terrace or coastal shelf.
ii. Surrounding landform: gently undulating, part of the large, rather flat terrain.
iii. Microtopography: nil, influence of termite mounds.

Slope: 1-2% W and NW

Land use: Cultivated field for fruit trees, kapok, cassava, jackfruits, using velvet bean as cover crops. Other trees in the vicinity: mango, coconut, cashew nut, etc.

Climate: Generally in tropical savannah climate but transitional to tropical monsoon climate as rainfall gradually increases toward the east. Rainfall at nearby Satahip (20 km west of the site) is 1312 mm annually, whereas at Chantaburi (about 200 km east) rainfall is 3025 mm which is tropical rain forest climate.

II. GENERAL INFORMATION ON THE SOIL

a. Parent material: Old marine alluvium, probably of granite rock origin (presence of coarse sand fragments in the soil).
b. Drainage: Moderately well drained.
c. Moisture condition: Dry when described, down to about 50 cm.
d. Depth of groundwater table: Unknown, usually deep, 2-3 m.
e. Presence of stone and outcrop: None.
f. Evidence of erosion: None at the site.
g. Human influence: Usually on the surface layer only, indication that termite mounds in the area had been leveled in the last 3-5 years.

III. GENERAL DESCRIPTION OF THE PROFILE

Moderately well drained and moderately deep brown profile. Clay loam to clay texture with distinct presence of coarse sand fraction (possibly granite derived). Strong mottles and lateritic nodules or mottled clay are prominent in the lower part of the profile (about 1 m). Root distribution is normal.

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-15	Grayish brown (10YR5/2 and 10YR6/1), dry; clay loam, with coarse sand in the sand fraction; weak crumb structure in upper 5 cm but weak fine subangular blocky in the lower part; very hard dry, slightly sticky and slightly plastic; common very fine interstitial pores; common fine roots; pH 6.0; clear and wavy boundary.
A2	15-25	Light yellowish brown (10YR6/4 and 10YR7/3) dry; clay loam, with coarse sand in the sand fraction; weak fine subangular blocky structure; very hard dry, slightly sticky and slightly plastic; common very fine interstitial pores; common fine roots; pH 5.5; gradual and smooth boundary.
B21t	25-53	Pale brown (10YR6/3) and very pale brown (10YR7/4) when dry; few fine faint mottles; coarse sandy clay; weak fine subangular blocky structure; hard, sticky and plastic; patchy thin cutans, moderately thick in pores and channels; common very fine interstitial and tubular pores; common fine roots; pH 5.5; gradual and smooth boundary.
B22t	53-88	Very pale brown (10YR7/4); common fine faint mottles; coarse sandy clay; weak to moderate fine subangular blocky structure; very firm, sticky and plastic; common very fine interstitial and few very fine tubular pores; broken thin cutans, with moderately thick in pores and channels; few fine lateritic nodules, increasing with depth; pH 4.5; gradual and smooth boundary.
B31	88-105	Very pale brown (10YR7/4) matrix, with common medium distinct mottles (lateritic nodules); coarse sandy clay; weak, medium subangular blocky structure; firm, sticky and plastic; pores and cutans similar to above horizon; increasing lateritic nodules (red and yellow); pH 4.5; clear and smooth boundary.
IIB32	105-140	Very pale brown to yellow (10YR7/4 to 7/6); few fine prominent reddish yellow (5YR6/8) mottles; coarse sandy clay, 33% of lateritic nodules; weak to moderate medium subangular blocky structure; firm, sticky and plastic; common fine tubular pores; few fine roots; pH 5.0; clear and wavy boundary.
IIIC1	140-165	Very pale brown (10YR7/3 to 7/4); common medium brownish yellow (10YR6/8) and common prominent yellowish red (5YR5/8) mottles; coarse sandy clay, approximately 36% of nodules; massive; firm, sticky and plastic; common fine vesicular and tubular pores; very few fine roots; pH 5.0; clear and wavy boundary.
IIIC2	165-235	Very pale brown (10YR8/3); many medium and coarse prominent yellowish red and red (5YR5/8 and 2.5YR5/8) mottles; coarse sandy clay, approximately 50% of lateritic nodules; massive; firm, sticky and plastic; few fine tubular pores; no roots; the nodules are largely hard; pH 5.0.

Profile: SR-9 (Southeast Coast)
Sattahip series (Sh)

Classification: Gray Podzolic soils

Described by: Santhad Rojanasoonthon and Jitti Pinthong
Date: December 29, 1967

I. INFORMATION ON THE SITE

Location: Tambon Thung Sukla, Amphoe Siracha, Changwat Chon Buri.
In Kasetsart University Student Training farm, about 15 m south of the farm pond, west of Thung Ngua Hill.
AMS series L708 no. 5150 II
NS coordinate 708.6 EW coordinate 1450.9

Elevation: 45 m.

Landform: i. Physiographic position: old marine terrace.
ii. Surrounding landform: undulating and partly hilly.
iii. Microtopography: nil.

Slope: Sloping 4-5% SE.

Land use: Cultivated field, at present, Napier grass, few <u>Eupatorium</u> <u>odoratum</u>, <u>Imperata</u>, etc. (earlier planted to cassava).

Climate: Tropical savannah climate, rainfall at Chon Buri (25 km north of the site) average at 1335.6 mm annually.

II. GENERAL INFORMATION ON THE SOIL

a. Parent material: Old marine alluvium, with some influence possibly from quartzite hill, with gneiss and schist rocks in the area.
b. Drainage: Well drained.
c. Moisture condition: Dry when described at least 50-60 cm.
d. Depth of groundwater table: Unknown but generally deep, 3-4 m, with strong lateral movement down from the adjacent hill east of the site.
e. Presence of stone and outcrop: Few quartzitic stones from the quartzite hill nearby.
f. Evidence of erosion: Sheet erosion with some moderately deep gully erosion nearby especially in the pond which contains water only two to three months of the year.
g. Human influence: On surface layer with possibly leveling and grading of the whole area.

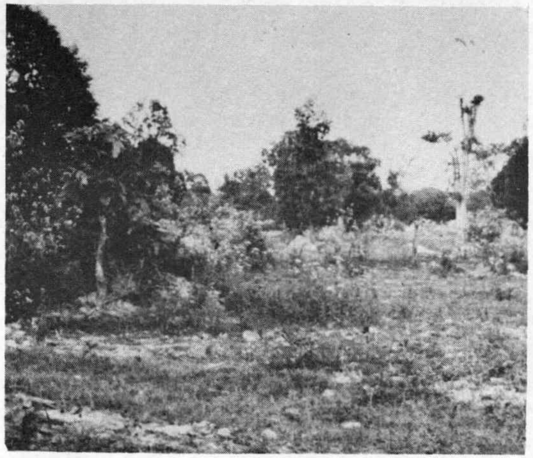
III. GENERAL DESCRIPTION OF THE PROFILE

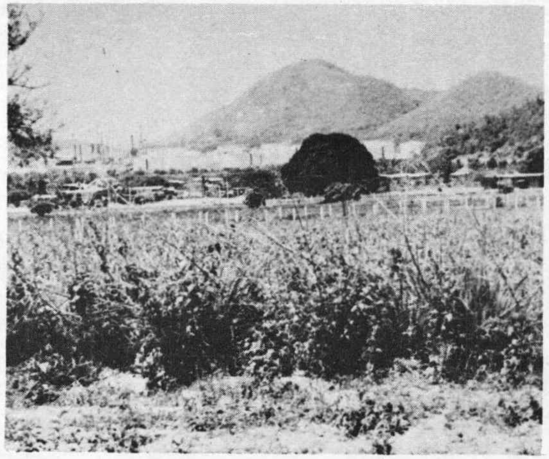
Moderately well drained, deep strong brown profile with reddish subsoils. Structural development in B is weak and horizonation is ill defined. Worm holes are common throughout. Roots are concentrated mainly on the surface horizons.

