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ABSTRACT

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The undulating plateau, which accounts for about 80% of Northeast Thailand, is known for its extremely low soil fertility. Basement rocks of the plateau consist of sandstone or siltstone of the Mesozoic age, of which the greater part is underlain by rock salt bed. The undulating relief of the plateau has been formed by a denudation process. The sediments covering the land surface are not riverine deposits, but deposits formed by mass movement of the weathered mantle of the bed rock.

The low soil fertility is attributed mainly to the extremely low exchange and buffering capacity, and quasi absence of mineral reserves in the surface soils due to the sandy texture, predominance of quartz in sand fractions and low organic matter status. In addition to these, salinity (saline soils) and presence of an ironstone layer at shallow depths (skeletal soils) aggravate the situation in a considerable part of the Northeast plateau.

1) Sandy surface soils: Although the sandy texture is partly derived from the nature of the parent rocks, it has largely resulted from various secondary processes, e.g. 1) selective loss of clay by percolating and seepage water, 2) selective loss of finer particles by runoff or overflow water (micro-erosion), 3) selective loss of finer particles in association with mass movement. It seems that the clearing of forests and careless soil management have enhanced these processes. Destruction of clay by ferrolysis, if any, can not be a major process in the formation of sandy surface soils. Mulching, minimum- or no-tillage and crop rotation so as to keep the vegetative cover are recommended. Soil improvement to enrich active clay and mineral reserves should be considered seriously.

2) Skeletal soils: It is assumed that ironstones had originally been scattered more sparsely in the profile, and that thick ironstone layers have been formed as a result of the removal of the soil matrix and consequent residual concentration of iron nodules in association with mass movement. Soils with ironstone layers or iron-pans are not suited to the growth of crop plants. Northeast Thailand has already been reclaimed beyond its capability. It seems reasonable to preserve the major part of the skeletal soil areas as forests.

3) Saline soils : Salt source of saline soils is considered to be salt-impregnated sandstone or siltstone instead of deep seated rock salt bed. A major problem, however, is the expansion of salt-affected soils by human activities, including deforestation, salt-making operations, construction of reservoirs and ponds, etc. First of all, the mechanism of salinization must be fully clarified. We must be extremely careful in changing the land use, landform or whatever may affect the existing water balance.

CONTENTS

I. INTRODUCTION

I.1. Geography of the Region

Northeast Thailand is saucer-shaped basin, bordered to the North and East by the Mekong River, to the West by Phetchabun range and to the South by Phanom Dongrak range (Fig.1). The basin is separated into two parts by Phu Phan range, i.e. Korat

Fig. 1 Physiography of the Northeast Thailand

basin to the South and Sakon Nakhon basin to the North. For the convenience of explanation, the Northeast Thailand is divided here into four geographic units, i.e. alluvial plains, plateaus, intramountainous highlands and mountainous areas. Intramountainous area refers to the undulating to rolling highlands in between mountainous areas.

Alluvial plains are distributed along the Mun and Chi Rivers and their tributaries in the Korat basin and along the Mekong River and its tributaries in the Sakon Nakhon basin. Fertile soils like Tropaquepts (Hydromorphic Alluvial soils) and Tropepts (Alluvial soils) are found there. But alluvial plains are rather small in area, accounting for only 6% of the total area of the Northeast.

Mountainous area consists of three major mountain ranges (Phetchabun, Phanom Dongrak, and Phu Phan) and some independent mountains and hills, altogether making up about 13% of total area. Rock species are;

Phetchabun range

(sedimentary rock) sandstone, shale, limestone of Paleozoic and Mesozoic era (igneous rock) rhyolite, andesite

Phanom Dongrak and Phu Phan range

sandstone and siltstone of Mesozoic Korat group

Soils of mountainous area have not been surveyed yet, and are shown merely as 'slope complex' in soil map. In *intramountainous highland* we can find relatively fertile soils like Haplustults (Reddish-Brown Lateritic soils), Haplustalfs (Reddish-Brown Earth), Haplustox (Red-Yellow Latosols), etc. But again the area is rather small.

Gently undulating *plateaus* comprise a greater part (nearly 80%) of the Northeast. Basement rocks are sandstone and siltstone of Korat Group (Mesozoic-Tertiary), among which Mahasarakam Formation (formerly called Salt Formation) is most widespread, and soils on the plateau have been directly or indirectly derived from them. Paleustults (Red-Yellow Podzolic and Gray Podzolic soils) and Paleaquults (Low Humic Gley soils) are widespread there. Unfortunately, the fertility of these soils is low to very low because of sandy texture of the top soils, low organic matter level, low available nutrient status, etc.

In addition, saline and sodic soils including Natraqualfs (Solonchak) and Halaquepts (Solonchak) occur widely on the plateau. Mahasarakam Formation which contains salt, is considered to be the major source of salt. Soils that have an ironstone layer at a shallow depth (Plinthustults and Plinthaquults) are commonly found on the plateau, being particularly widespread in Sakon Nakhon basin. Soils that are sandy throughout (Quartzipsamments) are also found frequently on the plateau. Saline soils, skeletal soils and sandy textured soils are regarded as three major problem soils in the Northeast. All these problem soils are found on the plateau and it is anticipated that they will expand gradually as will be explained later.

Rainfall is quite unreliable in the Northeast except in part of Sakon Nakhon basin, where the annual rainfall ranges between 1500 and 2000mm or more. In Khon Kaen, for example, only two months in the latter half of rainy season can enough rainfall be expected (Fig.2). Moreover the distribution of rainfall in rainy season is quite erratic with long dry-spells occurring frequently.

I.2. Land Use

Alluvial plains and lower part of the plateau that are annually flooded are mostly used for cultivation of rice.

Middle and higher parts of the plateau are now widely used for growing upland crops. However, due to low soil fertility and frequent drought the kinds of crops are limited to such crops as cassava and kenaf, which are tolerant to drought and poor nutrient status (Table 1). Maize, the second major upland crop, is grown for the most part in relatively fertile intramountainous and hilly area. Nowadays rice fields have expanded partly to the middle part of the plateau. Cultivation of both rice and upland crops on the plateau is practiced mostly under rainfed condition. Fertilizers are rarely used due to their high price, poor response to crops, low price of the agricultural products and unreliability of rainfall.

Until the 1930's, the area of rice fields had been rather constant at the level of eight hundred thousand hectares, or about 5% of the total area, and those of the upland crop fields had been negligible in the area (Table 2). The fact that the area of rice fields in those periods roughly corresponds to the area of alluvial plain may suggest that rice cultivation was practiced mainly on alluvial lowlands and parts of the lower plateau

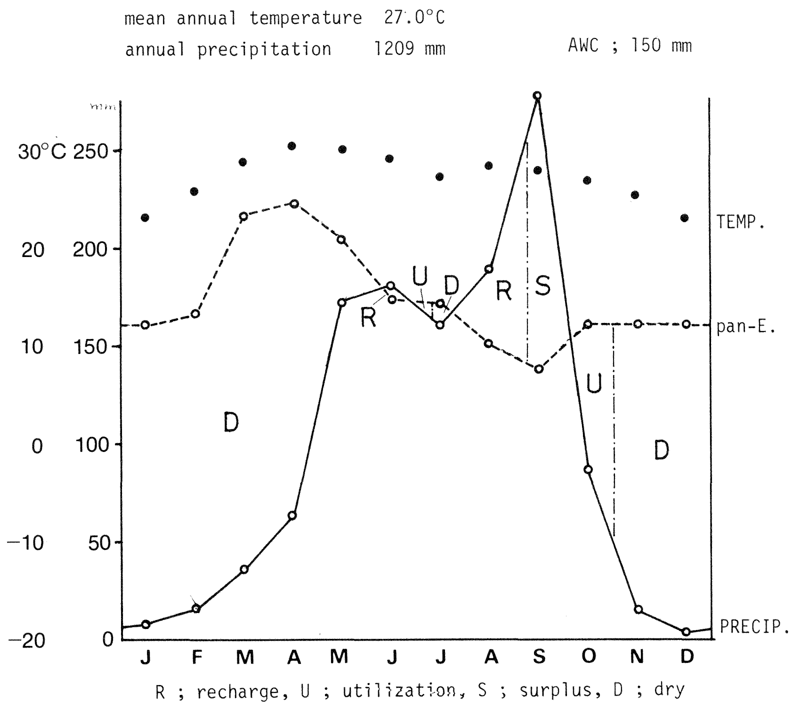


Fig. 2 Soil moisture regime of Khon Kaen province

Table 1 Crop production in the Northeast Thailand

crops	planted area x1000 ha	mean yield 1978–83 kg/ha	N.E. as percentage of national production
rice	4257	1200	36
cassava	726	13400	59
maize	501	1780	22
kenaf	217	1040	100
sugarcane	104	39800	11
peanuts	28	1020	19
cotton	25	1270	25
mungbean	18	664	4

Source ; OAE 1983

where regular flooding can be expected in the rainy season. Stable and fairly high yields could have been achieved (Table 2) because of regular flooding and high soil fertility of alluvial lowlands.

Since the 1940's, however, farmlands have expanded very quickly in the middle and higher parts of the plateau as well as in the mountainous and hilly areas at the expense of forests (Table 2). Particularly the area of cash crops including cassava, kenaf and maize has increased at an amazing rate in the past quarter of the century. Rice fields have also expanded considerably. Rice cultivation seems to be self-sustaining by nature in view of the fact that per-head production of rice has been rather constant during the past 40 years and coincides well with an estimated per-capita consumption of rice (Table 2), and the fact that in most of the provinces, the greater part of rice produced is a glutinous one which is consumed domestically. Therefore the increase of rice fields may have been forced mainly by the pressure of population increase. In contrast, the rapid increase of cash crop may have resulted from the strong desire for higher standard of living.

Table 2 Changes in farmland area and population during the past 40 years

	rice		upland crop area 1000 ha	population × 1000	kg rice* /head
	area × 1000 ha	yield (unhulled) kg/ha			
1930-'34	816	1356	negligible	4260	260
1950-'54	2160	988	59	7170	297
1960-'64	2528	1056 (1963 only)	276	9660	276
1973-'77	3712	1181	877	14820	296

Source : JICA (1981) Present situation and near future of Northeast Thailand
* Consumption of rice/head/year is estimated at about 280 kg (unhulled rice basis).

The past quarter of the century was the age of a large scale migration and settlement from old rural areas to new rural areas by clearing forests. Now there is no room left for the expansion of farmlands. Presently, forests can be seen only in the mountainous areas. The percentage of forestlands in the Northeast is now estimated at 13%, which corresponds roughly to the percentage of mountainous areas. Farmlands which thus expanded in the plateau are now facing various difficulties. Soils that had been originally infertile are further deteriorating due to the exhaustion of natural fertility and inadequate management. Due to the low soil fertility and the erratic rainfall, the two major constraints, crop yields are estimated at about two thirds of national average. Because of low productivity of farmlands and heavy dependence of the local economy on agriculture, per-capita income of the Northeast is said to be only about 40% of national average.

II. PROBLEM SOILS IN THE NORTHEAST

II.1. Sandy Textured Soils

(1) Characterization

As will be explained in section III.1, soils on the plateau, which cover nearly 80% of the Northeast, are classified into about 10 great groups and more than 20 soil series based on the difference in soil color, texture, degree of base saturation, depth to ironstone layer, etc.

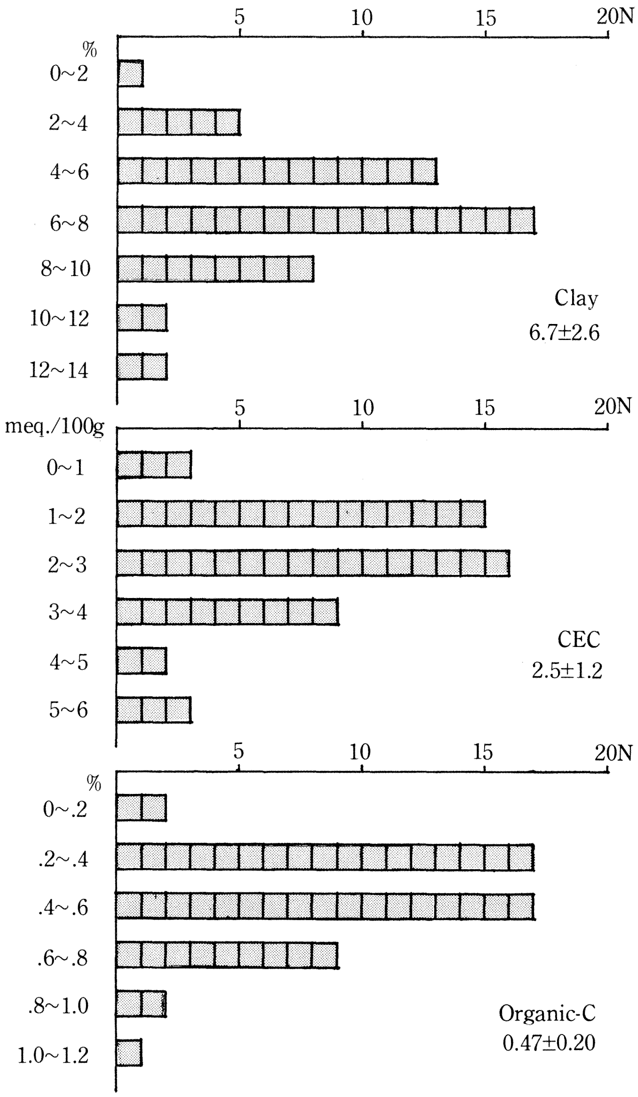


Fig. 3 Histograms for clay, CEC and organic carbon of the topsoils of upland soils of the Northeast plateau Source; Ogawa et al. (1980), Prateep (1986) etc.

However these soils share some important characteristics. Be it Psamments, Ustults or Aquults, the surface soils invariably sandy textured with low organic matter content. As shown in Fig.3, the average clay content of the topsoils is as low as 6% and organic carbon content is only 0.4% on an average (Prateep, 1986). Clay minerals are mostly kaolinitic and therefore low in activity (Fig.4 and Anchalee et al. 1985).

Due to the small amount of low activity clay, combined with a low organic matter level, the top soils are extremely low in cation exchange capacity (2.5 meq./100g on the average, Fig.3), and ill-buffered against changes in environments. In this regard, Ragland (1986) likened the cultivation of crops on the plateau to 'sand culture' rather than soil culture. Furthermore sandy soils with a small amount of low activity clay

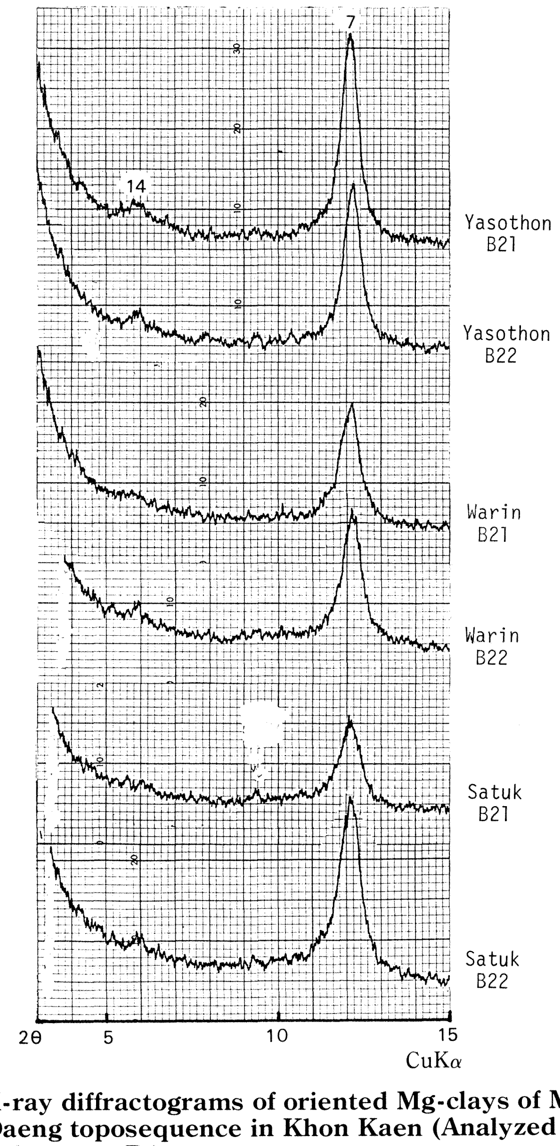


Fig. 4 X-ray diffractograms of oriented Mg-clays of Mor Din Daeng toposequence in Khon Kaen (Analyzed by Laksamee, R.)

cannot keep organic matter in the form of stable organo-mineral complexes. Upon reclamation of land, uncombined forms of organic matter are more susceptible to microbial attack and more dispersible in run-off water.

Since the degree of weathering has gone to an extreme, the sand and silt fractions consist almost exclusively of quartz (Arita, 1981). This indicates that soils are extremely poor in mineral nutrients as well as in potential mineral reserves that become available on weathering. Table 3 shows the average contents of the nutrient elements in the topsoils of the Northeast plateau, together with those of Tropical Asia and Japan. The topsoils of the Northeast are critically low in the contents of total nitrogen, available phosphorus, exchangeable cations and available silica.

Table 3 The contents of some nutrient elements in topsoils of the Northeast plateau

		total N %	avail. P_2O_5 mg/100g	exch. Ca ←	exch. Mg me/100g	exch. K →	avail. SiO_2 mg/100g
Northeast plateau	upland soils	0.04	0.92	0.73	0.26	0.09	-
	paddy soils	0.04	0.50	1.13	0.50	0.11	2.6
Tropical Asia	paddy soils	0.13	3.8	10.4	5.5	0.4	27.0
Japan	paddy soils	0.29	12.9	9.3	2.8	0.4	19.5

Source: Kawaguchi and Kyuma (1969), Prateep Verapattananirund (1986)
Motomura et al. (1979)

Physical properties are also unfavorable to the growth of crop plants. As shown in Appendix II, soils of the Northeast plateau often exhibit unusually high bulk densities and soild phase ratios, and become extremely hard when dry. Figure 5 shows that soils of the Northeast plateau, as represented by the Warin and Yasothon soils, are much more dispersible and poor in stable soil aggregates as compared to the Pak Chong soil in intramountainous areas, probably due to the low contents of free iron and organic matter which act as cementing agents. The near absence of stable aggregates combined with fine-sand dominated particle size distribution tend to cause a close packing. Closely-packed subsurface soils seriously interfere with the ramification of plant roots, and might cause an intermittent waterlogging in times of heavy rain.

Unfavorable soil moisture regime, as mentioned before, is another major constraint in the Northeast. The writers monitored the soil moisture change after the topsoil was nearly saturated by 20mm rainfall toward the end of the dry season. The result (Fig.6) showed that topsoil became 'dry' again (beyond permanent wilting point) in less than one week. Dry-spells for more than one week are quite common in the Northeast. Fig.6 also shows that soils become 'dry' at least to a depth of one meter in the dry season.

Samarn (1982) considered the sandy texture soil as one of seven problem soils in Thailand. But he restricted it to Quartzipsamments (Regosols) alone. However, all the

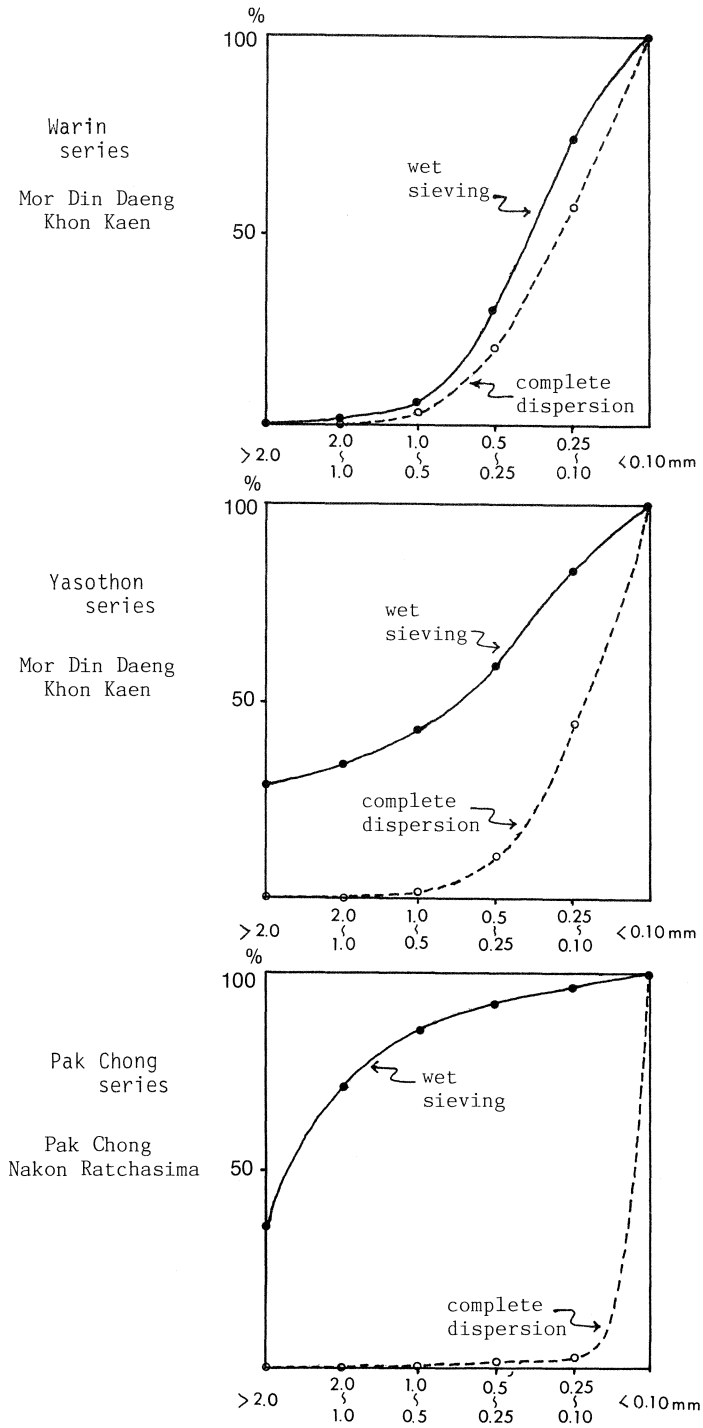
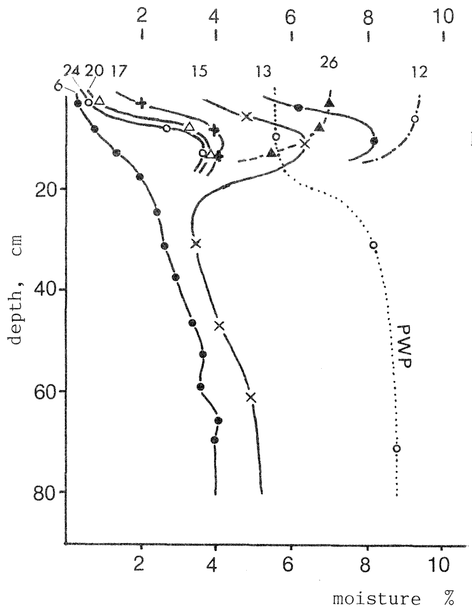


Fig. 5 Cumulative curve of aggregates with different size (Analyzed by Naris, N. and Khemkaeng, U.)



moisture in mm in top 15 cm

March	6	2.0 (-)
	12	22.2 (+20.2)
	13	17.8 (-4.4)
	15	12.9 (-4.9)
	17	7.8 (-5.1)
	20	5.9 (-1.9)
	24	5.7 (-0.2)
	26	16.1 (+10.4)

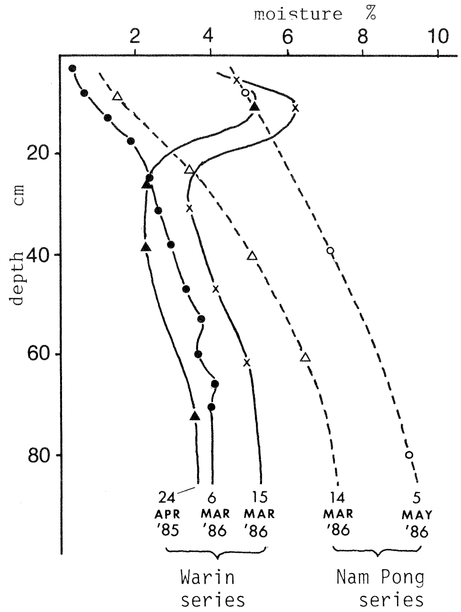
PWP ; permanent wilting point

Fig. 6 Moisture changes in top soil of Warin series of ADRC experimental farm after the first rain towards the end of the dry season

soils with a sandy textured topsoil in the Northeast, in the writers' opinion, should be regarded as problem soils. Sandy texture of topsoil with low mineral reserves and unfaborable soil moisture regime are the two greatest limiting factors for crop production in the Northeast.

Contrary to general expectation, Quartzipsamments in the Northeast are considered to be better for the growth of crop plants compared to other types of soils on the plateau. This is probably due to the favorable moisture regime of Quartzipsamments here. As shown in Fig. 16, these soils are quite often underlain by a gray/orange mottled, finer textured subsoil, which indicates an impeded drainage and a high moisture retentivity. In the rainy season the subsurface sandy layer right above the impermeable subsoil is normally saturated with water and a perched water table often appears there (Fig.16). Another example is given in Fig.7, which shows clearly higher moisture contents in the Nam Pong soil (Quartzipsamment) than in Warin soil (Paleustult). Another factor which might contribute to the better moisture regime of Quartzipsamments is the high available water capacity (AWC). Table 4 shows that the Nam Pong soil (Quartzipsamment) contains a larger amount capillary pore and therefore can store a larger amount of available moisture than the Yasothon and Warin soils (Paleustults).

As far as the topsoil where roots ramify is concerned, there is little if any difference among different soils on the plateau.



Warin soil ; ADRC experimental farm
Nam Pong soil ; rain-fed agriculture project site, 15 km north of Khon Kaen

Fig. 7 Vertical distribution of soil moisture in the late dry season and early rainy season

Table 4 Pore-size distribution of soils of Mor Din Daeng toposequence

soil	depth cm	pore-size distribution V% coarse pF0-1.8	capillary pF1.8-4.2	fine pF 4.2	solid phase V%	bulk density g/cm
Yasothon	1.(0- 22)	20.6	21.2	5.7	52.6	1.38
AWC=183mm	2.(22- 41)	11.8	19.5	8.3	60.5	1.58
	3.(41- 67)	17.5	17.6	9.1	55.7	1.48
	4.(67+)	18.4	16.2	8.6	56.4	1.49
Warin	1.(0- 19)	16.5	18.8	5.6	59.1	1.63
AWC=153mm	2.(19- 43)	15.9	15.7	8.1	60.4	1.63
	3.(43- 99)	20.0	13.9	8.8	57.6	1.52
	4.(99-150)	20.6	16.0	9.4	54.0	1.48
Nam Pong	1.(0- 26)	12.7	24.4	4.8	58.1	1.52
AWC=204mm	2.(26- 41)	12.6	22.2	5.1	60.1	1.59
	3.(41- 88)	16.6	18.7	4.4	60.4	1.60
	4.(88-122)	17.5	15.9	6.7	59.9	1.61
	5.(122+)	14.2	17.1	6.5	62.2	1.65

(Analyzed by Somsak,S.)

(2) Soil deterioration

Accelerated erosion such as gully and rill erosion can be seen in many places. Once mountainous and hilly areas are cleared for field crops, erosion seems to be accelerated drastically. In the Northeast, however, severe erosion can take place even in gently sloping plateau as shown in Photo.1. As stated before, soils of the plateau are generally very poor in stable aggregates. Structureless soils are more easily subject to erosion. Anti-erosion measures are necessary not only in mountainous and hilly areas, but also in gently undulating plateau.

The writers realized that there is another kind of erosion in which clay and organic matter are removed selectively from soils (selective erosion). Two different types of selective erosion were recognized.

One type of this kind of erosion can be compared to the 'micro-erosion' reported by Moormann and Santhad (1972). In the rainy season, black or dark-gray films can often be seen in small depressions in the fields together with white sandy films on relatively higher sites (Photo.2). Analysis was made for the content of clay, organic matter and available P and K on three fractions, i.e. black film, white sandy film, and bulk surface soil at three sites (Table 5). The results showed a much higher concentration of clay and organic matter in black films. Available P and K were also concentrated in black films. This indicates that clay and organic matter, being disturbed by the impact of raindrops, are suspended in water and later concentrated in small depressions, leaving clean sand at higher sites. This implies that, in case of heavy rain, clay and organic matter can be lost by being suspended in runoff water. Before the next crop, clean sands on the surface are incorporated into the surface soil by ploughing and the plough layer below is brought to the surface, and again subject to disturbance and 'selective erosion'. This could lead to a gradual decrease of the content of clay and organic matter in the topsoils. As mentioned previously, soils are

Table 5 Separation of topsoil between clayey black film and sandy film after heavy rainfall

		organic matter %	particle size distr. %			avail.P (Bray II) ppm	NH_4OAc extr. K ppm
			clay	silt	sand		
Kalasin FCES	bulk*1	0.26	3.5	4.2	92.3	6.5	29
	black film*2	3.45	19.9	25.5	54.6	15.9	89
	sandy film*3	0.10	1.9	0.9	97.2	3.0	20
Roi-et FCES	bulk	0.25	3.8	2.4	93.8	7.4	60
	black film	2.34	26.8	18.9	54.3	10.1	230
	sandy film	0.02	1.0	0.2	98.8	5.0	38
Mahasarakam FCES	bulk	0.72	5.9	8.5	85.6	5.2	31
	black film	2.65	18.2	32.7	49.1	3.4	109
	sandy film	0.27	3.0	1.7	95.3	1.7	19

*1 bulk plowlayer soil
*2 thin black film at small depressions in the field
*3 thin sandy film at relatively higher sites in the field

(Analyzed by Laksamee, R., Tanongsak, S. and Suchinda, S.)

largely structureless, and clay and organic matter are present separately instead of forming organo-mineral complexes. For this reason the dispersibility of clay is extremely high in these soils (Kubota et al., 1982), and finer particles are easily suspended in water and taken away with it.

The same type of selective erosion takes place in the plough layer of paddy soils on the plateau. The loss of clay and organic matter tends to be more conspicuous in parts of paddy soils than in upland soils since finer particles are artificially suspended in flood water by puddling. Materials suspended in flood water can be lost where overflow takes place. Selective erosion can be even more severe in salt-affected areas because sodium-dominant clay, when excess salt is washed away by early rain, tends to be dispersed easily in run-off or overflow water. Fig.8 shows the particle-size distribution of slightly salt-affected paddy soil. A sharp decrease in the content of clay has occurred in the plough layer, while clay contents are rather uniform below. In the plough layer of the paddy soil studied, sorting by particle size has taken place with a very thin clayey crust (up to 5 mm thick) at the surface. This indicates that clay particles are kept suspended in surface water for a long time after puddling. A sharp drop of clay in topsoil can be ascribed mainly to its loss by overflow.

The other type of selective erosion is associated with mass movement or washout process. When soils absorb a large quantity of rainwater they acquire a fluidity, and begin to move as a mass down the slope. Finer particles tend to be removed selectively from outwash deposits by being further transported beyond the point where a greater part of the mass deposits. As will be discussed later (section III.3), thin sandy topmost

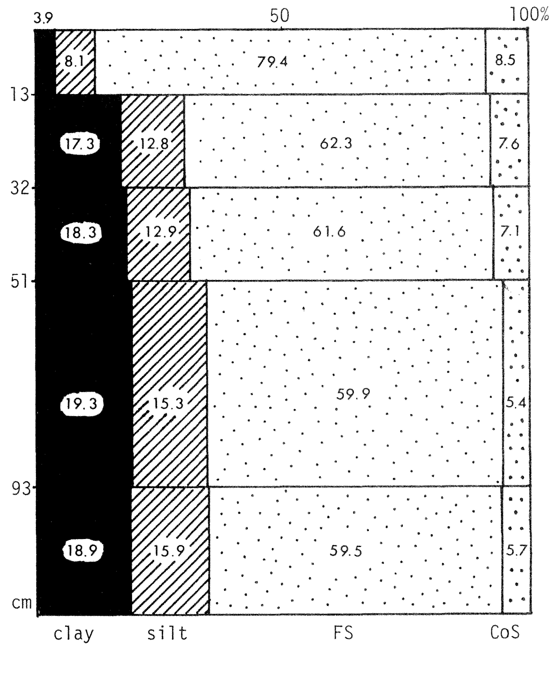


Fig. 8 Particle-size distribution of Kao Yoi soil (Paleaqualf), Amphur Muang, Chaiyaphum province

layers can often be seen resting with sharp boundaries on loamy subsoils (Fig.18). On the outskirts of Khon Kaen, the writers found many artifacts embedded along the boundary between sandy topmost layer and underlying subsoil. Therefore the boundary indicates the time gap. Selective erosion associated with mass movement is believed to be mainly responsible for the formation of the sandy topmost layer resting unconformably on finer textured subsoil.

Selective erosion seems as detrimental as an ordinary type of erosion since it takes away the vital portion of soils and occurs in flat areas as well as in sloping lands. More detailed studies on the degree and extent of this type of erosion, and studies on protective measures are urgently needed.

(3) Countermeasures

Improvement of the unfavorable properties of these soils is by no means an easy task. At the present stage, emphasis should be placed on the prevention of further deterioration, i.e. the prevention of both bulk and selective erosion. Various countermeasures including terracing, minimum or no tillage and crop rotation have so far been recommended for the prevention of soil erosion. Mulching is reported to be effective for protecting the soils from erosion by mitigating the impact of raindrops and decreasing the amount of runoff (Ueno et al., 1983).