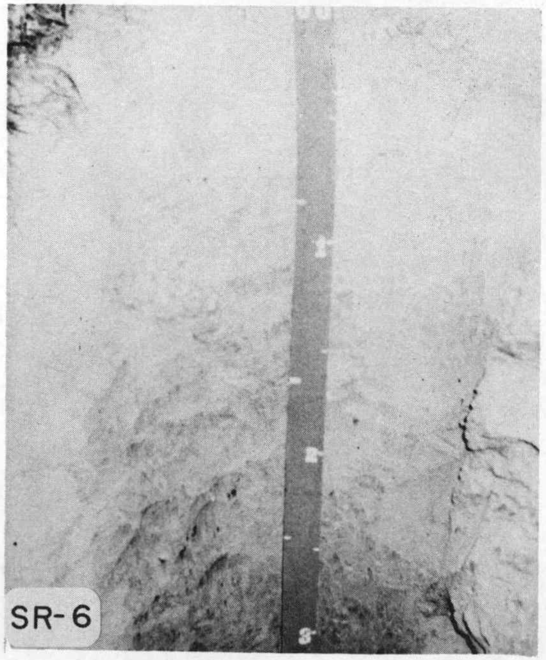
IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-19	Brown to dark brown (10YR4/3); (light) fine sandy loam; weak fine subangular blocky structure to slightly platy; hard, firm, slightly sticky and non plastic; common very fine interstitial pores; common fine roots; pH 6.0, abrupt and smooth boundary.
A2	19-36	Strong brown (6YR5/6); fine sandy loam; weak fine subangular blocky structure; hard, friable, slightly sticky and non plastic; common very fine interstitial and few very fine tubular pores; few fine to moderate ant holes; common fine roots; pH 6.0; gradual and smooth boundary.
B21t?	36-68	Yellowish red (5YR5/6); sandy loam; weak fine to medium subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine interstitial and tubular pores; patchy thin cutans; few roots; pH 6.0; gradual and smooth boundary.
B22t?	68-105	Yellowish red (5YR5/6); sandy loam (with more clay); weak to moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; common very fine tubular pores; patchy thin cutans; sparse roots; pH 5.5; gradual and smooth boundary.
B23	105-155	Yellowish red (5YR4/6); coarse sandy loam with 9% fragments (largely quartz); weak to moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; patchy thin cutans; common very fine tubular and vesicular pores; few very fine and medium roots; pH 5.5; gradual and smooth boundary.
B3	155-210	Yellowish red (4YR4/6); very coarse sandy loam with 12% quartz fragments; very weak fine subangular blocky structure; friable, slightly sticky and non plastic; patchy thin cutans; common very fine tubular and interstitial pores; few fine and medium roots; pH 5.5; gradual and smooth boundary.
IIC1	210-265	Red (2.5YR4/6); very coarse loamy sand with 40% quartz fragments; noncoherent (single grain); loose, non sticky and non plastic; many fine and medium interstitial pores; few fine roots; pH 6.0; gradual and smooth boundary.
IIIC2	265-280+	Variegated color (patches) of 40% red (2.5YR4/6); 30% light gray (10YR7/1) and 30% of yellowish brown (10YR5/6); coarse sandy clay loam with 47% quartz fragments; massive; firm, sticky and slightly plastic; common fine tubular and few vesicular pores; pH 6.0; this horizon resembles weathered crystalline rocks, possibly granitic gneiss.

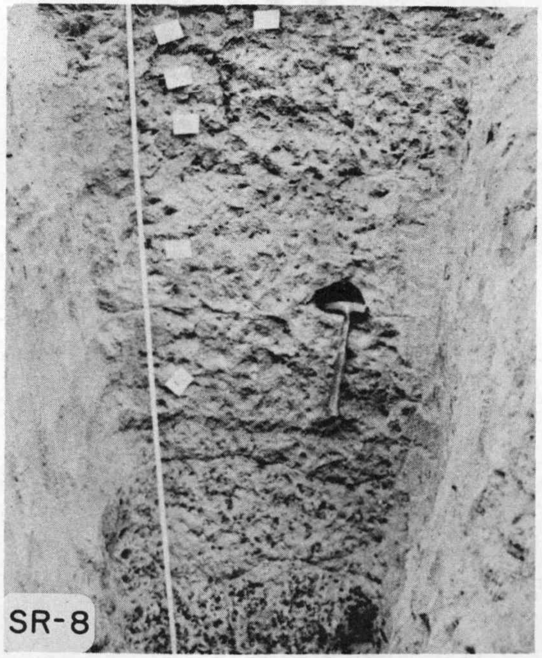
Note: Common worm holes 1-2 mm diameter throughout profile. Sand grains, varying in size mainly 2-4 mm and coarser down the profile.







SR-6



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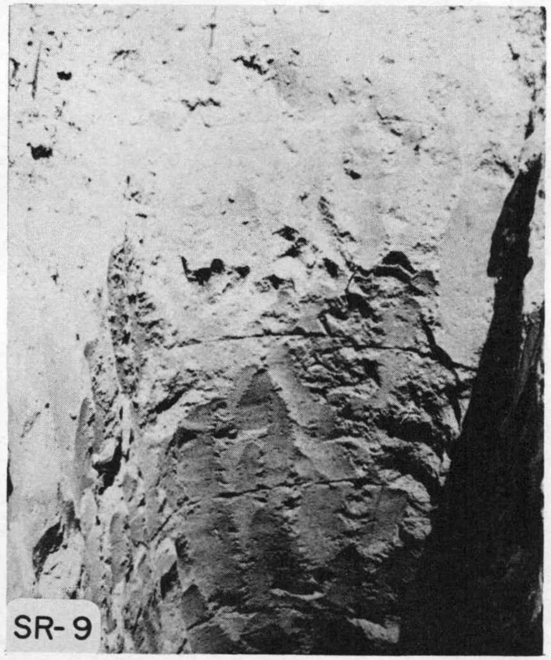


SR-9

Profile:	SR-2 (Peninsular Thailand) Kho Hong series (Kh)
Classification:	Gray Podzolic-Yellow Latosols
Described by:	Santhad Rojanasoonthon
Date:	December 22, 1967

I. INFORMATION ON THE SITE

Location: Amphoe Hat Yai, Changwat Songkla (Peninsular Thailand).
In Rubber Research Center, Kho Hong. About 30 m south of the station gate, directly in line and east of the administration building of the Center.
AMS series L708 map sheet 5132 III "Ban Nam Krachai"
NS coordinate 665.8 EW coordinate 775.6

Elevation: Approximately 10-12 m.