Hydroxyaluminum ($Al(OH)_{1.5}Cl_{1.5}$ or $Al(OH)_{2.5}Cl_{0.5}$) has been reported to be effec-

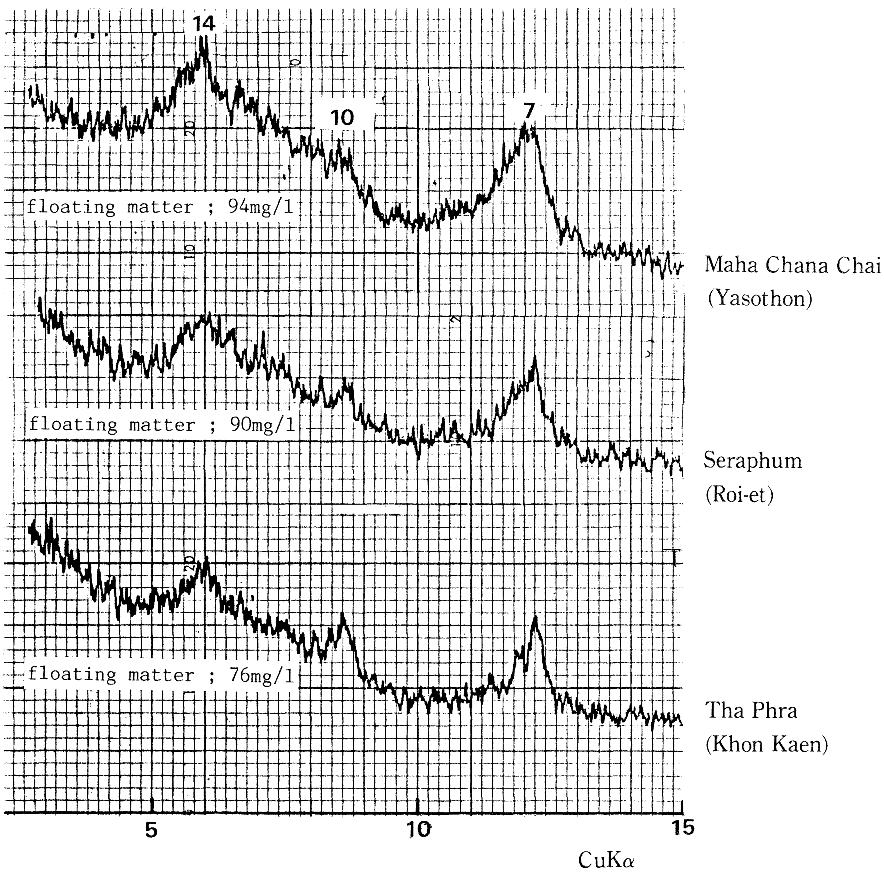
Table 6 Effect of hydroxyaluminum on the formation of soil aggregates

	size fraction (mm)					%
	>2	2-1	1-0.5	0.5 -0.25	0.25 -0.1	<0.1
Satuk soil (roadcut, 3km north of Khon Kaen)						
non-treated (1)	5.5	1.6	2.9	11.2	36.7	42.1
non-treated (2)	4.1	2.3	3.3	13.3	36.1	40.9
Al-level I*	34.6	9.2	8.2	13.3	20.4	14.3
Al-level II (1)	34.8	8.2	6.7	10.8	22.4	17.0
Al-level II (2)	40.8	10.5	9.0	11.6	19.7	8.4
Warin soil (ADRC experimental farm)						
non-treated (1)	15.2	6.3	12.0	23.9	26.0	16.5
non-treated (2)	13.2	5.5	9.4	24.0	27.5	20.3
Al-level I	55.6	7.6	8.3	13.0	10.3	5.2
Al-level II (1)	39.7	8.6	11.4	17.0	14.8	8.5
Al-level II (2)	36.6	9.6	13.0	22.6	11.6	6.6
Yasothon soil (roadcut, Mor Din Daeng, Khon Kaen)						
non-treated	23.7	6.2	6.8	18.4	28.6	16.3
Al-level I	51.6	5.6	5.2	11.0	15.2	11.4
Al-level II	26.6	8.4	8.9	17.9	22.9	15.4

* $Al_{2.5}(OH)_{0.5}Cl$ solution (Al ; 12.5%, Cl;8.3%),pH 3.5
level I ; 1ml/100g
level II; 2ml/100g

tive for the formation of stable aggregates as well as for the stabilization of organic matter (Koga and Shiraishi, 1985; Kubota et al., 1986). The writers themselves conducted an experiment in which hydroxy-aluminum-treated soils were buried in an experimental farm for three and half months, and then analyzed for soil aggregates. As shown in Table 6, the hydroxyaluminum-treated soils showed a remarkable increase in the waterstable aggregates. It should be taken into acount that the results apply to the subsurface soils (B horizons) with clay contents ranging from 10 to 15%. The effectiveness of hydroxyaluminum for sandy topsoils is yet to be investigated. At any rate, the use of hydroxyaluminum is worthy to be studied for the prevention of both bulk and selective erosion.

However the loss of clay from the topsoil appears to have gone to a near extreme. Enrichment of clay, instead of the prevention of further loss, seems indispensable to the improvement of soils. Irrigation of clay-suspended river water or swamp water as a means of soil dressing may be one of the effective means. Since floating matter in river water is rich in 14Å minerals with a considerable amount of micaceous clay (Fig.9), this sort of 'soil dressing' would be effective in increasing the amount of active clay as well as in increasing mineral nutrients. The writers were told that in the Chi



(Sumida, H. unpublished data)

Fig. 9 X-ray diffractograms of floating matter

river bank near Roi-et where sands were being collected for construction material by dredging river-bed soils, the paddy fields where muddy water had accidentally flowed in showed much better growth of rice than neighboring paddies (Umebayashi, 1986; pers. comm.).

The following materials for soil dressing are worthy to be tested further;

1) Swelling clay rich soils
2) swamp bottom soils
3) basalt (powder)
4) marl and dolomite (powder)
5) shale (powder)

The writers conducted a preliminary pot experiment using sweet corn as a test plant in which these materials were mixed with the topsoil of Korat series at 5 and 10% levels. The results (Table 7) showed a better growth of corn for swelling clay rich-,

Table 7 Effect of various soil amendments on the growth of sweet corn

treatment		stem length (cm) 24/Sept./1986	plant weight (gr) 24/Sept./1986		pH (H_2O) (1:2.5)
			fresh weight	dry weight	
Chok Chai series	10%	20	6.34	1.61	4.91
	20%	28	13.42	2.97	4.51
Bun Kaen Nakhon	10%	16	7.33	1.84	4.42
	20%	15	7.88	1.55	4.30
Pallid zone	10%	38	20.44	4.76	4.78
	20%	30	17.19	3.72	4.55
Takhli series	10%	72	59.19	12.43	7.60
	20%	53	66.3	15.16	7.70
Shale powder	5%	32	19.55	3.84	4.71
	10%	40	44.05	8.46	4.42
marl powder	5%	55	56.94	11.21	8.00
	10%	62.5	53.73	11.99	7.91
basalt powder	5%	45	38.86	7.36	5.40
	10%	64	54.16	12.48	5.35
control (Korat series)		37	12.15	4.84	4.80
		35	29.23	6.40	4.83

seeding :18/July/1986
transplanting : 23/July
fertilizer : 5/September/1986

basalt-, marl-, and shale-plots. Pallid, mottled and saprolite zones between ironstone layer and bedrock (Fig.18) normally contain a large amount of swelling clay with some micaceous minerals (Fig.21). Swelling clay rich soils have also developed in the intramountainous areas, e.g. Vertisols from basalt and Mollisols from marl. Swamp bottom soil is also promising because of its high clay and organic matter contents. Basalt plateaus are found scattered in the southern part of the Northeast. Marl and dolomite are found in the Phetchabun range. Marl, dolomite and basalt are expected to serve as long-lasting fertilizers as well as neutralizers for acid soils. Shale is found extensively in the Phetchabun range, from which relatively fertile soils have been developed. In Brazil, finely-ground basalt, marl, schist, etc. were found to be effective soil amendments for strongly weathered lateritic soils (Leonardos et al., 1987). They argued that conventional NPK fertilizers are inappropriate for strongly leached lateritic soils, and must be supplemented by 'petro-fertilizers' (ground rocks) in order to attain a well-balanced mineral nutrient status.

For the improvement of moisture regime, mulching with crop residues has been recommended (Kubota et al. 1982, Inoue et al. 1984, Nakaya et al. 1986). This method is particularly effective in drought years when the moisture status is a limiting factor (Uehara et al. 1985). Recently, high-absorbent polymer has been recommended because of its high moisture retention capacity. Experiment was conducted using Warin topsoil, in which soils mixed with polymer were packed into 100ml steel cylinders, saturated with water, and then allowed to evaporate. As shown in Fig.10, the soil was kept moist for two weeks by addition of 0.2% polymer, while non-treated soil became dry in one week. The main problem is the duration of the effectiveness since re-wetted samples after drying showed a sharp decrease in moisture retention capacity. Field test is yet to be undertaken.

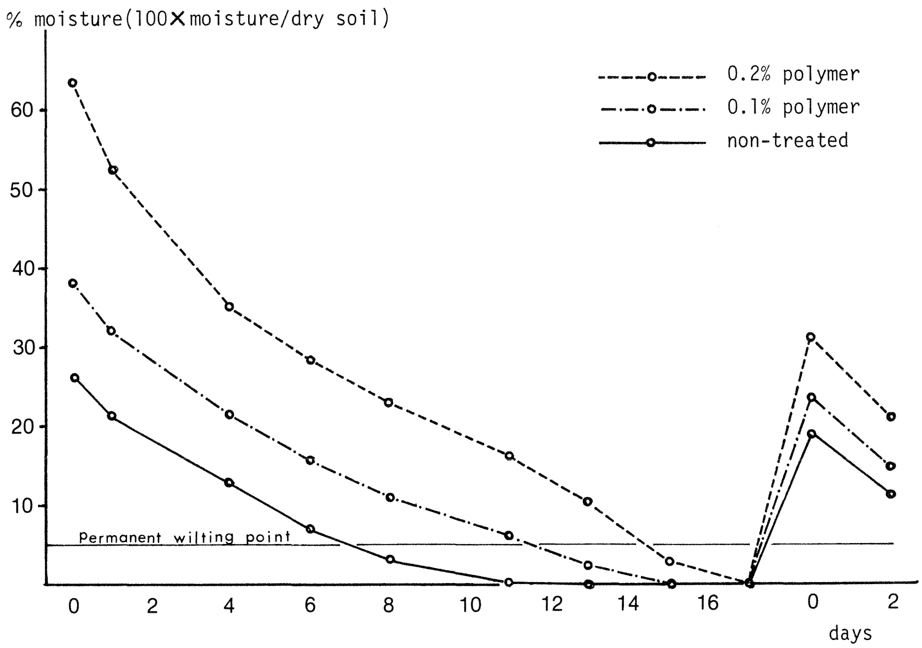


Fig. 10 Effect of high-absorbent polymer on the moisture retention capacity of soils

II.2. Skeletal Soils

Skeletal soils are another problem soil. Skeletal soils are defined as having a layer within 50cm of the surface, in which ironstones or gravels account for more than 35% by volume. Ironstones are largely present separately (loose laterite), but in places they are cemented to each other with ferruginous materials forming a hard iron-pan (sheet laterite). Soils with loose and sheet laterite layers predominate among skeletal soils and soils with gravel layers are less extensive as shown in the followings:

Phon Phisai series	15899 km^2	9.34%	loose laterite
Sakon series	389	0.23	sheet laterite
Phen series	2237	1.31	loose laterite, aquic
On series	588	0.35	sheet laterite, aquic
Chiang Khan series	42	0.03	gravel

Phon Phisai and Sakon series and their aquic counterparts, Phen and On series are representative of lateritic skeletal soils. Skeletal soils cover about 13% of the Northeast.

Region-wise, skeletal soils are most widespread in the Sakon Nakhon basin to the North of the Phu Phan range. The ironstone layer itself is widely found both in the Sakon Nakhon basin and the Korat basin, and the difference between the two basins lies in the average depth to the ironstone layer. In the Sakon Nakhon basin ironstone layers appear at a shallower depth.

(1) Forming process of ironstone layers

In the Northeast, tektites, black and glassy objects with pitted surface, are often found embedded in the uppermost part of the ironstone layer. Tektites date back to 700,000 years BP, indicating that the ironstone layer formed the land surface at that time.

It has been widely believed that the major source of iron in the ironstone layer was derived from the underlying mottled and pallid zones (refer to III.3, Soil Stratigraphy), from where mobile ferrous ion moved upward under a seasonally or permanently water-saturated conditions. The ferrous ions that moved upward precipitated upon oxidation at or near the then land surface.

However, a question arose when the vertical distirbution of free iron oxides was analyzed. As seen in Table 8, the ironstone layers have very high iron oxide contents, seven to ten times higher than those of the underlying mottled and pallid zones. Unexpectedly, however, the mottled and pallid zones are as high as or even slightly higher in iron contents than the saprolite zones and bed rock. If the mottled and pallid zones had been the source of iron in ironstone layer, the iron contents of these zones should be clearly lower than those of the saprolite zone and bed rock, and an ironstone layer one meter thick must have required an underlying layer several meters thick to be completely deprived of iron.

An alternative explanation would be a residual concentration of ironstone due to the removal of soil matrix by erosion. According to this hypothesis, ironstones may have been formed by in-situ segregation, being scattered more sparcely in the profile than at present. The removal of finer textured soil matrix and the residual concentration of ironstones took place on the then land surface.

However, the removal of the finer matrix by the impact of rain alone would have resulted merely in the formation of thin ironstone lines. Mass movement must have

Table 8 Free and total iron oxides of skeletal soils

Udon Thani province

horizon	depth cm	DCB extract Fe_2O_3%	HCl extract Fe_2O_3%	sum Fe_2O_3%
		--- Amphur Phen ---		
Apcn	0- 5	27.3 (65%)	14.9 (35%)	42.2
B1cn	5- 60	24.8 (58)	18.1 (42)	42.9
B2cn	60-100	22.4 (58)	16.2 (42)	38.6
B3g	100-150	5.10(84)	0.99(16)	6.09
B4g	150-240	5.24(86)	0.86(14)	6.10
Cg	240-300	3.81(86)	0.63(14)	4.44
		--- Amphur Muang ---		
B1cn	0- 40	-	-	52.9
B2g	40-150	-	-	5.08
B3g red	150-200	-	-	7.29
B3g white	150-200	-	-	1.25
Cg	200-	-	-	5.58
R (Udon Thani)		2.05(68)	0.95(32)	3.00
R (Khon Kaen)		2.86(70)	1.24(30)	4.10

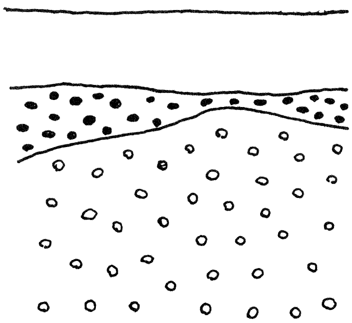
cn;ironstone layer, Bg;mottled or pallid zone, Cg;saprolite zone
R;bed rock

(Analyzed by Laksamee, R.)

been involved in the separation of a large soil mass between ironstones and the soil matrix. Fig.11 shows particular modes of occurrence of the ironstone layer. At Mor Din Daeng site, the ironstone layer is underlain by a gravel layer more than three meter thick with a red-colored soil matrix. The gravel layer cannot have been the source of iron in the ironstone layer because of its oxidizing condition. In the Non Saen profile, the ironstone layer rests directly on slightly weathered sandstone fragments over a hard sandstone bedrock. Here again, underlying layers cannot have been the source of iron in the ironstone layer. In both sites, ironstones must have been transported probably for a short distance from somewhere else. In general ironstone layers are quite variable in thickness ranging from $<$ 10cm to more than one meter. Field evidence and laboratory analysis suggest that mass movement with the removal of soil matrix and the resultant concentration of ironstones had been involved in the formation of the thick ironstone layer.

Field observations further suggest that in many cases, if not all, weathered

Mor Din Daeng, Amphur Muang, Khon Kaen

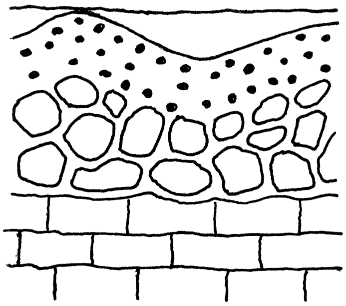


200cm Yasothon soil

10-100cm ironstone layer with uppermost part being partly indurated

300cm gravel layer with red-colored (2.5YR 4/8) soil matrix

Ban Non Saen, Amphur Non-Sa-Ak, Udon Thani



0-70cm dull yellow orange(10YR 7/4),SL

70cm ironstone layer

100cm slightly weathered fragments of bed rock

massive, hard sandstone

Fig. 11 Particular mode of occurrence of ironstone layer

fragments of bedrock served as nuclei in the formation of ironstones (Paiboon et al. 1984). In the field we often came across red colored saprolite fragments in deeper profile gradually changing upward through soft nodules to hard ironstones that retain the original rock structure. The process can be formulated as follows:

$$\text{bed rock} \xrightarrow[\text{under aquic regime}]{\text{weathering}} \text{red/white mottled saprolite} \xrightarrow[\text{toward red mottles}]{\text{iron concentration}} \text{soft nodule} \xrightarrow{\text{hardening}} \text{hard nodule}$$

X-ray analysis of iron nodules (Fig.12) showed that from the bottom upward crystalline iron minerals (hematite and goethite) as well as the iron oxide content increased regularly, whereas the quartz content decreased presumably due to dilution with an increasing amount of iron oxides. It seems that a favourable condition for the segregation and hardening of the nodules could be met in the upper profile where distinct wet and dry conditions alternate.