Landform:
i. Physiographic position: lower terrace probably marine in origin.
ii. Surrounding landform: gently undulating.
iii. Microtopography: nil.

Slope: General direction of the slope is 1-2% N.

Land use: At present, it is under rubber plantation with the stand of about 10-15 years old. Other areas when not under rubber plantation carry a rather dense stand of shrubs.

Climate: Because of the two-three months of dry period, usually January-February-March when rainfall is lower than 60.9 mm (2.4 inches) the area fits Köppen's Tropical Monsoon (Am) climate rather than tropical rain forest (Af). Annual rainfall recorded at Songkla (35 km east of the site) is 2231 mm.

II. GENERAL INFORMATION ON THE SOILS

a. Parent material: Old (possibly marine) alluvium.
b. Drainage: Moderately well drained to well drained.
c. Moisture condition: Moist when described.
d. Depth of groundwater table: Unknown, but most likely will be about 1.5 to 2.m.
e. Presence of stone and outcrop: None.
f. Evidence of erosion: None at the site.
g. Human influence: Confined to surface layer. Recently, the area has been ploughed every two years. There is also evidence that some leveling and spreading of termite hills may have been done at one time or other in the past (i.e., maybe during leveling of the land when setting up the station.

III. GENERAL DESCRIPTION OF THE PROFILE

Deep, moderately well drained, almost uniformly brown profile. Structure is weakly developed and texture is sandy loam changing to more clayey B horizon in the lower part of the profile. Cutans are usually thick, mostly lining pores, particularly the larger animal and root pores. The distribution of roots is normal throughout. Mixing of the termite and ant activities, partly due to human influence, is dominant all through the profile.

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap (A1)	0-15	Brown (10YR5/3); sandy loam; weak, fine subangular blocky structure; very friable, slightly sticky and slightly plastic; very fine to fine vesicular and tubular pores; many fine roots; pH 5.5; clear and wavy boundary.
A2	15-53	Yellowish brown (10YR5/4); sandy loam; weak, fine subangular blocky structure; friable, slightly sticky and slightly plastic; thin pore lining cutans in few fine animal pores; very fine to fine tubular and vesicular pores; common fine roots; pH 5.5; gradual and smooth boundary.
B1	53-67	Strong brown (7.5YR5/6) with some darker spots (10YR5/4) of horizon above; sandy clay loam; weak fine subangular blocky structure; friable, slightly sticky, slightly plastic; moderately thick cutans lining animal holes, thin patchy ped coatings; common very fine tubular pores, few fine animal holes; few fine roots; pH 4.5; gradual and smooth boundary.
B21t	67-91	Strong brown (7.5YR5/6); few fine faint mottles; sandy clay loam; weak medium subangular blocky structure; friable, slightly sticky and plastic; moderately thick cutans in pores and on peds; common medium animal holes (termite and ants), common very fine tubular pores, few fine vesicular pores; few fine roots; pH 4.0; gradual and smooth boundary.
B22t	91-125	Strong brown (7.5YR5/6) common medium distinct mottles (red and brown); sandy clay, with about 10% of lateritic nodules; weak medium subangular blocky structure; sticky and plastic; thick continuous cutans in animal pores, moderately thick patchy on peds; many very fine to fine tubular pores, few fine animal pores; pH 4.0; gradual and smooth boundary.
B3g	125-143+	Brownish yellow (10YR6/6) matrix with many medium prominent mottles, red and brown (10YR4/6, 7.5YR5/8); sandy clay with 80% lateritic nodules (soft); massive; sticky and plastic; few very fine tubular pores; pH 4.5.

<u>Note</u>: Common ant and termite holes throughout the profile, varying in size from 3 cm to 20 cm in diameter. Activity of such animals in these soils is quite vigorous.

Profile: SR-3 (Peninsular Thailand)
Nam Krachai series (Ni)

Classification: Gray Podzolic-Low Humic Gley soils or Yellow Latosols

Described by: Santhad Rojanasoonthon
Date: December 22, 1967

I. INFORMATION ON THE SITE

Location: Kho Hong, Amphoe Hat Yai, Changwat Songkla. In Rubber Research Center. The pit is in between rows of rubber trees, 7-10 years old. Opposite the station officers' quarters and about 300 m SW of the Center's Agronomy Building.
AMS series L708 map sheet 5132 III "Ban Nam Krachai"
NS coordinate 666.0 EW coordinate 775.2

Elevation: Approximately 7-10 m above sea level.

Landform:
i. Physiographic position: lower concave portion of the lower terrace (marine).
ii. Surrounding landform: gently undulating.
iii. Microtopography: nil.

Slope: General direction of the slope is 1-2% N.

Land use: At present it is under rubber plantation with the stand of 7-10 years old (TJ-1 variety).

Climate: Similar to SR-2.

II. GENERAL INFORMATION ON THE SOILS

a. Parent material: Old marine alluvium.
b. Drainage: Somewhat poorly drained.
c. Moisture condition: Moist to wet when described.
d. Depth of groundwater table: 1.20 m.
e. Presence of stone and outcrop: None.
f. Evidence of erosion: None at the site.
g. Human influence: Confined to surface layer, ploughing at an interval of at least two-three years, also some evidence of leveling and grading of the land probably when starting the station.

III. GENERAL DESCRIPTION OF THE PROFILE

Moderately deep, somewhat poorly drained, brown to strong brown profile. Mottles are almost to the surface and become very prominent in the lower textural B horizon. This variegated mottled color resembles the "soft laterite" layer at 100 cm. Structure is moderately developed throughout. Fine root development concentrates mainly in the upper 20 cm. Larger tree roots (rubber) are frequently encountered throughout the profile.

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
A1 (Ap)	0-17	Brown (10YR5/3); light sandy loam; moderate fine to medium subangular blocky structure; very friable, slightly sticky and slightly plastic; few very fine vesicular pores; common fine roots; pH 5.5; gradual and wavy boundary.
A2	17-35	Pale brown (10YR6/3), few fine faint mottles (10YR6/6); light sandy loam; moderate medium subangular blocky structure; friable, slightly sticky and plastic; few very fine tubular pores, few fine animal holes; few fine roots; pH 5.0; diffuse and smooth boundary.
B1?	35-63	Light gray (10YR7/2) matrix; common fine distinct mottles (10YR6/8); sandy clay loam; moderate medium subangular blocky structure; friable, sticky and plastic; common very fine tubular pores and few very fine vesicular pores; few fine animal holes; few fine roots; pH 5.0, diffuse and smooth boundary.
B21t	63-89	Light gray (10YR7/1) matrix; common fine faint mottles (10YR6/6); sandy clay; moderate fine to medium subangular blocky peds; friable, sticky and plastic; many very fine tubular and very fine vesicular pores, few fine animal holes; moderately thick cutan in holes, thin cutan around peds; few fine roots with some larger roots; pH 5.0; clear and wavy boundary.
B22t	89-120+	Light gray (10YR7/1) matrix, many medium prominent mottles (5YR4/6), 19YR6/8) as in lateritic nodules; fine sandy clay; moderate medium subangular blocky peds and common soft lateritic nodules; sticky and plastic; common very fine vesicular and tubular pores, few fine animal holes; thin discontinuous cutans; pH 4.5.