Sometimes soft nodules or soft plinthite can be found right below the ironstone layer, which harden irreversibly when exposed to the air and dried. In places local people are cutting out soft plinthite to make laterite bricks for construction materials. It is suspected that human activities including reclamation of forests for growing

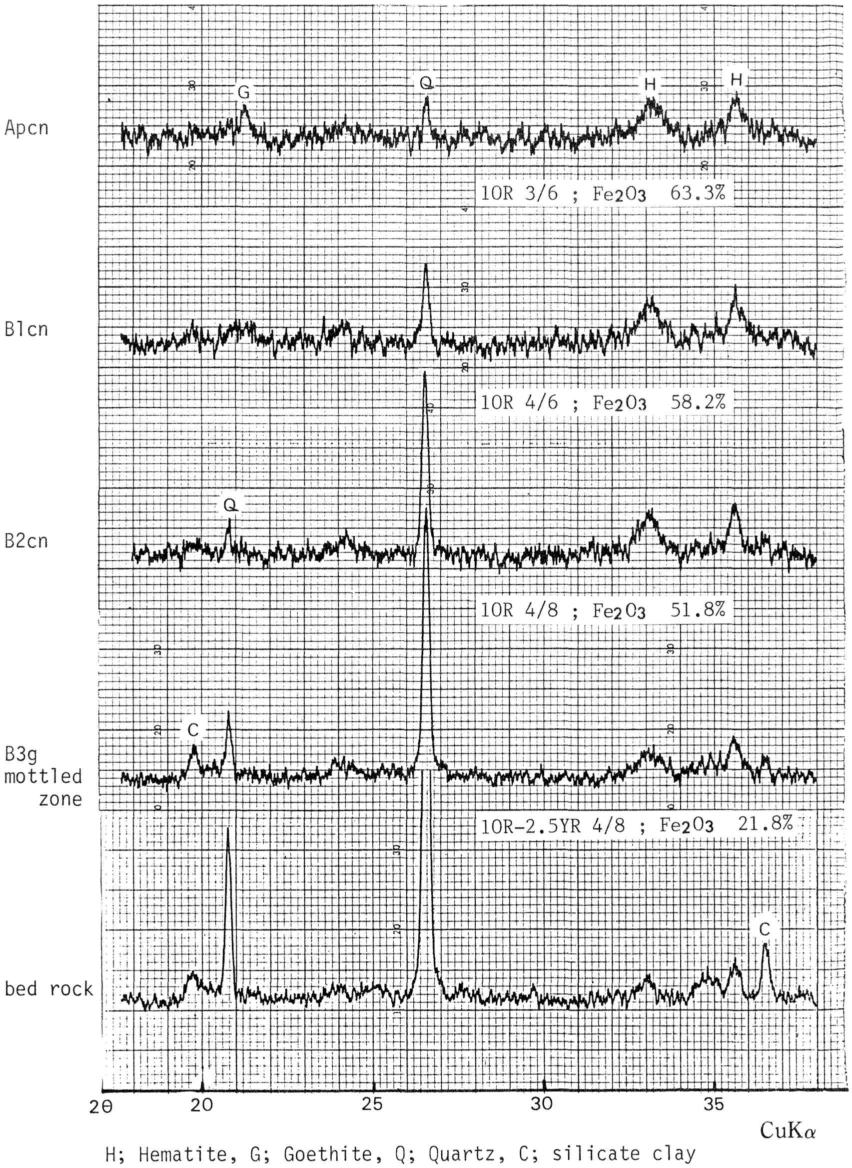


Fig. 12 X-ray diffractograms of nodules in Phon Phisai profile (Ban Mahachai, Amphur Plapak, Nakon Phanom province)

crops since prehistoric ages have contributed to a gradual hardening and thickening of the ironstone layers.

(2) Constraints and countermeasures

Ironstone layers severely interfere with the elongation of roots and also causes difficulties in ploughing. Shallow soils resting on them display poor chemical and physical properties. Soil moisture regime must be very unstable because of the shallow effective soil depth. For these reasons lateritic skeletal soils had been left largely unused until recently.

Prevention of soil erosion should be imperative for these soils. If part of the surface soil is lost by erosion, ironstone layers interfere more severely with crop performance, and in extreme cases erosion may bring them to the surface as often observed in these areas, making the land unsuitable for crops.

Pisoot (1984) has suggested the establishment of permanent pasture for livestock farming as the best use of the lands. The idea of one of the writers (Pichai) of digging many ponds for irrigation is promising in the Sakon Nakhon basin in view of the clayey impermeable substratum (Table 9). The substratum is more often salt-free than in the Korat basin presumably due to the higher rainfall. Montmorillonite-rich substrata (Fig.21) that are dug out can be used for soil dressing and the thickening of effective soil depth. Efficient methods for destroying and loosening the ironstone layer are worthy to be studied. In parts of the Sakon Nakhon basin where annual rainfall exceeds 1500 mm, the introduction of crop trees including pararubber is also worthy of consideration.

Table 9 Particle-size distribution of lateritic soils

Analyzed by Somchai, Y.

	fine soil wt.%					bulk soil wt.%		
	CoS	FS	silt	clay	tex.	iron-stone	gravel	fine soil
	Ban Ham Hae, Kalasin province							
1. A { sandy	18.2	71.9	3.5	6.4	LFS	-	-	-
2. C { topmost layer	16.1	74.0	4.5	5.5	LFS	-	-	-
3. IIB21 yellow subsoil	15.8	48.8	3.9	31.8	SC	-	-	-
4. IIB22g mottled subsoil	15.5	50.1	7.4	27.1	SC	-	-	-
5. IIIB23cn laterite layer	15.2	47.6	7.6	29.7	SC	62.2	0.9	37.0
6. IIIB24cn gravel layer	14.4	36.8	12.7	36.2	LiC	47.0	15.6	37.4
7. IVB25g mottled zone	10.7	38.0	13.7	37.6	LiC	-	-	-
8. IVB26g pallid zone	0.9	30.0	19.9	49.3	HC	-	-	-
	Amphoe Muang, Udon Thani province							
1. B21cn laterite layer	5.6	54.6	6.8	33.1	SC	-	-	-
2. B22g pallid zone	2.6	18.3	27.0	52.1	HC	-	-	-
3. B23g* transitional zone	0.3	13.0	23.3	63.5	HC	-	-	-
4. Cg* saprolite zone	0.3	17.1	32.3	50.3	HC	-	-	-

* treated with sonic vibration

However, we must be extremely careful in expanding crop fields at the expense of forests in skeletal soil areas. Land has already been reclaimed beyond its capacity. Rather, research efforts should be focused on the improvement of the lands so as to restore existing poor bushes to well developed forests.

II.3. Saline Soils

Saline soils are distributed mostly as spots in the depressions or low lying lands in the Northeast. In the strongly salt-affected spots where a greater part of the land surface is covered with salt crusts, no plants can grow except for a few kinds of salt-tolerant plants. Rice plants, especially those transplanted in the first half of rainy season, often suffer from salt damage due to a water shortage and accumulation of salt at the surface (Phote. 3).

Taxonomically, most of the salt-affected soils fall within the category of aquic (hydromorphic) soils, e.g. Natraqualfs and Halaquepts as shown below.

Natraqualfs	1612 km^2	0.95%	Kula Ronghai series
Halaquepts	735 km^2	0.44%	Udon series

This implies that, for the formation of saline soils, the groudwater level must be shallow enough for a capillary fringe to reach the land surface.

Both Natraqualfs and Halaquepts are aquic soils of which the exchange sites are dominated by sodium, and the difference between the two lies in the presence in the former and the absence in the latter of a clay-illuvial horizon (natric horizon).

(1) Mechanism of salinization

The distribution of saline soils is confined to the area of the Mahasarakam Formation (Cretaceous, formerly called 'Salt Formation'), which is widespread in the Northeast. Mahasarakam Formation has rock salt beds in its lower part, and these rock salt beds have long been considered to be the major source of salt in saline soils. However, it seems that the depth to rock salt (20–70m from the surface) is too great for the salt to come up to the land surface with the capillary rise of the groundwater.

Recently Somsri and Takaya (1974) and Takaya et al. (1984) made a field survey on the salt source and mechanism of salinization. They divided the Mahasarakam Formation into two parts, the upper clastic member (red siltstone and sandstone) and the lower rock salt bed. They found that the upper clastic member, which had long been considered salt-free by many experts, is also salt-impregnated and is a major source of salt. In fact, the writers found that fresh outcrops of red clastic rocks often taste salty, and a sample collected from a fish pond near Amphur Muang, Khon Kaen contained approximately 0.4% salt. According to Utsunomiya (1985; pers. comm.), pond water is normally free of salt in case that only mottled and pallid zones are exposed. Mottled and pallid zones (Fig.18) are believed to have formed under seasonally or permanently water saturated condition in the geological past, and salt must have been washed away by the groundwater. But when a pond is excavated further down to the uniformly red bedrock, the pond water often becomes salty.

As to the mechanism of salinization, Takaya and Somsri pointed out two main causes : 1. direct salinization in case the salt-bearing rocks are at or near the land surface, 2. salinization of downslope or low-lying lands by saline seepage water from adjacent higher lands.

A strange phenomenon, the 'Nam Dun' formation is another cause of salinization. Taking the example of Tha Phra, Khon Kaen, the formation of Nam Dun went like this : First muddy water suddenly sprang out from underground in paddy fields. Usually it went up to man's height. After a short while it subsided and unripened mud (mixture of swelling clay and sand) continued to come out and finally small mounds with a diameter of about 5m and height of 30 to 50 cm were formed. Salinity and alkalinity as well as the low bearing capacity (Table 10) made the land unsuitable for rice. Scores of such Nam Dun can be seen in rice fields near Tha Phra, Khon Kaen. The same phenomena have been reported by Takaya et al. (1984) in the salt-affected area in Nakon Ratchasima province.

The above findings mainly account for the natural causes of salinization. On the other hand, salt-affected soils are expanding considerably due to human activities.

Table 10 Some physical and chemical properties of Nam Dun soil at Tha Phra, Khon Kaen

depth cm	three phase V% solid	liquid	air	bulk density g/cm	EC (1:5) mS/cm	pH (1:5)	moisture condition
0 - 2	-	-	-	-	3.80	-	dry
2 - 19	47.1	42.5	10.5	1.33	1.40	9.8	wet
19 - 49	36.1	63.3	0.6	0.96	1.10	9.8	wet,unripened
49 - 73	28.2	71.8	0.0	0.77	0.95	9.8	wet,unripened

Date of sampling : 20-Feb.-1986 (Analyzed by Pramote, Y. and Montree, L.)

Various types of salinization caused by human activities (Fig.13) have so far been encountered or reported.

(1) salinization of the lands surrounding reservoirs, tanks and along unlined canals
(2) salinization by salt-making operation
(3) salinization of lands irrigated with salinized river and reservoir water
(4) salinization caused by lowering of land level due to erosion and engineering work
(5) salinization caused by deforestation

Reservoirs, ponds and unlined canals (1) raise the groundwater level of their surrounding area, which enables saline groundwater to reach the land surface by capillarity. Salt is being made on a commercial scale (2) by injecting water into rock salt beds, then pumping up saline water and spreading it on the land to evoporate. Not only the land used for evaporation, but the surrounding lands, nearby reservoirs and rivers are also salinized due to the dissemination of salt by overflowing. Salt-making in Borabu, Mahasarakam has been banned by the Government, but it left about 130 hectares of strongly salt-affected soils and also strongly salinized reservoir 'Nong Bor' (Table 11). Salt is still now being made at Ban Dung, Udon Thani province. Reservoir 'Nong Bor' (3) had contributed considerably to the dissemination of salt in rice fields before the discontinuation of the use of water for irrigation. Water from the rivers Mun and Chi is said to become slightly saline (up to 2 mS/cm) in the dry season. Erosion triggered by land clearing, digging of ditches on both sides of the roads, etc. (4) results in a relative rise of the groundwater level, thus enabling the groundwater to reach the land surface by capillarity. Deforestation (5) changes the balance between rainfall and evapotranspiration, and increases percolation and seepage water (Fig.13). Salinized seepage water causes salinization of foot slopes and low-lying lands.

(2) Constraints and countermeasures

Ordinary plants cannot absorb saline water because of its high osmotic pressure. Therefore even if there is enough moisture, the soil is called 'biologically dry'. Alkalinity and acidity are another problem of saline or sodic soils (Brinkman 1977, Kimura 1985). According to Kimura (1985), the pH of many saline soils fluctuates seasonally, rising up to 8-9 in the rainy season and decreasing to 3-2 in the dry season. The mechanism he suggested is as follows:

(wet season) $Na^+ \cdot \text{clay} + H_2O \longrightarrow H^+ + Na^+ + OH^-$
(dry season) $H^+ \cdot \text{clay} + Na^+ \longrightarrow Na^+ \cdot \text{clay} + H^+$

Sandy ill-buffered topsoils aggravate the problem.

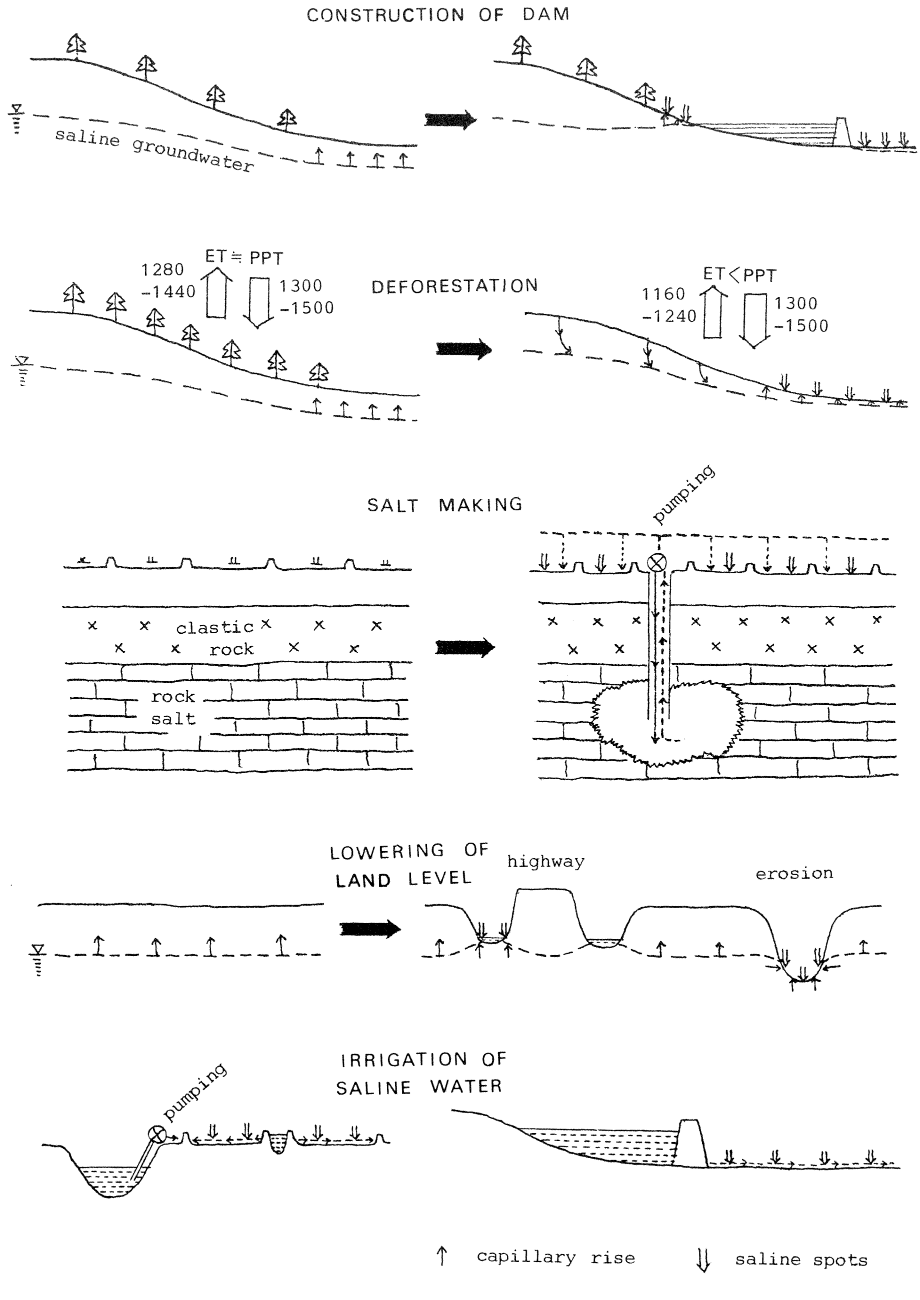


Fig. 13 Some of the artificial causes of salinization

Table 11 EC and pH of some salt-affected water bodies

1986

	EC mS/cm	pH	date of sampling	location
reservoir 'Noonsanun'	1.60	7.65	7/June	Chiang Yun, 30 km east of Khon Kaen
reservoir 'Nong Bor'	40.3	8.07	1/Aug.	Borabu, Mahasarakam
pond 'Bun Sri Than'	2.40	8.32	13/Jan.	Khon Kaen Univ.
pond at Chonnabot	7.15	6.56	13/Jan.	5 km west of Ban Phai, Khon Kaen
pond at Nong Thun	3.98	-	15/Nov.	Yang Talat, Kalasin
pond at Phra Yun	2.53	7.25	4/June	20 km SW of Khon Kaen
pond at Joho	15.0	7.05	6/Aug.	Nakhon Ratchasima, LDD regional office
pond at Ban Nong Kung	19.0	7.30	17/Sept.	10 km south of Muang Phon, Khon Kaen
groundwater at Borabu	100	7.52	1/Aug.	near reservoir 'Nong Bor', Mahasarakam
groundwater at Ban Klum Phaya	2.45	7.50	17/Sept.	Kham Thale So, Nakhon Ratchasima
gushing water from Nam Dun	2.00	8.87	20/Feb.	Ban Sun Mong, Tha Phra, Khon Kaen
small stream at Ban Dung	8.09	-	12/Nov.	Ban Dung, Udon Thani
Chi river water	0.09	8.0	12/Sept.	Maha Chana Chai, Yasothon
Mun river water	0.09	7.7	18/Sept.	Phimai, Nakhon Ratchasima
sea water at Ko Hae Island	47.1	-	10/Dec.	4 km off Phuket
sea water at Penang Island	41.9	-	6/Dec.	Telok Bahang, Penang Island

Na-clay, when excess salt is removed by early monsoon rain, begins to disperse easily in soil water. Part of the organic matter becomes soluble in alkaline media. This enhances the loss of clay and organic matter by runoff or overflow water (selective erosion as discussed in section II.1). In paddy fields, clay is artificially suspended in flood water by puddling. Clay once suspended seems to remain suspended for many days. Overflow water easily takes away the suspended clay. As a result, saline soils often show a sharp distinction between sandy topsoil and clayey subsoil. In saline soils clay can be lost even by percolating or seepage water. Kimura (1986) noticed, in his leaching experiment of saline soils, that the leachates turned turbid due to suspended clay.

As for the countermeasures for salinization, Somsri (1985) presents a package of countermeasures as shown below. Drainage system includes, together with open ditches and underdrains, plantation of eucaliptus trees as interceptors of saline seepage water. Mulching improves the soil moisture status and salinity by suppressing the evaporation and increasing the proportion of rainwater that enters the soil. Compost or organic amendments in general also improve the soil moisture status and salinity by increasing the water holding capacity and buffering capacity of the soils. Kimura (1985) found that a combination of mulching and compost application was most effective for the amelioration of saline soils.

In the writers' opinion, more emphasis should be placed on the prevention of artificial salinization which is brought about by various causes as already explained. The reclamation of already salinized soils often appears hopeless for financial and technical reasons. One must refrain from any strategies which might lead to an expansion of salinized areas. Man-made salinity can be rather easily avoided if preventive measures are properly taken. For that purpose, the mechanism of salinization must be fully clarified. Careful impact-assessment should be made prior to any change in land use, land form or whatever may affect the existing water balance.

moderately and strongly salt-affected area	reclamation	leaching by rainwater or by irrigation water drainage system land leveling
slightly salt-affected area	short-term salinity control	leaching by early rain land leveling organic amendments salt-tolerant species higher seeding rate transplant of old seedlings split application of fertilizer mulching etc.
potential salt-source area	prevention	reforestation deep interceptor drain

III. SOIL GENESIS, CLASSIFICATION AND STRATIGRAPHY

III.1. Classification and Mapping of Soils

Re-classification of Thai soils after Soil Taxonomy (Soil Survey Staff, 1975) has recently been completed. Soil maps of scale 1 : 100,000 have covered the whole country. The concepts of soil taxa have been improved in that they are defined in quantitative terms. More detailed soil surveys are now under way in parts of Thailand in association with various kinds of projects. Generalized soil maps and interpretation maps of various kinds have been published.

New and former taxonomic units of the soils of the Northeast plateau are roughly correlated as follows:

new system	former system
Paleustults	Red-Yellow Latosols Red-Yellow Podsolic soils Gray Podsolic soils
Plinthustults	Red-Yellow Podsolic soils
Paleaquults	Low Humic Gley soils
Plinthaquults	Low Humic Gley soils
Quartzipsamments	Regosols
Natraqualfs	Solonchaks
Halaquepts	Solonchaks

Soils that are sandy throughout are classified as Quartzipsamments. They are further subdivided into Nam Pong series (nonaquic) and Ubon series (aquic). Quartzipsamments are defined as having sandy texture (S or LS) with quartz and other unweatherable minerals comprising more than 95% of the sand fraction. Saline soils are grouped with Natraqualfs (Kula Ronghai series) or Halaquepts (Udon series). Both soils are dominated by exchangeable sodium in exchange sites and the difference between the two lies in the presence (Natraqualfs) or absence of clay-illuvial horizon. Skeletal soils that have ironstone or gravel layer within 50 cm of the surface are classified as skeletal Plinthustults (non-aquic) or Plinthaquults (aquic). Skeletal Plinthustults are subdivided into Phon Phisai series (loose laterite) and Sakon series (sheet laterite), and Skeletal Plinthaquults into Phen series (loose laterite) and On series (sheet laterite).

The rest of the soils, i.e. non-sandy, non-saline, and non-skeletal soils are grouped mostly with Paleustults or Paleaquults and partly with Paleaqualfs.

Paleustults are red to brown colored upland soils that have less than 35% base saturation and have a clay-illuvial horizon at a greater depth. Paleustults are subdivided based on soil color and texture. When the soil color is red (2.5YR or redder), the soils are classified as Yasothon series (fine loamy) or Chumphung series (coarse loamy), when it is red-yellow, the soils are grouped with Warin series (5YR) or Satuk series (7.5YR–10YR, chroma >4), and when brown (7.5YR–10YR, chroma $\leqq 4$), the soils go either to Korat series (fine loamy) or to San Pa Thong series (coarse loamy). These soils constitute a catenary sequence with red soils occurring on higher plateau, red-yellow and brown soils on middle plateau in this order.

Gray colored, aquic soils occur on annually flooded lower plateau. Acid soils with less than 35% base saturation, are grouped with Paleaquults (e.g. Roi-et series), and soils with a higher base saturation with Paleaqualfs (e.g. Tha Tum series). In many cases Paleaqualfs seem to have been more or less affected by salt. Major soil series occurring in the Northeast are listed in Table 12, and the interrelationship among major soil series on the plateau is illustrated in Fig.14.

Table 12 Major soils in the Northeast

(area > 0.25%)

Series	Km^2	%	
Korat	36370	21.37	Paleustult (GP)
Roi-et	35106	20.62	Paleaquult (LHG)
Phon Phisai	15920	9.35	Plinthustult (RYP)
Nam Phong	5274	3.10	Quartzipsamment (R)
Ubon	4182	2.46	Aquic Quartzipsamment(HR)
Alluvial complex	3997	2.35	Tropaquept Tropept
Warin	3477	2.04	Paleustult (RYP)
Satuk	3122	1.83	Paleustult (RYP)
Borabu	2743	1.61	Plinthustult (RYP)
Phen	2237	1.31	Plinthaquult (LHG)
Phimai	2217	1.30	Tropaquept (H.All)
Yasothon	2034	1.20	Paleustult (RYL)
Tha Tum	1757	1.03	Paleaqualf (LHG)
Ratchaburi	1629	0.96	Tropaquept (H.All)
Renu	1509	0.88	Paleaquult (LHG)
Tha Yang	1333	0.78	Paleustult (RYP)
Kula Ronghai	1190	0.70	Natraqualf (Solonchak)
Chatturat	1147	0.67	Haplustalf (RBE)
Si Songkram	1139	0.67	Tropaquept (H.All)
Lat Ya	848	0.50	Paleustult (RYP)
Chok Chai	789	0.46	Haplustox (RYL)
Muak Lek	732	0.43	Haplustalf (NCB)
Pak Chong	673	0.40	Paleustult (RBL)
Surin	606	0.36	Paleustalf (RBL)
On	594	0.35	Plinthaquult (LHG)
Loei	588	0.35	Paleustult (RBL)
Wang Saphung	564	0.33	Haplustalf ( )
Buntarik	479	0.28	Paleaquult (LHG)
Slope complex	22636	13.29	
		90.98	

All;Alluvial soils, LHG;Low Humic Gley soils, R;Regosols, GP;Gray Podzolic soils, RYP;Red Yellow Podzolic soils, RYL;Red Yellow Latosols, RBL;Reddish Brown Lateritic soils, NCB;Non-calcic Brown soils

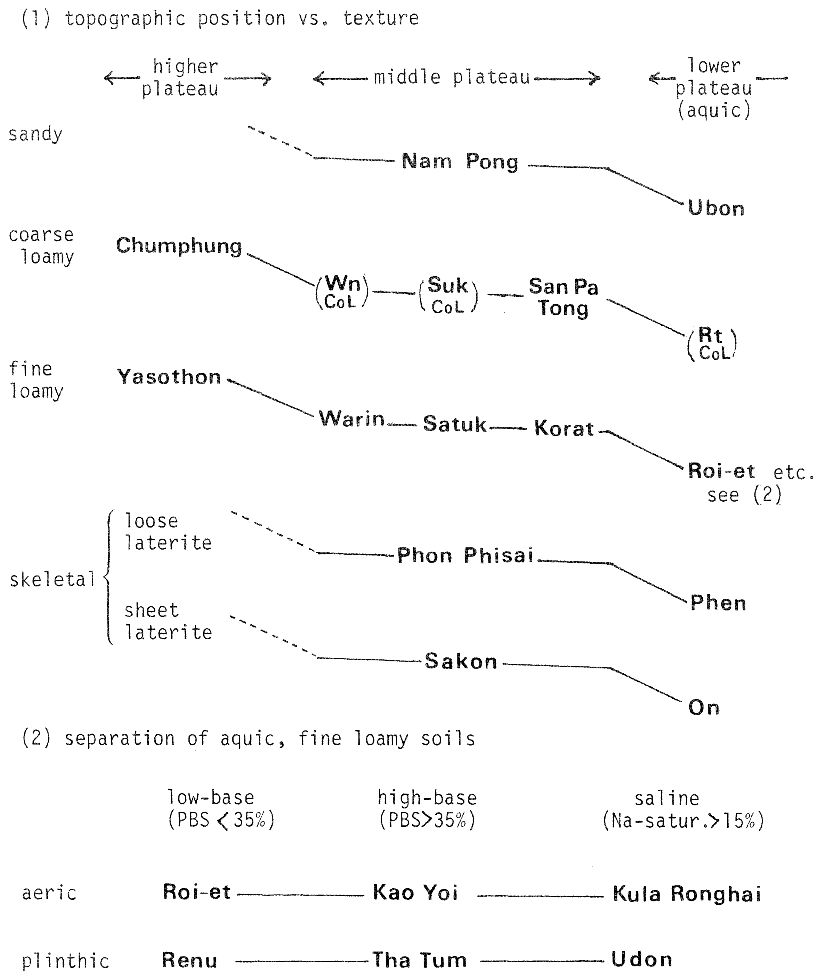


Fig. 14 Interrelation among major soil series of the plateau

Although soil maps have covered the whole country as aforementioned, soil surveys have not always been completed. This is one step in the long-lasting effort to complete an inventory of soil resources. A large number of studies should be carried out for the improvement of classification system and soil maps. The following problems have been observed.

1) Distribution of Korat and Roi-et series

According to the soil map (1:100,000), the Korat and Roi-et series are most widespread on the plateau, each comprising about 20% of the total area (Table 12). Strangely enough, it is very difficult to find these soils in the fields. In the lower plateau where, according to the map, Roi-et soil prevails, one can seldom encounter aquic soils with low base status (base saturation <35%), which is an essential requirement of Roi-et soil (Paleaquults). Motomura et al. (1979) present analytical data of 21 Low Humic Gley soils of the Northeast. Only 4 out of 21 profiles met the requirement of base saturation for Aquults. The degree of base saturation of all the horizons (n=80) averaged 68.1 (±23.7) percent. Again it is very difficult to find non-aquic soils that meet both texture (fine loamy) and color (hue;7.5YR–10YR, chroma$\leqq$4) requirement of Korat soils (Paleustults).

This could be attributed partly to historic background. Pendleton and Sarot (1962) classified all of the non-aquic soils on the plateau as Korat soils and all of the aquic soils as Roi-et soils. Moormann and Sarot (1964) separated some soil series from them and re-defined the Korat and Roi-et soils. However their definitions were still qualitative and flexible. For example although they characterized 'modal' Roi-et soil as having A/Bt profile and an acid reaction, soils that are loamy throughout and neutral or even slightly alkaline in reaction, were also included. Soil survey and mapping were conducted using these definitions as guide line. Rigid and quantitative definitions were introduced later on with the adoption of Soil Taxonomy.

Whatever the cause, the discrepancy between soil map and actual distribution of soils is too wide to leave as it is. It would jeopardize the users' trust of soil map unless it is corrected as soon as possible.

2) Inceptisols on the plateau

As mentioned earlier (II.1), the intensity of present-day washout process is considerable on the plateau. In profile 5 of Appendix I, for example, one meter thick solum above artifact-bearing layer is the sediment of historic age. Loamy or finer textured soils on the plateau are currently grouped with Ultisols or Alfisols, but Inceptisols should be provided for younger soils on the plateau.

3) Aquorizemic (or anthraquic) soils

In parts of paddy soils where water moves downward under flooded condition, eluviation of iron and manganese from the surface and accumulation of these metals in the subsoil takes place. As a result, morphological features characteristic of paddy soils develop (Mitsuchi, 1974b). Kawaguchi and Kyuma (1969) proposed a great soil group 'Aquorizem' for these soils. The same authors found aquorizemic features in 5 profiles out of 20 Low Humic Gley soils they studied in the Northeast. Loamy textured paddy soils in the Northeast plateau are moderately permeable and aquorizemic features seem to develop rather easily. Within the framework of Soil Taxonomy, 'anthraquic' subgroup seems appropriate for these soils.

4) Re-examination of Quartzipsamments

Recently the argillic (Bt) horizons were found at a greater depth in some of the sandy soils that are currently grouped with Quartzipsamments (Nam Pong series). Thus the thick sandy layer of these soils turned out to be the albic (E) horizon instead of the C horizon. Part of the Quartzipsamments as currently classified are expected to shift to Paleustults.

Quartzipsamments in the Northeast often have dark-colored thin horizontal bands in the profile. Thin section analysis revealed the presence of grain argillans and intergranular-void argillans in the dark bands (Photo.4). Table 13 shows that the clay content of the dark horizontal band is more than twice higher than that in the sandy matrix above and below, and that fine clay is much more concentrated in the dark bands. The bands are therefore lamellae of illuvial clay. However the bands are too few and too thin to be qualified as argillic horizon. For the soils of this kind, 'alfic' subgroup should be provided in Quartzipsamments.

5) Slope complex

As mentioned earlier, the soils of the mountainous areas have not been surveyed and mapped yet. Mountainous areas are indicated merely as slope complex in the soil maps. Information on the soils of the mountainous areas is indispensable to the selection of tree species for reforestation, prediction of growth rate of trees,

Table 13 Particle size distribution and organic matter of sandy matrix and dark band in Nam Pong soil

	particle size distribution				fine clay	fine clay /co. clay	organic matter
	CoS	FS	silt	clay			
sandy matrix	17.6	74.4	5.35	2.60	1.36	1.10	0.060
dark band	18.8	69.3	5.21	6.36	3.91	1.60	0.129

conservation and development plans, etc. There is no reason for excluding mountainous areas from the preparation of inventories of soil resources.

III.2 Some Aspects of Soil Genesis

In the preceding chapter (II), the writers already discussed some of the pedogenic processes involved in the formation of the three problem soils. Here we would like to focus on the other pedogenic issues which have not yet been dealt with.

(1) Forming processes of sandy surface soils

In the preceding chapter, the writers raised the micro-erosion and mass movement as the processes whereby clays are removed selectively from the surface. But there are some other causes which have to be taken into account in the formation of sandy topsoils.

As shown in Fig.15, the clay contents increase regularly with depth whereas the silt

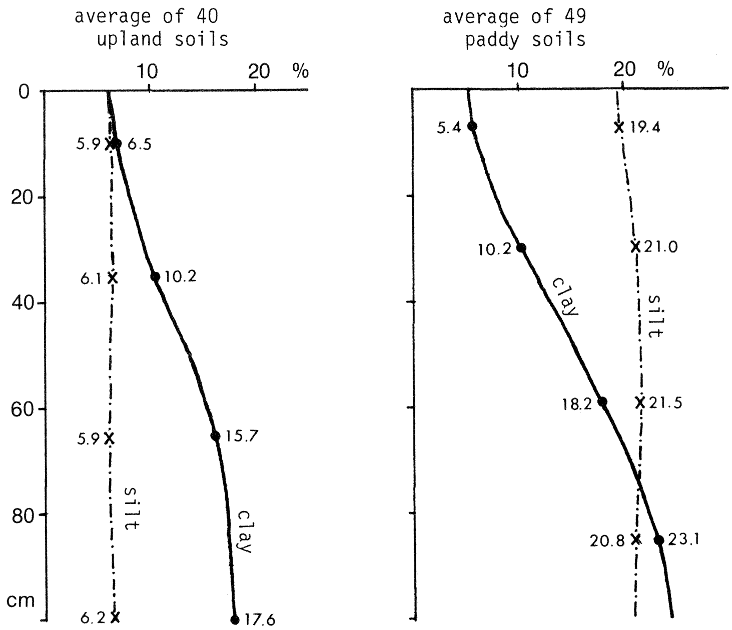


Fig. 15 Vertical distribution of clay and silt in soils of the Northeast plateau

Source; Prateep (1986), Ogawa et al. (1980), Motomura et al. (1979), Kawaguchi and Kyuma (1969), Ragland (1986) contents are rather uniform throughout the profile. This strongly suggests that the downward translocation of clay (lessivage) has taken place in the soils of the plateau. Thai scientists have already confirmed the presence of argillic horizons in soils of the Northeast plateau. Lessivage may account largely for the decrease of clay in the upper profile. At the same time it is strongly suspected that the loss of clay in lateral direction by seepage water has also contributed to a considerable extent to the formation of sandy surface soils. In the rainy season, perched water that seeped out into the pits was often turbid due to suspended clay. The perched water is believed to be moving along the slope.