Profile: SR-4 (Peninsular Thailand)
Kho Hong series (East coast) (Kh)

Classification: Gray Podzolic-Yellow Latosols

Described by: Santhad Rojanasoonthon
Date: December 23, 1967

I. INFORMATION ON THE SITE

Location: Nikom Kuan Ka Long (Thung Nui), Amphoe Muang, Changwat Satun.
At Satun road turn off to Nikom (land settlement), about 13 km after the turn off, the site is located in the orchard behind Nai Plaoui's lot which is about 1.5 km after the road's first hill passage with rock outcrop.
AMS series L708 map is not available, located on British topographic map (1" to a mile) L501 no. B-47 k. Sheet name "Alor Star".
NS coordinate 25.9 (approx.) EW coordinate 64.8 (approx.)

Elevation: About 20 m.
Landform:
i. Physiographic position: lower terrace of marine origin (?).
ii. Surrounding landform: part of gentle swells adjacent to the gravelly higher terrace.
iii. Microtopography: nil.

Slope: General direction 2% S.
Land use: Clearing of shrubs and higher hardwood forest for orchard. It has been under orchard for five years with tangerine, jackfruit, mango, banana, etc.
Climate: Being on the east coast, rainfall is higher due to the southwest monsoon. Annual rainfall measured at Satun (30 km southwest of the site) is 2415 mm.

II. GENERAL INFORMATION ON THE SOILS

a. Parent material: Old alluvium (possibly marine).
b. Drainage: Moderately well drained.
c. Moisture condition: Moist when described (except 0-7 cm horizon).
d. Depth of groundwater table: Unknown but most likely will be at about 1.5-2 m.
e. Presence of stone and outcrop: None.
f. Evidence of erosion: None at the site but gully erosion is present nearby.
g. Human influence: Confined to surface 13 cm.

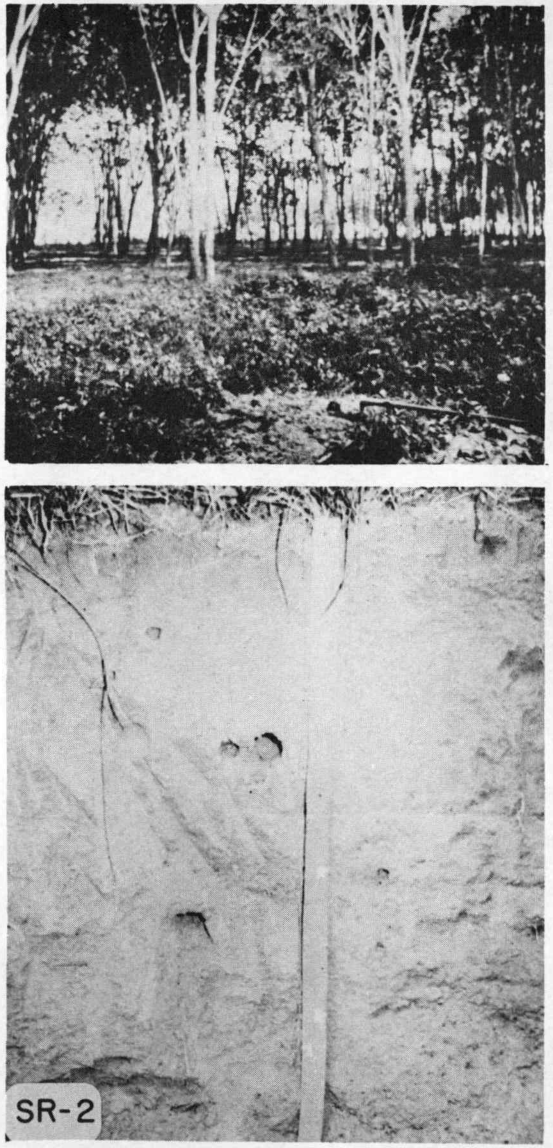
III. GENERAL DESCRIPTION OF THE SOILS

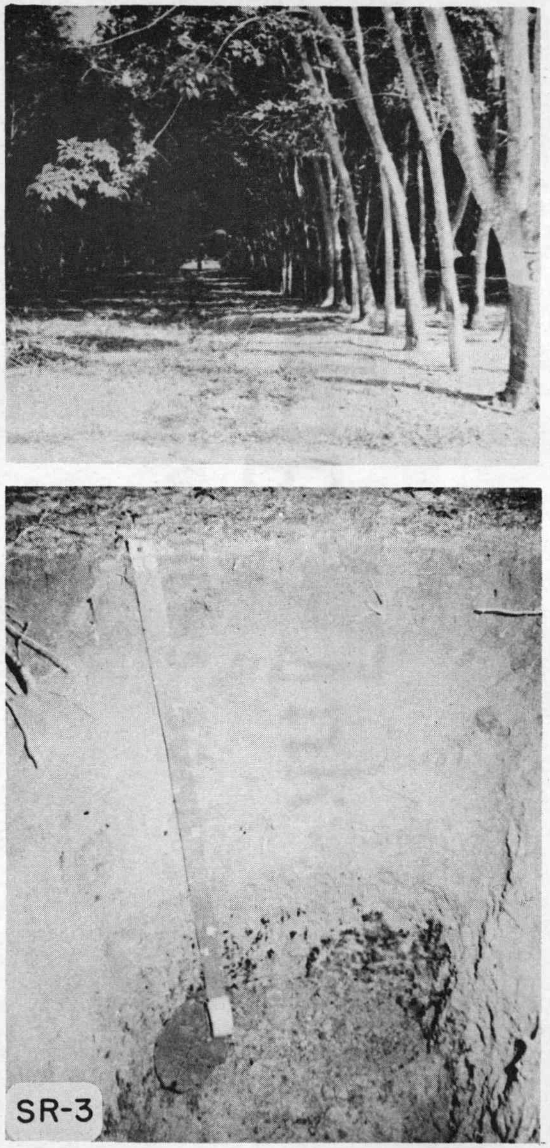
Deep, moderately well drained, dark brown to strong brown profile. Structure is moderate throughout, with a compact pan-like layer beneath the plow layer when dry. Sandy loam texture changing to sandy clay in the lower horizon results in a well developed B horizon with thick cutans. Mottles are common from 50 cm and stronger with depth. Ant holes are common throughout. Root distribution is normal.

IV. PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap1	0-7	Dark brown (10YR3/3), pale brown (10YR6/3) dry; loam; moderate fine granular structure; firm, slightly sticky, slightly plastic; fine to very fine interstitial and vesicular pores; common fine roots; pH 6.0; clear and smooth boundary.
Ap2	7-13	Dark brown (10YR3/3), loam; moderate fine, granular structure; more compact than Ap1, firm, slightly sticky, slightly plastic; fine to very fine interstitial and vesicular pores; common fine roots; pH 6.0; abrupt and smooth boundary.
A2?	13-28	Yellowish brown (10YR5/4); sandy loam; moderate fine subangular blocky structure; compact pan-like, hard dry, slightly sticky, slightly plastic; few coarse faint spots resemble mottles; common very fine tubular and vesicular pores; few medium charcoal fragments; few fine roots; pH 5.5; gradual and smooth boundary.
B1	28-41	Dark brown to brown (7.5YR4/4); fine sandy clay loam; moderate fine subangular blocky structure; friable, slightly sticky and slightly plastic; few dark spots resemble mottles; thin cutans in pores; common very fine tubular and vesicular pores; few fine roots, common fine dead roots; pH 5.0; gradual and smooth boundary.
B21t	41-68	Dark brown to strong brown (7.5YR4/4 to 4/6), common fine faint mottles; fine sandy clay; moderate medium subangular blocky structure; friable, sticky and plastic; thick, continuous cutans in pores and holes, moderately thick cutans on peds; fine to very fine tubular pores; few very fine roots; few medium charcoal fragments; pH 5.0; gradual and smooth boundary.
B22t	68-86	Dark brown to strong brown (7.5YR4/4 to 4/6); common fine distinct mottles; fine sandy clay; moderate fine to medium subangular blocky structure; friable, sticky and plastic; cutans as in above horizon; few very fine tubular pores; few clear quartz grains; few fine roots; few fine charcoal fragments; pH 5.0; clear and smooth boundary.
B3g?	86-120+	Yellowish brown (10YR5/6); clay; many fine distinct mottles; moderate fine subangular blocky structure; friable, very sticky and plastic; cutans as above; few very fine tubular pores; few fine roots; pH 5.0.

Note: Common ant holes throughout profile, usually 2-4 mm in diameter but some large ones (1-2 cm in diameter) are also present.


SR-2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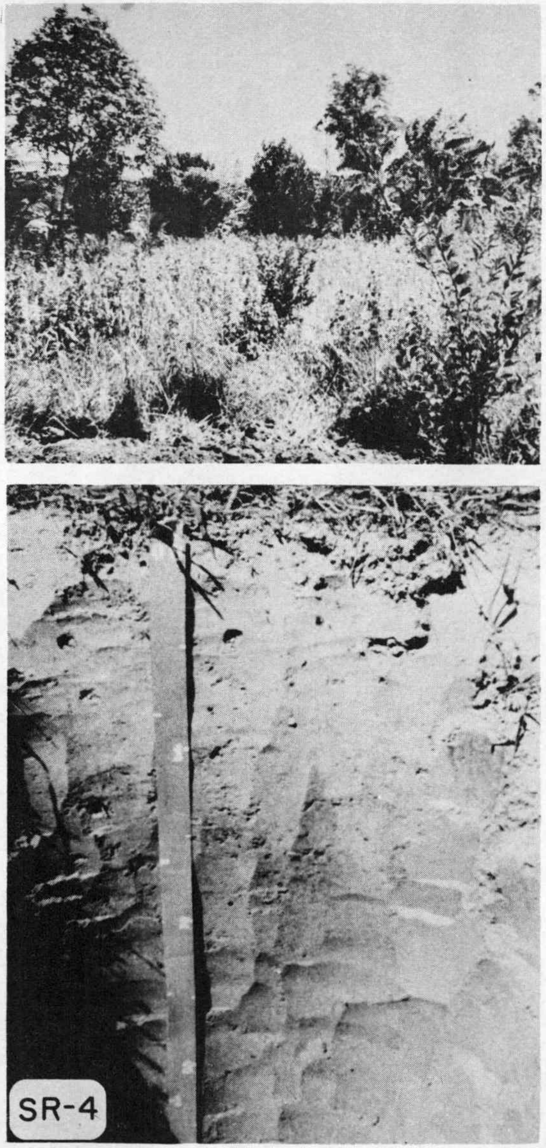
SR-4

APPENDIX B

Appendix Table 1. Particle size distribution of the nine Gray Podzolic soils in this study.

Sample	Depth (cm)	Horizon	V. Co % sand	Co % sand	M % sand	F % sand	VF % sand	Sand (%)	Silt (%)	Clay (%)	Textural class	Field estimation
<u>N-Chiang Mai</u>												
SR-1-1	0-5	A1	3.1	12.1	9.7	21.7	14.9	61 52	29.38	9.10	sl	sl
1-2	5-11	A2	-	-	-	-	-	61.47	30.20	8.33	sl	sl
1-3	11-40	B1	5.2	13.2	9.3	20.2	13.2	61.13	27.29	11.58	sl	sl
1-4	40-73	B2t	-	-	-	-	-	59.03	26.78	14.19	sl	scl
1-5	73-122+	B3	7.3	8.4	5.0	10.1	9.5	40.30	22.54	37.16	cl	c
<u>NE-Khon Kaen</u>												
SR-7-1	0-6/10	Ap	0.1	1.9	5.7	13.7	39.1	60.36	29.55	10.09	sl	Li sl
7-2	6/10-34	A2	-	-	-	-	-	54.24	29.54	16.24	sl	sl
7-3	34-62	B1	0.2	1.8	5.0	9.6	29.4	45.87	29.97	24.16	l	scl
7-4	62-94	B21t	-	-	-	-	-	43.34	30.34	26.32	l	scl
7-5	94-130	B22t	0.2	1.8	5.0	10.6	27.5	45.08	27.42	27.50	cl	sc
7-6	130-155	B3-1	0.3	1.3	4.8	19.5	18.9	44.81	25.00	30.19	cl	sc
7-7	155-198	B3-2	0.2	1.2	4.1	17.7	17.9	41.06	24.50	34.44	cl	sc
7-8	198-235	IIC-1	-	-	-	-	-	31.04	22.31	46.65	c	c
7-9	235-270	IIC-2	0.1	0.8	2.3	11.2	13.3	27.74	20.12	52.14	c	c
<u>NE-Nakhon Panom</u>												
SR-5-1	0-8/12	Ap	-	-	-	-	-	59.07	28.02	12.91	sl	sl
5-2	8/12-40	A21	0.6	2.9	6.8	11.4	34.3	56.02	27.98	16.00	sl	sl
5-3	40-53	A22	-	-	-	-	-	55.15	27.27	17.58	sl	sl
5-4	53-72	B1	1.0	3.1	6.5	18.4	23.4	52.38	25.71	21.91	scl	scl
5-5	72-119	B21t	-	-	-	-	-	52.70	26.94	20.36	scl	scl
5-6	119-147+	B22t	1.1	3.0	6.0	11.0	29.3	50.37	27.40	22.23	scl	scl

(Continued on next page)

Appendix Table 1. (Continued)