Another possible cause of the decrease of clay in the upper profile is 'ferrolysis' which takes place in seasonally flooded paddy soils under alternate reducing and oxidizing conditions (Brinkman, 1970).

$$\text{(reducing)} \quad Fe^{2+} + Al^{3+} \cdot \text{clay} \longrightarrow Fe^{2+} \cdot \text{clay} + Al^{3+}$$

$$\text{(oxidizing)} \quad Fe^{2+} \cdot \text{clay} \xrightarrow[\text{oxidation}]{} H^{+} \cdot \text{clay} + \text{Fe-oxide} \xrightarrow[\text{partial destruction}]{} Al^{3+} \cdot \text{clay}$$

With 2:1 layer clay, a part of Al^{3+} · clay follows the path described below, resulting in the formation of Al-chlorite.

$$Al^{3+} \cdot \text{clay} \xrightarrow[\text{partial neutralization}]{} \text{hydroxy-Al} \cdot \text{clay} \xrightarrow[\text{polymerization}]{} \text{Al-chlorite}$$

In addition a part of the Fe^{2+} is trapped in interlayers after drying, thus blocking the exchange sites. Therefore ferrolysis results in the destruction and chloritization of 2:1 clay minerals, leading to a decrease in clay contents as well as a decrease in cation exchange capacities (Mitsuchi, 1974a).

Brinkman (1977) considered ferrolysis to be a major process in the formation of sandy topsoils of paddy fields of Northeast Thailand. However, in the writers' opinion, ferrolysis should not be regarded as the major process responsible for the loss of clay from the surface. Upland soils and paddy soils on the plateau show a similar depth distribution pattern of clay (Fig.15), suggesting that a major process, different from ferrolysis, is common to both soils. Recently Eaqub and Blume (1982) compared seasonally flooded paddy soil and neighbouring non-flooded forest soil in Bangladesh. They found that both soils showed a similar vertical distribution pattern of clay, which led them to a conclusion that ferrolysis was not a dominant factor in the formation of sandy surface soils. Overestimation of ferrolysis may turn our attention away from the real major cause.

(2) Formation of quartzipsamments

The writers quite often came across unusually high pHs of around 8 in sandy upper solum of Quartzipsamments as shown in Fig.16. Quartzipsamments of this type normally have a clayey subsoil, and in rainy season perched water or stagnant water appears in the sandy layer right above the clayey impermeable subsoil. Perched water that seeped out into the pits was clay-suspended. As we came across the high pHs so often, we now suspect that such high pHs are by no means an exception in Quartzipsamments. The writers also noticed in permeability measurement of Quartzipsamment of this type that distilled water that passed through the soil column turned turbid due to suspended clay.

These findings suggested that salt has been involved in the formation of a considerable part of the Quartzipsamments. According to this hypothesis, exchange

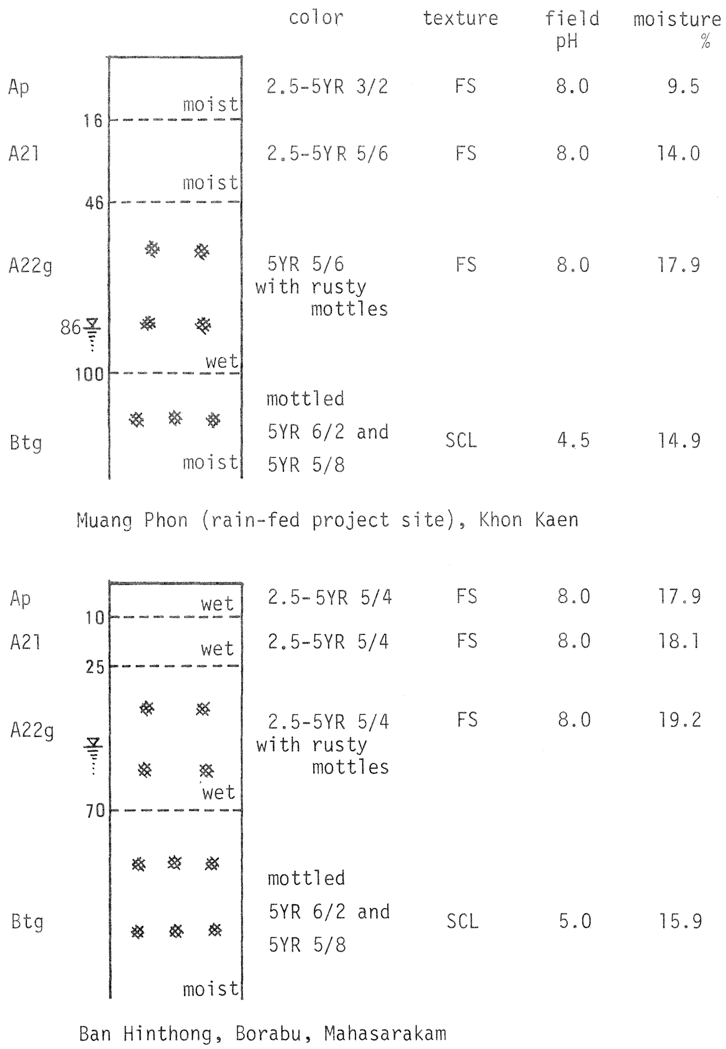


Fig. 16 Two examples of Nam Pong soil profiles (Quartzipsamment) (Sept. 29, 1987)

site of clay minerals is dominated by sodium in the dry season. In the rainy season, wet soils become slightly alkaline due to hydrolysis of Na-clay, and the clay, being suspended in water, can be removed in the lateral or vertical direction by seepage or percolating water. This seems to be at least one of the mechanisms which led to the formation of Quartzipsamments. Further studies are necessary for the confirmation of this hypothesis.

(3) Forming process of soil toposequence

As mentioned before (III.1), red soils (e.g. Yasothon series) occur on the upper plateau, and red-yellow soils (e.g. Warin and Satuk series) on the upper middle plateau and brown soils (e.g. Korat series) on the lower middle plateau, respectively. The genetic relationship among a series of soils that constitute a toposequence is very interesting. According to the data analysed by Prateep (1986), the Yasothon soils have clearly lower CECe, CECe/clay and SiO_2/Al_2O_3 ratios than Warin, Satuk and Korat soils (Table 14). Data supplied by the Soil Survey Division, DLD (1978) also showed a lower CECe/clay ratio and lower pH for Yasothon soil than for the soils of the lower plateau. Buree (1984) found that kaolinite was predominant in Yasothon and Warin soils, while montmorillonite was dominant in the Korat and Roi-et soils. X-ray analysis of clay by Sompob (1985) also gave sharper 7Å reflection for the Yasothon soil

Table 14 Comparison of some properties of four upland soil series constituting a toposequence in the northeast plateau

--- the B horizons only ---

items	soil series	mean ± STD	max.-min.	var. coef.
CECe meq./100g	Yt (14)*	0.54 ± 0.17	0.91-0.36	31
	Wn (28)	0.80 ± 0.41	1.75-0.11	52
	Suk(23)	1.14 ± 0.60	2.57-0.36	52
	Kt (8)	0.71 ± 0.39	1.29-0.22	55
pH (H_2O)	Yt	4.67 ± 0.20	4.90-4.31	4
	Wn	4.97 ± 0.68	7.16-4.26	14
	Suk	5.17 ± 0.58	6.28-4.43	11
	Kt	5.69 ± 0.48	6.44-4.91	8
ΔpH	Yt	0.70 ± 0.12	0.86-0.41	18
	Wn	0.86 ± 0.21	1.42-0.42	24
	Suk	0.91 ± 0.15	1.25-0.68	16
	Kt	0.92 ± 0.15	1.04-0.54	16
SiO_2/Al_2O_3 ratio	Yt	44.5 ± 13.2	68.9-26.1	30
	Wn	60.0 ± 48.1	239 -23.0	80
	Suk	67.8 ± 63.4	288 -18.8	94
	Kt	177 ±134	373 -42.0	75
free Fe_2O_3 %	Yt	1.06 ± 0.25	1.71-0.75	23
	Wn	0.54 ± 0.17	0.90-0.26	32
	Suk	0.57 ± 0.29	1.24-0.16	51
	Kt	0.28 ± 0.12	0.48-0.13	44
clay %	Yt	15.1 ± 2.8	21.3-10.6	19
	Wn	14.2 ± 4.1	22.8- 4.4	29
	Suk	15.3 ± 6.0	26.4- 4.4	39
	Kt	8.5 ± 4.1	14.1- 2.2	48
CECe/clay ×100	Yt	3.68 ± 1.29	6.59-2.32	35
	Wn	8.03 ± 5.48	26.3 -3.29	68
	Suk	7.99 ± 2.87	16.8 -3.56	36
	Kt	7.95 ± 2.01	10.9 -5.16	25

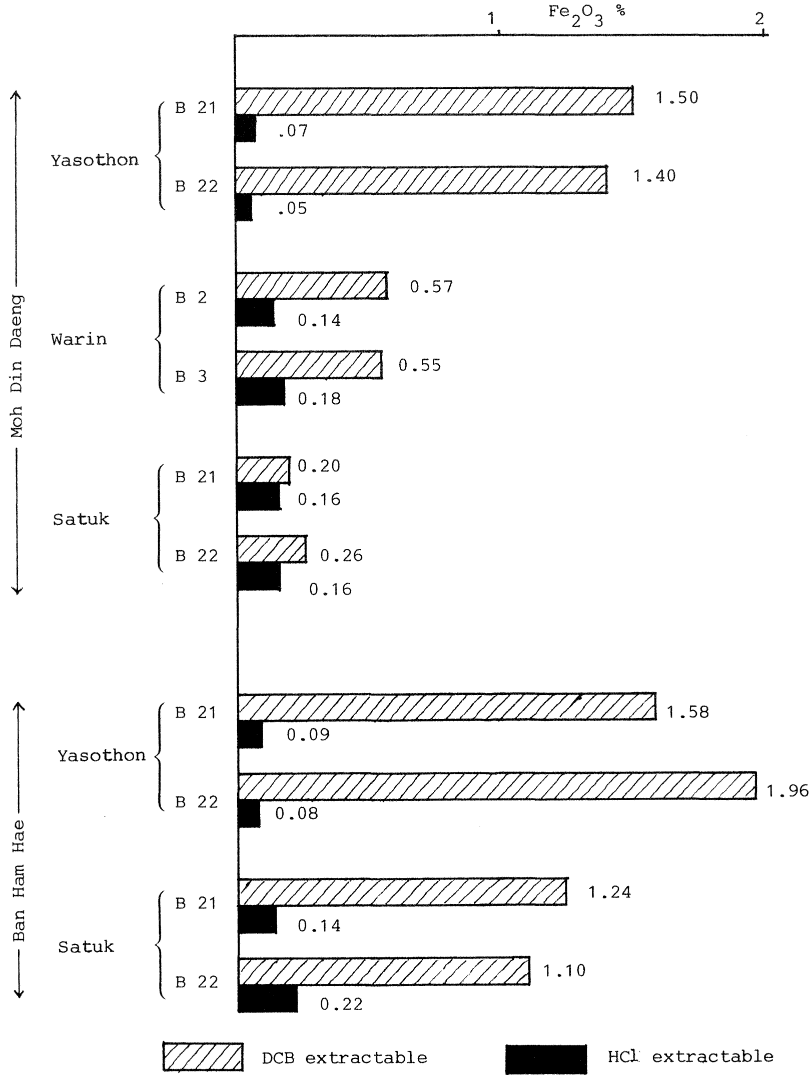
Yt;Yasothon series, Wn;Warin series, Suk;Satuk series, Kt;Korat series

* number of samples

Source : Prateep V.(1986) Upland soils of Thailand, their characterization and capacity evaluation than for Warin soil. All these facts indicate that soils of the upper plateau are at a more advanced stage of weathering.

It is not yet known whether these differences reflect the difference in the age of the soils or the difference in the intensity of weathering. But the writers are inclined to think that the difference in the soil properties reflect the difference in the age of soils. If the present relief is the product of a denudation (dissection) process, the lower the position, the younger must be the soil materials.

Soils in two toposequences were analyzed for iron oxides (Fig.17). The hot HCl-extractable iron (regarded here as iron in crystalline lattice) increased down the slope, suggesting that soils become younger with the lowering of the elevation.



Note; Soils were first treated with dithionite-citrate-bicarbonate (DCB), and then the residues were treated with hot 6N HC1.

Fig. 17 Iron oxides in free (DCB extractable) and in crystalline form (HCl extractable) in upland soils

In contrast to this, the free (DCB-extractable) iron oxides contents decreased gradually down the slope. Data analysed by Prateep (Table 14) also showed a regular decrease in free iron oxides down the slope. This cannot be explained by the age of the soils. In many places the writers observed that soils on the middle plateau are often mottled with red, yellow and white, indicating a periodical reducing condition probably in the geological past. Rich and Obenshain (1956) showed, in their study of soils of catenary sequence, that the hydromorphic properties became increasingly stronger and that free iron oxides decreased regularly down the slope due to the increasingly stronger reductive eluviation. It is likely that, in the toposequence of the Northeast plateau, the difference in free iron oxide contents has also resulted from the difference in the intensity of reductive eluviation. The aquic regime in the past gradually gave way to the aerobic one with the drop of groundwater level due to a further dissection. The morphological features indicating wetness such as mottles that had once formed, have been obliterated in most places by subsequent disturbance and homogenization.

III.3. Soil Stratigraphy

The gently undulating plateau that makes up neary 80% of the Northeast is characterized by the soil stratigraphy shown in Fig.18. This figure indicates a complete set of stratigraphic units, and one or more of the units are often absent in actual soils.

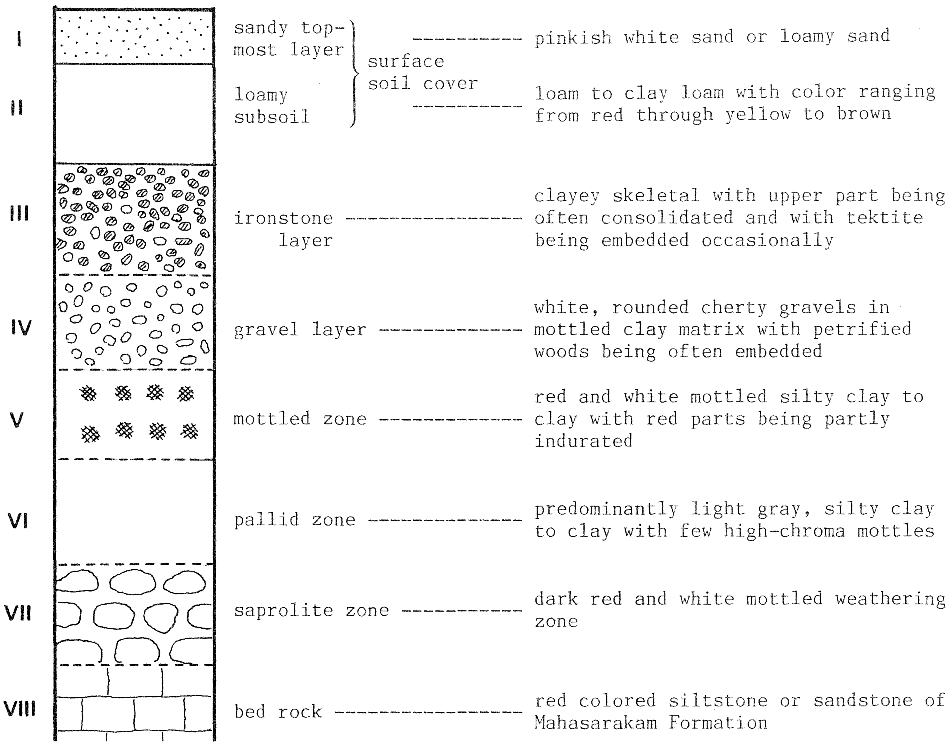


Fig. 18 Generalized upland soil stratigraphy in Khon Kaen province and its vicinity

(1) Surface soil cover

The surface of the plateau is covered extensively with sandy to loamy materials, which rest directly on the ironstone layer. This surface soil cover ranges from one meter to three meters or more in thickness except in the skeletal soil area where the ironstone layer appears within 50cm of the surface. The soil color is varied; red, red-yellow, brown and gray. Clay minerals are predominantly kaolinite (Fig.3), and primary minerals are mostly (>95%) quartz, indicating a highly advanced stage of weathering and kaolinization. Classification of soils depends chiefly on the properties and thickness of the surface soil cover as explained in the preceding section.

As a rule red soils occur at a higher elevation and with decreasing elevation the soil color changes through red-yellow to dull brown, and finally to gray. Moormann et al. (1964) considered that the plateau consists of river terraces and that the surface soil cover was an old alluvium in the Pleistocene age. They divided the plateau into three different levels of terraces, i.e. high, middle and low terraces, and assigned the red soils to the high terrace, the red-yellow to brown soils to the middle terrace, and the gray, aquic soils to the low terrace. However, in all places observed, transition from one soil to another is quite gradual in morphology as well as in elevation without any discernable scarps. In view of the present geomorphic situation, it is unlikely that the greater part of the Northeast was covered with fluvial deposits in the Pleistocene. Present landform of the plateau must have evolved through a denudation (dissection) process and land surface is an erosional one. Present reliefs reflect primarily those of the basement rock. Paiboon et al. (1985) considered that the surface soil cover consisted of outwash deposits judging from the fact that size-distribution of the sand fractions from the surface soil cover was similar to that of the underlying weathered bedrock and clearly different from that of fluvial deposits. Tamura (1986) also reached a similar conclusion and called it 'colluvium'. He thought that the surface cover had been derived directly or indirectly from the weathered mantle of bedrock, and transported over a relatively short distance by wash, creep, wind action, etc.

Surface soil cover is clearly coarser in texture as compared with the underlying mottled and pallid zones, which are considered to be the product of residual weathering of the bedrock. Clay content ranges from 40 to 60% in the underlying weathering zone as compared to an average of 15% in the surface soil cover. As mentioned above, the mode of sedimentation of the surface soil cover must have been of outwash type mass movement. Selective loss of finer particles must have been involved in washout process.