Sample	Depth (cm)	Horizon	V.Co % sand	Co % sand	M % sand	F % sand	VF % sand	Sand (%)	Silt (%)	Clay (%)	Textural class	Field estimation
<u>NE-Nakhon Panom</u>												
SR-6-1	0-5/7	Ap	0.1	0.2	0.8	9.9	35.5	46.54	45.91	7.5	sl-l	sl
6-2	5/7-17	A2	-	-	-	-	-	45.04	46.45	8.51	l	sl
6-3	17-39	B21t	0.1	0.2	0.8	5.6	33.8	40.49	42.14	17.37	l	sl
6-4	39-70	B22t	-	-	-	-	-	36.78	40.79	22.43	l	scl
6-5	70-100+	B23tg	0.2	0.3	0.2	1.5	35.9	38.12	40.46	21.42	l	scl
<u>SE-Rayong</u>												
SR-8-1	0-15	Ap	12.6	15.3	10.7	7.3	16.1	62.06	9.75	28.19	scl	cl
8-2	15-25	A2	-	-	-	-	-	62.34	7.65	29.98	scl	cl
8-3	25-35	B21t	21.6	12.0	6.5	9.2	4.1	53.43	5.80	40.77	sc	sc
8-4	35-88	B22t	-	-	-	-	-	54.33	5.61	40.06	sc	sc
8-5	88-105	IIB31	30.8	12.1	5.7	2.3	9.1	60.03	5.80	34.17	scl	sc
8-6	105-140	IIB32	17.8	11.5	5.5	6.1	3.3	44.21	6.84	48.95	c	sc
8-7	140-165	IIIC1	8.4	7.2	3.7	4.7	3.2	27.19	6.41	66.40	c	sc
8-8	165-185	IIIC2-1	-	-	-	-	3.7	25.93	9.13	64.94	c	c
8-9	185-235	IIIC2-2	6.3	5.9	2.9	1.2	8.0	24.35	10.35	65.30	c	c
<u>SE-Siracha</u>												
SR-9-1	0-19	Ap	9.5	12.8	9.9	18.6	17.9	68.67	24.29	7.04	sl	f. sl
9-2	19-36	A2	-	-	-	-	-	67.62	22.89	9.49	sl	f. sl
9-3	36-68	B21	-	-	-	-	-	65.84	24.99	9.17	sl	sl
9-4	68-105	B22	11.0	13.6	9.7	19.2	13.8	67.27	24.04	8.69	sl	sl
9-5	105-155	B23	12.4	15.4	11.4	17.1	11.8	68.10	20.93	10.97	sl	Co. sl
9-6	155-210	B3	-	-	-	-	7.6	74.46	15.57	9.97	sl	Co. sl
9-7	210-235	IIC1-1	40.6	20.5	6.9	7.3	4.8	80.07	9.77	10.16	sl-ls	ls
9-8	235-265	IIC1-2	-	-	-	-	6.0	77.13	12.97	9.90	sl	ls
9-9	265-280	IIIC2	18.2	12.6	5.8	10.6	11.1	58.29	25.45	16.26	sl	scl

(Continued on next page)

Appendix Table 1. (Continued)

Sample	Depth (cm)	Horizon	V.Co % sand	Co.% sand	M % sand	F % sand	VF % sand	Sand (%)	Silt (%)	Clay (%)	Textural class	Field estimation
S-Hat Yai												
SR-2-1	0-15	Ap	0.1	2.0	4.5	22.5	36.6	65.71	25.44	8.85	sl	sl
2-2	15-53	A2	-	-	-	-	-	60.74	26.17	13.09	sl	sl
2-3	53-67	B1	-	-	-	-	-	60.73	26.05	13.22	sl	scl
2-4	67-91	B21t	0.4	2.1	4.8	27.8	23.1	58.17	26.51	15.32	sl	scl
2-4	91-125	B22t	-	-	-	-	-	52.53	23.98	23.49	scl	sc
2-6	125-143+	B3t	0.3	1.5	3.6	24.4	21.5	51.26	24.67	24.07	scl	sc
S-Hat Yai												
Sr-3-1	0-17	A1(Ap)	0.3	1.3	3.7	28.7	25.6	59.57	30.94	9.49	sl	Li. sl
3-2	17-35	A2	-	-	-	-	-	56.63	32.65	10.72	sl	Li. sl
3-3	35-63	B1?	0.8	1.2	3.7	24.1	25.6	55.38	32.04	12.58	sl	scl
3-4	63-89	B21t	-	-	-	-	-	50.63	31.26	18.11	l	sc
3-5	89-120+	B22t	0.3	0.9	3.5	23.5	29.8	58.01	30.92	11.07	sl	sc
S-Satun												
SR-4-1	0-7	Ap1	0.4	1.8	2.5	1.9	31.6	38.18	46.36	15.46	l	l
4-2	7-13	Ap2	-	-	-	-	-	40.09	45.45	14.46	l	l
4-3	13-28	A2	-	-	-	-	-	40.70	46.77	12.53	l	sl
4-4	28-41	B1	-	-	-	-	-	35.86	46.39	17.75	l	f. scl
4-5	41-68	B21t	0.7	1.4	1.8	2.3	24.3	30.45	41.48	28.07	cl	f. sc
4-6	68-86	B22t	-	-	-	-	-	27.27	40.07	32.66	cl	f. sc
4-7	86-120+	B3	0.3	0.9	1.2	3.7	19.2	25.31	40.11	34.58	cl	c

Appendix Table 2. Chemical analysis of the nine Gray Podzolic soil profiles.

Sample	Horizon	pH 1:1 H_2O	pH 1:1 KCl	% C	% N	C/N	Exchangeable bases Ca	Exchangeable bases Mg	Exchangeable bases K	Exchangeable bases Na	Sum of bases	Exchangeable acidity	CEC by sum (me)	CEC/ 100 g clay (me)	Base saturation	P Bray no. 2 (ppm)	K Amm. acetate (ppm)	Conductivity 1:5 25°C (u mho)
N-Chiangmai																		
SR-1-1	A1	5.9	5.0	0.93	0.06	16	2.1	0.4	0.1	0.2	2.8	4.8	7.6	83.5	37	14.2	66	18.5
1-2	A2	5.8	4.5	0.25	0.04	6	0.5	0.2	0.1	0.2	1.0	2.1	3.1	37.3	32	9.7	36	12.0
1-3	B1	5.4	4.3	0.03	0.02	2	0.2	0.2	0.1	0.2	0.7	1.2	3.6	16.4	37	19.6	39	9.0
1-4	B2t	5.7	4.4	0.04	0.02	2	0.2	0.2	0.1	0.2	0.7	1.6	3.0	16.2	30.	25.8	51	8.0
1-5	B3	5.4	4.2	0.08	0.03	3	0.7	0.5	0.3	0.2	1.7	4.8	5.2	17.4	26	42.6	134	8.8
NE-Khon Kaen																		
SR-7-1	Ap	6.25	5.35	0.48	0.03	16	1.0	0.4	0.1	0.2	1.7	2.9	4.6	45.5	37	47.9	69	18.0
7-2	A2	5.9	5.65	0.25	0.02	12	0.4	0.4	0.1	0.2	1.1	2.9	4.0	24.7	28	57.8	57	11.7
7-3	B1	5.35	4.65	0.18	0.01	18	0.2	0.7	0.2	0.2	1.3	4.7	6.0	24.8	22	73.8	110	9.0
7-4	B21t	5.6	4.15	0.15	0.02	8	0.2	0.8	0.2	0.2	1.4	5.2	6.6	25.1	21	94.4	113	8.5
7-5	B22t	5.9	4.15	0.15	0.03	5	0.2	0.7	0.2	0.2	1.3	5.1	6.4	23.3	20	75.0	104	7.1
7-6	B3-1	4.65	3.75	0.07	-	-	0.3	0.4	0.2	0.1	1.0	6.1	7.1	23.5	14	-	-	4.0
7-7	B3-2	4.6	3.65	0.07	-	-	0.3	0.4	0.2	0.1	1.0	7.0	8.0	23.2	12	-	-	3.4
7-8	IIC-1	5.0	3.8	0.08	-	-	0.4	0.4	0.2	0.1	1.1	8.7	9.8	21.0	11	-	-	3.8
7-9	IIC-2	5.1	3.8	0.07	-	-	0.7	0.4	0.2	0.1	1.4	10.7	12.1	23.2	12	-	-	3.1
NE-Nakhon Panom																		
SR-5-1	Ap	5.4	4.6	1.07	0.08	13	1.0	0.3	0.1	0.2	1.6	4.1	5.7	44.2	28	7.6	51	20.0
5-2	A21	6.4	5.15	0.63	0.06	10	1.7	0.3	0.1	0.2	2.3	4.1	6.4	40.0	36	1.8	24	18.0
5-3	A22	5.7	4.95	0.36	0.05	7	1.0	0.4	0.04	0.2	1.6	3.2	4.8	27.3	33	1.4	21	11.7
5-4	B1	5.25	4.5	0.29	0.04	7	0.5	0.2	0.1	0.2	1.0	4.8	5.8	26.5	17	1.2	18	10.0
5-5	B21t	5.2	4.7	0.26	0.03	9	0.2	0.1	0.04	0.2	0.5	4.7	5.2	25.5	10	1.2	24	8.4
5-6	B22t	5.0	4.7	0.22	0.03	7	0.2	0.1	0.1	0.2	0.6	5.4	6.0	27.0	8	1.2	24	27.0

(Continued on next page)

Appendix Table 2. (Continued)

Sample	Horizon	pH 1:1 H_2O	pH 1:1 KCl	% C	% N	C/N	Exchangeable bases Ca	Mg	K	Na	Sum of bases	Exchangeable acidity	CEC by sum (me)	CEC/ 100 g clay (me)	Base saturation	P Bray no. 2 (ppm)	K Amm. acetate (ppm)	Conductivity 1:5 25°C (μ mho)
NE-Nakhon Panom																		
SR-6-1	Ap	5.55	4.1	0.92	0.07	13	0.4	0.3	0.1	0.2	1.0	5.2	6.2	82.6	16	3.5	54	21.9
6-2	A2	5.5	4.4	0.31	0.02	16	0.3	0.1	0.1	0.2	0.7	2.7	3.4	40.0	21	2.0	24	11.0
6-3	B21t	4.5	3.4	0.14	0.03	5	0.2	0.2	0.1	0.2	0.7	4.7	5.4	31.0	13	2.0	36	6.5
6-4	B22t	5.55	4.45	0.22	0.02	11	0.1	0.1	0.1	0.2	0.5	5.3	5.8	25.9	9	1.3	33	8.2
6-5	B23tg	5.5	5.0	0.21	0.02	10	0.1	0.04	0.1	0.2	0.2	0.4	4.5	21.0	8	1.6	24	6.4
SE-Huai Pong																		
SR-8-1	Ap	6.15	5.4	0.91	0.09	10	2.0	0.7	0.1	0.2	3.0	3.9	6.9	24.4	44	8.2	72	21.0
8-2	A2	5.7	5.4	0.69	0.06	12	2.0	0.5	0.1	0.2	2.8	2.8	5.6	18.6	50	3.2	30	15.4
8-3	B21t	6.75	5.9	0.46	0.05	9	1.6	0.8	0.04	0.2	2.6	2.6	5.2	12.7	50	2.6	21	13.0
8-4	B22t	5.7	4.95	0.53	0.04	13	0.5	0.3	0.1	0.2	1.1	3.8	4.9	12.2	22	2.4	24	12.2
8-5	B31	5.65	4.6	0.35	0.02	18	0.2	0.1	0.1	0.2	0.6	4.0	4.6	13.4	13	2.4	30	15.0
8-6	IIB32	7.9	3.9	0.20	-	-	0.2	0.04	0.04	0.1	0.4	5.5	5.9	12.1	7	-	-	11.0
8-7	IIIC1	4.7	4.0	0.21	-	-	0.2	0.05	0.1	0.1	0.5	6.2	6.7	10.1	8	-	-	14.0
8-8	IIIC2-1	4.8	3.8	0.13	-	-	0.2	0.01	0.1	0.1	0.4	6.6	7.0	10.8	6	-	-	12.0
8-9	IIIC2-2	5.2	4.1	0.10	-	-	0.2	0.01	0.1	0.1	0.4	6.5	6.9	10.5	6	-	-	12.0
SE-Siracha																		
SR-9-1	Ap	7.0	6.3	0.54	0.05	11	1.1	0.5	0.2	0.3	2.1	1.2	3.3	47.1	64	4.1	116	31.0
9-2	A2	6.95	5.45	0.26	0.02	13	0.7	0.3	0.2	0.2	1.4	1.1	2.5	26.3	56	2.0	88	16.4
9-3	B21t	7.0	5.4	0.24	0.02	12	0.6	0.4	0.2	0.2	1.4	0.6	2.0	21.7	70	5.3	97	16.0
9-4	B22t	7.15	6.1	0.15	0.01	15	0.6	0.5	0.2	0.2	1.5	0.4	1.9	21.8	79	7.1	80	21.0
9-5	B23	5.3	4.3	0.08	-	-	0.2	0.3	0.1	0.1	0.7	1.2	1.9	17.3	37	-	-	6.0
9-6	B3	5.3	4.0	0.07	-	-	0.2	0.2	0.2	0.1	0.7	1.6	2.3	23.0	30	-	-	5.0
9-7	IIC1-1	5.4	4.1	0.07	-	-	0.3	0.3	0.2	0.1	0.9	1.0	1.9	18.6	47	-	-	6.4
9-8	IIC1-2	5.4	4.2	0.06	-	-	0.5	0.4	0.2	0.1	1.2	1.2	2.4	24.2	50	-	-	6.8
9-9	IIIC2	5.5	4.35	0.03	-	-	0.7	0.7	0.2	0.1	1.7	1.6	3.3	20.2	52	-	-	8.5

Appendix Table 2. (Continued)