As stated earlier, clay minerals consist almost exclusively of kaolinite, whereas the underlying saprolite zone, which is believed to be the parent material of the surface soil cover, is dominated by montmorillonite. Kaolinization must have proceeded over a geological length of time. Theoretically, the kaolinization process involves a decrease of clay contents by about 30% as shown below;

	chemical formula	M.W. of unit cell	rate %
montmorillonite	$Al_4Si_8O_{20}(OH)_4$	720.7	100
kaolinite	$Al_4Si_4O_{10}(OH)_8$	516	72

This process is believed to have contributed to some extent to the decrease of the clay content in the surface soil cover.

The surface soil cover is often separated by abrupt boundaries into two parts, thin sandy topmost layer and loamy subsoil as seen in Fig.18. At three sites the writers found pre-historic artifacts (earthenwares) being embedded along the boundaries. This indicates that the surface disturbance by outwash is still now taking place at a considerable rate, which causes a further loss of finer particles.

It may be said that the geological processes, i.e. past and present washout and kaolinization drew a rough sketch, and the pedogenetic processes including lessivage and selective-erosion put the finishing tough to the formation of the textural profile.

(2) Ironstone layer and gravel layer

Ironstone layer extensively underlies the surface soil cover. In places ironstones are cemented to each other forming a hard iron-pan. As already explained (II.2), the vertical distributions of iron oxides invalidated the prevailing view that underlying pallid and mottled zones are the major source of iron in the ironstone layer. In-situ segregation of iron rather than upward movement seems to have played a more important role in this process. At a certain point of iron segregation, red mottles began to harden irreversibly, particularly in the upper part of the profile where fluctuation between wet and dry conditions are more pronounced. Subsequent removal of the finer soil matrix in association with the washout process and resultant concentration of ironstone seem to account more properly for the formation of the ironstone layer. Tektites that are dated 700,000 years BP, are occasionally found embedded in the upper part of ironstone layer. The suggested forming process of the ironstone layer is illustrated in Fig.19.

The ironstone layer grades into the gravel layer in most places. The gravels are mostly rounded or subrounded cherty ones. According to Montri (1896; pers. comm.), the cherty gravels are considered to have been derived from conglomerates or conglomeritic sandstones of the Korat group (Phu Phan and Khok Kruat formation). Therefore gravels had been originally rounded in shape and transported over a

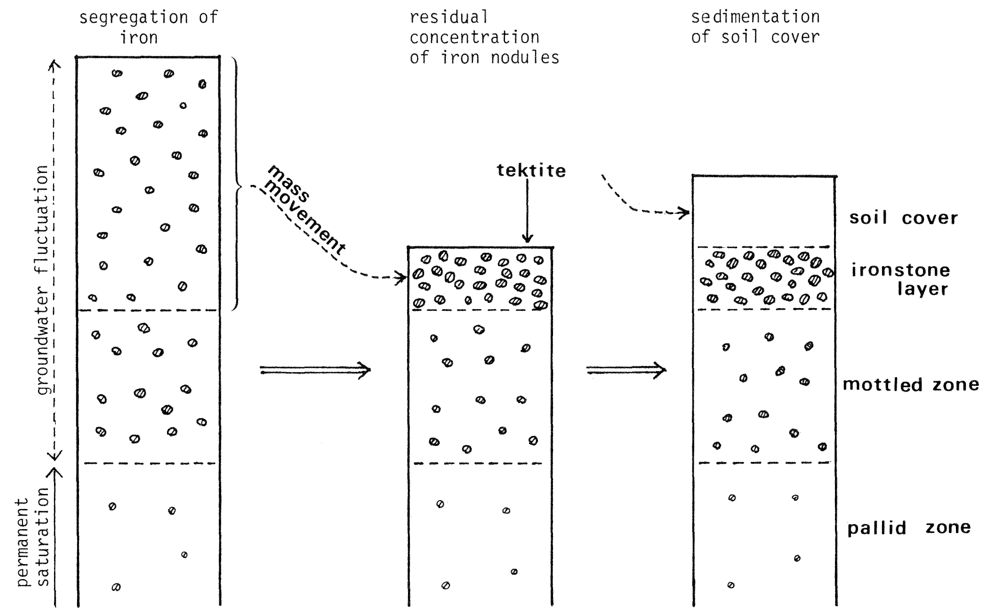


Fig. 19 Hypothesis for the forming process of ironstone layer

relatively short distance. In some places the gravels are cobble- or boulder-size fragments of sandstone. Petrified woods, which have been assigned to the Plio-pleistocene age (Mekong Secretariat, 1978), are often found in the gravel beds. In the

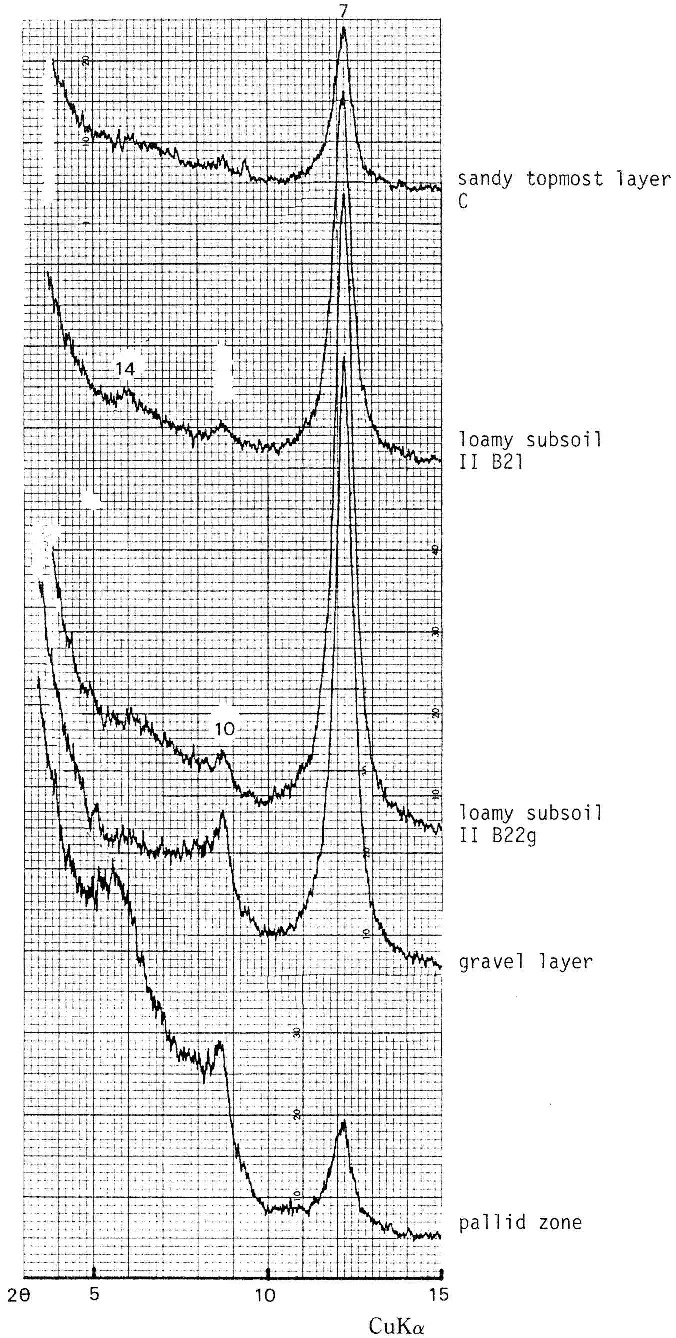


Fig. 20 X-ray diffractograms of oriented Mg-clay of Ban Ham Hae profile in Kalasin (Analyzed by Laksamee, R.)

main part of the Sakon Nakhon basin, however, gravel bed is normally absent.
Clay minerals are predominantly kaolinitic (7Å) with some micaceous minerals (10Å) in ironstone and gravel layers (Fig.20).

(3) Mottled and pallid zones

The gravel layer is underlain by a red/light gray mottled zone and a predominantly light gray colored pallid zone of clayey texture (Table 18). Combined thickness ranges from one meter to several meters. Soft and hard iron nodules are often embedded in the mottled zone and even in the pallid zone. Occasionally the mottled zones are qualified as plinthite, which is soft enough to be cut with a knife, but hardens

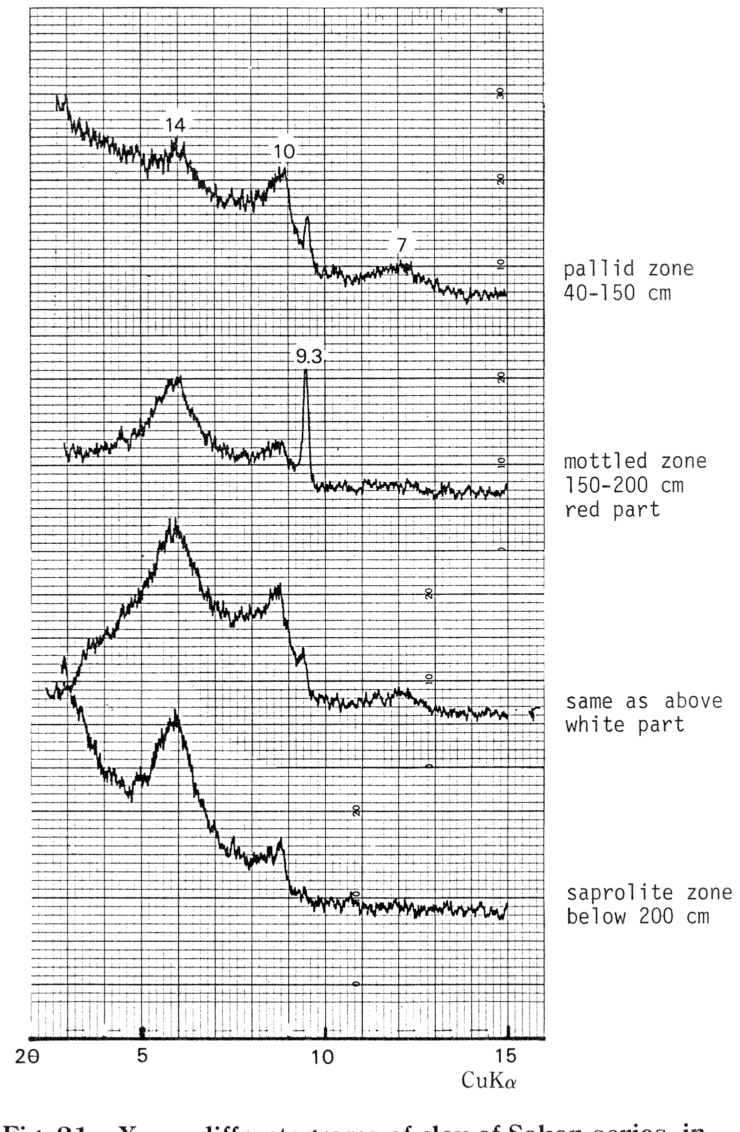


Fig. 21 X-ray diffractograms of clay of Sakon series, in Amphur Muang, Udon Thani province (Analyzed by Laksamee, R.)

irreversively when exposed to the air.

The morphology indicates a seasonally or permanently water-saturated (reducing) condition under a more humid climate probably in the geological past. Fragments of saprolites that retain the origianl rock structure are often found in these zones, indicating that these zones are mostly the products of residual weathering. In the upper part of these zones, clay minerals are a mixture of 14Å and 7Å minerals with a considerable amount of micaceous minerals, while 14Å minerals become increasingly dominant downward (Figs.20, 21). Clay minerals seem to have been derived from those of the parent rocks.

(4) Saprolite zone and bed rock

Red-colored weathered zone, which retain original rock structure (saprolite zone)

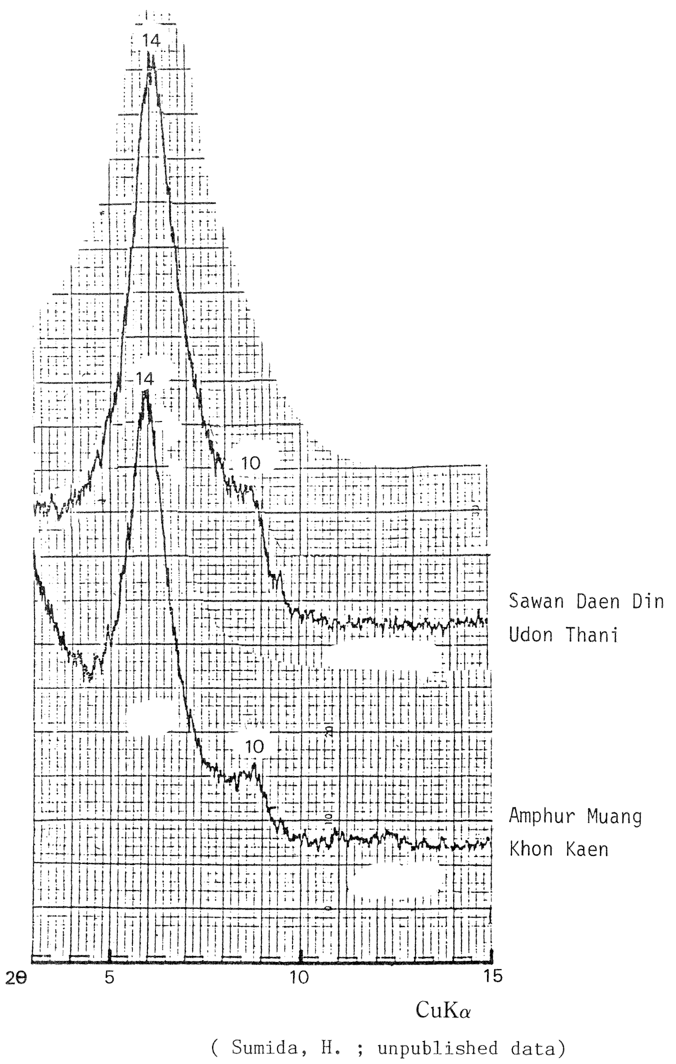


Fig. 22 X-ray diffractograms of clay separated from Mahasarakam bed rocks

underlies the pallid zone. Many light-gray mottles spread along the cracks and joints. Cracks and joints provided the sites for water saturation, from which iron has been removed under a reducing condition to form light-gray mottles. Where the bedrock is calcareous, many lime nodules can be found in saprolite zone.

Saprolite zones grade into bedrock. Basement rocks consist of sandstone, siltstone and partly conglomerate of Mesozoic Korat group, among which the uppermost member, the Mahasarakam Formation is most widespread. The Mahasarakam Formation consists of deep red colored siltstone or sandstone underlain by a rock salt bed. The materials are considered to have been deposited in an old 'Mahasarakam salt lake' or an isolated sea that must have been nearly saturated to over-saturated with salt. Even sandstone and siltstone are salt-impregnated and fresh outcrops of them often taste salty. Due to the salty depositional environment, no fossils are found in the Mahasarakam Formation.

Clay minerals in the saprolite zone and bedrock are predominantly montmorillonitic with a small amount of micaceous clay (Fig.22).

Afterword

This report is the outcome of research activities during the senior author's two year assignment starting from January 1985 at the Agricultural Development Research Project in Northeast Thailand. The project has been implemented with the assistance of the Japan International Cooperation Agency (JICA). Considering that the Project area is so huge and the Project has just started, the writers' effort was concentrated on getting the general view of the characteristics and constraints of the soils of the region instead of investigating in depth any specific subject.

As explained already, the soils on the plateau that have been derived from the Mesozoic sandstone or siltstone are most widespread, comprising nearly eighty percent of the total area. And it is these soils that have many problems and are the major cause of the poor crop performance in the Northeast. Therefore, this report dealt mostly with the infertile soils on the plateau.

The writers are afraid that they were too hasty to draw conclusions regarding the processes of soil formation and soil deterioration from insufficient evidences. Their intention was to invite lively discussions and give a clue to more detailed studies in the future. The writers hope that further studies will provide a firmer scientific basis for the utilization and improvement of the problem soils of the Northeast.

As for the countermeasures, the writers already hinted some ideas in the text. What the writers would like to stress here is that, in elaborating countermeasures, one should not be discouraged by considering the cost/benefit relation. Land has already been reclaimed beyond its capacity and we cannot continue the exploitation of natural soil fertility any longer. When the farmlands are regarded as a means of profit-making, the cost/benefit relation comes inevitably into consideration. But the case will be different when the farmlands are regarded as the natural resources on which the existence of a nation depends. The writers are well aware that the government and the international aid organization have so far allocated a huge amount of budget for the construction of infrastructures such as canals, dams, farm roads, etc. The writers hope that the same line of policy be extended to the improvement of farmlands. Land improvement is beyond the ability of farmers both technically and financially. The farmlands are of course the properties of farmers, but at the same time the asset of the nation and should be handed over to the generations to come.

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Literatures Cited

Anchalee SUDDHIPRAKARN, Irb KHEORUENROMNE, Pramualpong SINDUSEN and Kannica YOOTHONG (1985) Clay minerals and iron oxides of selected Red and Yellow soils in northeast plateau and southwest coast, Thailand, *Kasetsert Jour. (Nat. Sci.),* **19**; 265–271.

ARITA, Y. (1981) Primary minerals in Thai soils, *Nettai-Noken Shuho,* No. **40**, Trop. Agric. Res. Center, Japan (in Japanese).

BRINKMAN, R. (1970) Ferrolysis, a hydromorphic soil forming process, *Geoderma,* **3**; 199–206.

BRINKMAN, R. and DIELEMAN, P.J. (1977) Problem hydromorphic soils in northeast Thailand, 3. Saline acid condition, reclamation, improvement and management, *Netherland Jour. Agric. Sci.,* **25**; 263–277.