Sample	Horizon	pH 1:1 H_2O	pH 1:1 KCl	% C	% N	C/N	Exchangeable bases Ca	Exchangeable bases Mg	Exchangeable bases K	Exchangeable bases Na	Sum of bases	Exchangeable acidity	CEC by sum (me)	CEC/ 100 g clay (me)	Base saturation	P Bray no. 2 (ppm)	K Amm. acetate (ppm)	Conductivity 1:5 25°C (μ mho)
S-Hat Yai																		
SR-2-1	Ap	5.2	4.4	0.50	0.05	10	0.6	0.1	0.04	0.2	0.9	1.8	2.7	30.7	33	19.4	18	48.0
2-2	A2	5.45	5.2	0.26	0.05	5	0.3	0.1	0.03	0.2	0.6	3.3	3.9	29.8	15	7.9	15	27.0
2-3	B1	6.1	5.0	0.12	0.02	6	0.2	0.1	0.03	0.3	0.6	3.0	3.6	27.3	17	4.8	15	13.4
2-4	B21t	5.2	4.0	0.11	0.03	3	0.2	0.1	0.03	0.2	0.5	3.3	3.8	24.8	13	4.4	18	12.6
2-5	B22t	5.15	4.2	0.10	0.03	3	0.2	0.1	0.03	0.2	0.5	4.5	5.0	21.3	10	7.0	15	13.2
2-6	B3t	5.15	4.2	0.10	0.04	2	0.2	0.1	0.03	0.2	0.5	5.0	5.5	22.8	9	5.1	18	16.5
S-Hat Yai																		
SR-3-1	A1(Ap)	5.4	5.0	0.37	0.04	9	0.2	0.1	0.02	0.2	0.5	3.5	4.0	42.1	13	10.8	18	25.0
3-2	A2	5.1	4.3	0.13	0.02	6	0.2	0.04	0.02	0.2	0.5	2.6	3.1	29.0	16	2.6	13	13.8
3-3	B1?	5.0	3.85	0.11	0.03	4	0.2	0.02	0.02	0.2	0.4	2.4	2.8	22.2	14	6.2	13	13.0
3-4	B21t	5.25	4.4	0.10	0.02	5	0.3	0.1	0.03	0.2	0.6	3.8	4.4	24.3	14	5.6	13	14.0
3-5	B22t	5.35	4.7	0.03	0.02	2	0.2	0.02	0.02	0.2	0.4	1.5	1.9	17.1	21	4.4	10	17.0
S-Satun																		
SR-4-1	Ap1	6.0	4.4	1.22	0.13	9	2.2	0.6	0.3	0.2	3.3	6.1	9.4	61.0	35	12.7	146	35.0
4-2	Ap2	5.95	4.0	0.82	0.12	7	1.5	0.4	0.1	0.2	2.2	6.0	8.2	56.9	27	8.6	63	27.5
4-3	A2	5.65	4.4	0.55	0.06	9	0.8	0.3	0.1	0.2	1.4	5.2	6.6	52.8	21	5.3	39	14.5
4-4	B1	5.0	4.1	0.33	0.05	7	0.4	0.1	0.1	0.2	0.8	5.1	5.9	33.3	14	4.7	51	11.0
4-5	B21t	5.15	3.95	0.39	0.06	7	0.3	0.2	0.2	0.2	0.9	7.3	8.2	29.2	11	6.2	88	13.5
4-6	B22t	5.0	4.15	0.39	0.07	6	0.3	0.2	0.2	0.2	0.9	8.8	9.7	29.7	9	5.3	94	17.3
4-7	B3	5.0	4.4	0.37	0.07	5	0.3	0.2	0.2	0.2	0.9	8.1	9.0	26.0	10	5.3	75	16.5

APPENDIX C

Glossary of terms used in Micromorphological Descriptions of the Nine Gray Podzolic Soils Under Study (from Stace *et al.*, 1968)

Argillan - A cutan composed dominantly of clay minerals.

Asepic fabrics - Plasmic fabrics that consist dominantly of anisotropic clay minerals and exhibit a flecked extinction pattern under cross polarisers. Two types are recognized: argillasepic (containing a high proportion of clay minerals) and silasepic (containing a high proportion of fine silt-size minerals that are difficult to distinguish from the areas of clay minerals present).

Cutan - A modification of the texture, structure, or fabric at natural surfaces in soil materials due to concentration of particular soil constituents or *in situ* modification of the plasma.

Embedded grain argillan - An argillan on a grain that is embedded in the plasma.

Faecal pellets - The excreta of fauna.

Ferri-argillan - A cutan composed of intimately mixed clay minerals and iron oxides.

Clay domains - Small (5-15 μ) aggregated of sub parallel clay mineral grains and are characteristic of asepic fabrics (plasma separation is the characteristic of sepic fabric).

Glaebule - A three dimensional pedological feature within the s-matrix of the soil material, and usually approximately prolate to equant in shape; its morphology is incompatible with its present occurrence being within a single void in the present soil material.

Granular fabric - There is no plasma or all the plasma occurs as pedological features.

Interconnected vughs - Relatively large, highly irregular, interconnected voids that ramify the soil materials.

Intertextic fabric - The skeleton grains are linked by intergranular braces or are embedded in a porous matrix of plasma and small skeleton grains.

Inundulic fabric - A variety of undulic fabric in which a small proportion of the plasma occurs as "flecks" under crossed polarisers.

Litho-relicts - Features derived from the parent rock and usually recognized by their rock structure and fabric.

Metavughs - Vughs whose walls appear to be significantly smoother than would result from the normal random packing of plasma and skeleton grains.

Neo-argillan - a neo-cutan composed of clay minerals.

Neo-cutan - A pedological feature that occurs within the s-matrix but immediately adjoining and related to natural surfaces in the soil material.

Neo-ferran - A neo-cutan composed of a concentration of iron oxides.

Nodules - Glaebules with an undifferentiated fabric; in this context undifferentiated fabric includes recognizable rock and soil fabrics.

Papules - Glaebules composed dominantly of clay minerals with continuous and/or lamellar fabric, and sharp external boundaries.

Pedological features - Recognizable units within a soil material which are distinguishable from the enclosing material for any reason such as origin (deposition as an entity), differences in concentration of some fraction of the plasma, or differences in arrangement of the constituents (fabric).

Phytoliths - Inorganic bodies derived from replacement of plant cells; they are usually opaline.

Plasma - That part of the soil material that is capable of being or has been moved, reorganized, and/or concentrated by the processes of soil formation. It includes all the material, mineral or organic, of colloidal size and relatively soluble material that is not bound up in the skeleton grains.

Plasmic fabric - The fabric of the plasma of the s-matrix, that is, the arrangement of the plasma grains and intergranular voids.

Porphyroskelic fabric - The plasma occurs as a dense ground mass in which skeleton grains are set after the manner of phenocrysts in a porphyritic rock.

Sepic fabrics - Plasmic fabrics in which patches and/or zones of plasma have striated extinction patterns under crossed polarisers. The following types are recognized: insepic (isolated patches with a striated extinction pattern), mosepic (frequent patches), vosepic (zones associated with voids), skelsepic (zones associated with grains and/or glaebules), masepic (elongated zones through the plasma), bimasepic (elongated zones in two directions through the plasma), omnisepic (all the plasma has a complex striated extinction pattern). Compound fabrics can occur (e. g., skel-ma-insepic fabric) in which several fabric elements are present; in these the weaker elements are named first (skel- in the example) and the stronger elements last (insepic in the examples). Sepic fabrics can also be compounded with other types (e. g., skel-masepic undulic fabric).

Silasepic fabric - See asepic fabrics.

Skeletan - A cutan composed of skeleton grains.

Skeleton grains - Individual grains that are relatively stable and not readily translocated, concentrated or reorganized by soil-forming processes; they include mineral grains and resistant siliceous and organic bodies larger than colloidal size.

S-matrix - (of a soil material). The material within the simplest peds, or composing apedal soil materials, in which the pedological features occur; it consists of the plasma, skeleton grains and voids that do not occur as pedological features other than those expressed by specific extinction (orientation) patterns. Pedological features also have an internal s-matrix.

Voids argillans - Argillans associated with unspecified voids material (all the void argillans recorded are attributed to illuviation).

Vughs - Relatively large voids, usually irregular and not normally interconnected with other voids of comparable size; at the magnifications at which they are recognized they appear as discrete entities.