Buree BOONSOMPOPPUNTH (1984) Toposequence of soils in Nakhon Ratchasima province, The Northeast Thailand, *Proc. 5th ASEAN soil conference,* vol.1, B1.1–15.

EAQUB, M. and BLUME, H.-P. (1982) Genesis of a so-called ferrolysed soil of Bangladesh, *Z. Pflanzenernaehr. Bodenk.,* **145**; 470–482.

KAWAGUCHI, K. and KYUMA, K. (1969) Lowland rice soils in Thailand, *Report on research in southeast Asia, Nat. Sci. Ser., No.***4**, 270p., Center for Southeast Asian Studies, Kyoto Univ.

KOGA, H. and SHIRAISHI, K. (1985) Utilization of hydroxy-Aluminum for the improvement of soil physical properties, *Jap. Jour. Soil Sci. Plant Nutr.,* **56**; 68–70 (in Japanese).

KIMURA, M. (1985) Report on JSPS-KKU joint study on saline soils in Khon Kaen province.

KUBOTA, T., Prateep VERAPATTANANIRUND, Pongpit PIYAPONGSE, and Samnao PETCHAWEE (1979) The moisture regime and physical properties of upland soils in Thailand and their improvement by soil management, The report of cooperative research work between Thailand and Japan.

KUBOTA, T., Prateep VERAPATTANANIRUND, Pongpit PIYAPONGSE and Samnao PETCHAWEE (1982) Improvement of soil moisture regime of upland soils in Thailand by soil management, *Trop. Agric. Res. Ser., No.***15**, 351-372.

KUBOTA, T., HAKOISHI, T. and TAKAHASHI, S. (1986) Control of decomposition of rice straw farmyard manure by hyroxy-alluminum treatment, *Jap. Jour. Soil Sci. Plant Nutr.,* **57**; 155–160.

LEONARDOS, O. H., FYFE, W.S. and KRONGBERG, B.I. (1987) The use of ground rocks in laterite system: An improvement to the use of conventional soluble fertilizers, *Chemical Geology,* **60**; 361-370.

MEKONG SECRETARIAT (1978) Notes on geological, geomorphological and structural features of the Korat plateau, including particularly the Nam Mun and Nam Chi basin, Interim Committee for Coordination of Investigations of the Lower Mekong Basin, p.1–65.

MITSUCHI, M. (1974a) Chloritization in lowland paddy soils, *Soil Sci. Plant Nutr. Japan,* **20**; 107–116.

MITSUCHI, M. (1974b) Pedogenic characteristics of lowland paddy soils and their significance in soil classification, *Bull. Nat. Inst. Agric. Sci.,* **B25**; 29–115 (Japanese with English summary).

MOORMANN, F.R., Sarot MONTRAKUN, and Samarn PANICHAPONG (1964) Soils of northeastern Thailand, a key to their identification and survey, Land Development Department, Thailand.

MOORMANN, F.R., and Santhad ROJANASOONTHON (1972) Soils of the Kingdom of Thailand, with soil map (1:250,000), Soil Survey Div., Land Development Department, 32p.

MOTOMURA, S., Ashara SEIRAYOSAKUL, Pongpit PIYAPONGSE, and Wisit CHOLITKUL (1979) Field observation and laboratory analysis of paddy soils in Thailand, *Misc. Pub., No.* **45**, Trop. Agric. Res. Center, Japan.

OGAWA, K., Samnao PHETCHAWEE, and Orapin SURIYAPAN (1980) Field observation and laboratory analysis of upland soils in Thailand, *Misc. Pub., No.* **48**, Trop. Agric. Res. Center, Japan.

Pisoot VIJARNSON (1984) Skeletal soils of Thailand, *Proc. 5th ASEAN soil conference,* vol.**1**, F2, 1-14.

Paiboon PRAMOJANEE, Montri LIENGSAKUL, and Viroj ENGKAGUL (1985) Grain size analysis of some sand rises and stream sediments in the Northeast of Thailand in order to indicate depositional environment, *Proc. Conf. Geol. Min. Res. Devel. Northeast Thailand,* Khon Kaen Univ., 235-253 (in Thai with English summary).

Paiboon PRAMOJANEE, HASTINGS, P.T., Montri LIENGSAKUL, and Viroj ENGKAGUL (1984) The laterite in Sakon Nakhon basin; with reference to its landscape relationship and the agriculture potential of its occupying soil, *Proc. Conf. 'Application of Geology and the National Development',* Bangkok, 303-314.

Prateep VERAPATTANANIRUND (1986) Upland soils of Thailand, their characterization and capability evaluation, doctor thesis submitted to Kyoto Univ., Japan, 213p.

PENDLETON, R.L. and Sarot MONTRAKUN (1962) The soils of Thailand, *Proc. 9th Pacific Science Congress,* vol. **18**, Bangkok.

RAGLAND, J. and LADDA, B. (1986) Soil acidity and unbuffered sandy soils of northeast Thailand, a paper presented at FFTC/ASPAC Intern. Seminor on yield maximization of feed crops.

RICH, C.I. and OBENSHAIN, S.S. (1956) Distribution of free iron oxides in four coastal plain soils in Virginia, *Proc. 6th Intern. Congr. Soil Sci.,* **II.7.**; 447-451, Paris.

Samarn PANICHAPONG (1982) Problem soils of Thailand; Their characteristics, distribution and utilization, doctor thesis submitted to Tokyo Univ., Japan.

SOIL SURVEY DIVISION, LDD (1978) Characteristics of some soils in Thailand, Tour guide to International Soil Classification Workshop.

SOIL SURVEY STAFF, USDA (1975) Soil Taxonomy, *Agriculture Handbook, No.* **436**, Soil Conservation Service.

Sompob WONGSOMSAK (1985) Geomorphology and land use in Northeast Thailand - case study Changwat Buri Ram -, master thesis submitted to Kyoto Univ., Japan, 229p.

Somsri SINANUWONG and TAKAYA, Y. (1974) Saline soils in Northeast Thailand, their possible origin as deduced from field evidence, *Southeast Asian Studies,* **12**; 105-120.

Somsri ARUNIN (1983) Characteristics and management of salt-affected soils in the northeast of Thailand, *Proc. Intern. Seminar on Ecology and Management of Problem Soils in Asia,* Paper No.**19**, 26p.

TAKAYA, Y., HATTORI, T. and Pichai WICHAIDIT (1984) Study of problems of soil salinization consequent on irrigation development in the Korat plateau, Report submitted to interim committee for coordination of investigation of the lower

Mekong Basin, 31p.

TAMURA, T. (1986) Geomorphological development in northeast Thailand with reference to problem soil formation, Report of short term expert (6), Agricultural Development Research Project in Northeast Thailand, JICA.

UENO, Y., Kamrop BILLAMAS, Thirapong PIYASIRANANDA, Wirayut VATANAKUL and Pongpit PIYAPONGSE (1983) Improvement of soil moisture regime for the stabilization of field crop production in Thailand, The report of the cooperative research work between Thailand and Japan, 133p.

摘　　要

タイ東北部の大部分を占める波状の台地は，やせ土地帯として知られる．台地の基盤は中生代の砂岩またはシルト岩で，その下方に岩塩層をもつものが非常にひろい．台地の波状地形は，削はく作用(denudation)によって形成されたもので，河岸段丘ではないとみられる．したがって地表を覆う堆積物も河成堆積物でなく，ほとんどは基岩の風化物が斜面に沿って局所的に移動（mass movement）した堆積物である．

肥沃度の低い最大の原因は，表土がほとんど例外なく砂質で，かつ1)砂画分がほとんど石英よりなる，2)わずかの粘土はカオリナイト質，3)有機物がきわめて少ない，などのため養分保持能，同供給能が極端に低いことにある．それに加え塩類が地表に濃縮したり，鉄石層が浅い位置に出るなど，いわば二重苦を抱える土壌も少なくない．

(1)　砂質土壌：基岩直上の風化層は粘質で養分保持能も高いので，砂質な表土は母岩の性質を継承したものとはいえない．表土の砂質化は風化後の諸作用，すなわち1)土壌中の水のタテ，ヨコ方向の動きによる粘土の選択的持去り，2)表面流去水（水田では溢流水）が細粒部分を持ち去る作用，3)mass movement に伴う細粒部分の選択的除去，などの結果とみられる．フェロリシスによる粘土の破壊は，起こっているとしても表層の砂質化の主原因とは考えられない．森林伐採と不用意な土壌管理が表土の砂質化を加速させているとみられた．Mulching, minimum -または no-tillage，地表部を裸にしない栽培体系のほか，活性粘土を富化させる積極的な土壌改良も考えなくてはならない．

(2)　鉄石層をもつ土壌：厚い鉄石層は，もとは土壌中にまばらにあった鉄石が，mass movement により細粒部分が除去された結果，残留濃縮したものと推定された．鉄石層の最上部は，鉄石が互いに膠結されて盤層をなすことも多い．鉄石層や鉄盤層は農作物の培地としての「土」とはいいにくい．すでに拓かれ過ぎた東北タイでは，この地帯は森林の立地として管理・保全するのが賢明と思われる．

(3)　塩類土壌：塩類化は母岩中に含まれる塩に原因する．しかしこの問題の主要な側面は，むしろ人為による不注意な塩類土壌の拡大である．森林の伐採，ダム・溜池の造営，岩塩を利用した製塩などが塩類土壌をひろげている例がきわめて多い．塩類化のメカニズムの解明と，土地利用・水文条件・地形などに加える変更が塩類化を招かないよう細心の事前調査が重要である．

Appendix I. Soil Profile Description

Profile No.1. Yasothon series (Paleustult)

Location ; Ban Ham Hae Phonton, about 13km NE of Kalasin
Landuse ; abondoned secondary shrub
Landform ; higher plateau
Relief ; undulating
Drainage ; well drained
Date ; 9 August 1985
Surveyor ; Mitsuchi, M., Tanongsak, S. and Inoue, T.
Profile description

Ap	0-16cm	dark reddish brown (5YR 3/2) with dark reddish brown (2.5YR 3/6) part (30-40%) in the lower half, LFS, friable, moist, common fine and medium roots, loose (17mm), clear smooth boundary.
Bl	16-45cm	dark reddish brown (2.5YR 3/6), LFS, massive, friable, moist, common fine and coarse roots, loose (17mm), clear smooth boundary.
B21t	45-98cm	dark red (10R 3/6), L, weak subangular blocky, friable, weak cutan on ped face, moist, few fine to medium roots, loose (15mm), diffuse smooth boundary.
B22t	98-140cm+	red (10R 4/6), CL, massive, friable, moist, very few fine roots, compact (21mm).

Profile No.2. Warin series (Paleustult)

Location ; Mor Din Daeng, Khon Kaen, experimental farm of ADRC in Land Development Center
Landuse ; crop field
Landform ; middle plateau
Relief ; undulating
Drainage ; well-drained
Date ; 25 April 1985
Surveyor ; Mitsuchi, M., Tanongsak, S. and Somsak, S.
Profile Description ;

Ap	0-20cm	dull reddish brown (5YR 4/3), LFS, weak blocky structure, very friable, thin lateral reddish brown band along the boundary, benzidine test ++, moist, common fine roots, very loose (8mm), abrupt smooth boundary.
A3	20-31cm	dull reddish brown (5YR 4.5/3), FSL, massive, firm, benzidine test ++, moist, few fine roots, moderately compact (24mm), clear smooth boundary.
B1	31-44cm	dull reddish brown (5YR 5/4), FSL, massive, very hard, benzidine test +, dry, no roots, very compact (33mm), gradual smooth boundary.
B21t	44-100cm	bright reddish brown (5YR 5/6), SCL, massive, very hard, thin lateral reddish brown bands in the upper part, dry, no clay cutan was detected by hand lens, no roots, very compact (33-34mm), diffuse smooth boundary.
B22t	100cm+	bright reddish brown to orange (5YR 5.5/6), FSL, massive, hard,

dry, no roots, compact (27mm).

Profile No.3. Satuk series (Paleustult)

Location	;	Ban Kud Nam Sai, Amphur Kuan Ubonrat, Khon Kaen province (about 1 km south of paper mill)
Landuse	;	Eucalyptus plantation
Landform	;	middle plateau
Relief	;	undulating, Elevation ; 170m, Slope ; 2-3°
Drainage	;	moderately drained
Date	;	27 August 1985
Surveyor	;	Mitsuchi, M., Tanongsak, S., Inoue, T. and Saeree, J.

Profile Description ;

Ap	0-20cm	grayish brown (7.5YR 4/2), LFS, massive, very friable, moist, common fine to medium roots, loose (15mm), field pH ; 5.5, clear smooth boundary.
B1	20-38cm	dull brown (7.5YR 5/4), FSL, weak subangular blocky, very friable, few gray mottles and thread-like iron mottles, moist, few fine roots, moderately compact (20 mm), field pH ; 5.0, gradual smooth boundary.
B21t	38-71cm	bright brown (7.5YR 5/6), CL, weak subangular blocky, friable, few gray mottles and thread-like iron mottles, moist, few fine roots and few decayed tree roots, moderately compact (20mm), field pH ; 5.0, diffuse smooth boundary.
B22t	71-140cm+	bright brown (7.5YR 5/6), CL, weak subangular blocky, friable, few gray mottles and thread-like iron mottles, moist, very few fine roots and few decayed tree roots, moderately compact (20mm), field pH ; 5.0.

Profile No.4. Korat series (Paleustult)

Location	;	Kalasin Land Development Station, about 15km from Kalasin
Landuse	;	crop field in fallow
Landform	;	middle plateau
Relief	;	undulating, Elevation ; 155m, Slope ; 2-3°
Drainage	;	well-drained
Date	;	23 August 1985
Surveyor	;	Mitsuchi, M. and Inoue, T.

Profile Description ;

Ap	0-34cm	grayish brown to bright brown (5YR 4/2.5), LS, very friable, moist, common fine roots, loose (12mm), field pH ; 5.0, clear smooth boundary
B21t	34-74cm	dull reddish brown (5YR 5/4), SL-SCL, massive, very friable, moist, few fine roots, loose (13mm), field pH ; 5.5, diffuse smooth boundary.
B22t	74-110cm	dull orange to dull reddish brown (5YR 5.5/4), SL-SCL, massive, very friable, moist, very few roots, loose (14 mm), field pH ; 5.5, diffuse smooth boundary.
B23t	110cm+	dull orange to dull reddish brown (5YR 5.5/4), SL-SCL, massive, very friable, moist, very few roots, loose (12 mm), field pH ; 5.0.

Profile No.5. Korat series? (Dystropept)

Location	;	Ban Non Khon, Amphur Muang, Ubon Ratchathani province
Landuse	;	grass with scattered tree
Landform	;	middle plateau
Relief	;	undulating slope ; 2-3°
Drainage	;	well drained
Date	;	3 September 1985
Surveyor	;	Mitsuchi, M. and Inoue, T.

Profile description ;

A	0-18cm	brown (7.5YR 4/3), LS, massive, very friable, moist, few fine roots, moderately compact (22mm), clear smooth boundary.
B21	18-56cm	brown (7.5YR 4/4), SL, massive, very friable, moist, very few fine roots, moderately compact (20mm), gradual smooth boundary.
B22	56-94cm	dull brown to brown (7.5YR 4.5/4), SL, massive, very friable, moist, very few fine roots, loose (14mm), clear smooth boundary.
IIC1	94-160cm	dull brown to brown (7.5YR 4.5/4), SL, massive, very friable, moist, loose (12mm), *many fragments of earthenware.*
IIIC2	160cm+	dull orange (5YR 6/4), LFS, single grained, loose, moist, few iron mottles.

Profile No. 6. Nam Pong series (Quartzipsamment)

Location	;	Ban Kham Bon, Tam Bon Samran, Amphur Muang, Khon Kaen province (Rain-fed agriculture project site)
Landuse	;	crop field
Landform	;	lower plateau
Relief	;	undulating
Drainage	;	well drained
Surveyor	;	Mitsuchi, M. and Tanongsak, S.

Profile description ;

Ap	0-15cm	dull brown (7.5YR 5/3), LFS, massive, very friable, benzidine test ++, moist, common fine roots, very loose (9mm), clear smooth boundary.
C1	15-64cm	dull orange (5YR 6/4), FS, massive, very friable, benzidine test +, *dark horizontal lamellae of illuviated clay,* moist, few fine roots, moderately compact (21mm), clear smooth boundary.
C2	64-95cm	dull yellow orange (10YR 6/4), and dull orange (5YR 6/4), LFS, massive, friable, moist, loose (17mm), clear smooth boundary.
C3	95-115cm	dull orange (5YR 6/4), FS, massive, very friable, *few iron mottles along root channel,* moist, loose (16mm), clear smooth boundary.
C4	115cm+	dull orange (7.5YR 6/4), LFS, massive, friable, *few iron mottles along root channel,* moist, loose (16mm).

Profile No.7. Phon Phisai series (Plinthustult)

Location	;	Ban Mahachai, Amphur Plapak, Nakon Phanom province
Landuse	;	secondary shrub
Landform	;	middle plateau
Relief	;	undulating Elevation ; 190m
Drainage	;	somewhat poorly drained
Date	;	22 July 1985

Surveyor ; Mitsuchi, M. and Tanongsak, S.
Profile description ;

A	0-20cm	brown (7.5YR 4/3), CL, weak to moderate subangular blocky, friable, many ironstones (about 20% by volume), benzidine test +, moist, many fine and medium roots, moderately compact (24mm), field pH ; 5.5, abrupt smooth boundary.
B21cn	20-47cm	brown (7.5YR 4/4), CL, friable, *abundant rounded ironstones* up to 1cm in diameter (60-70% by volume), benzidine test ++, moist, few fine roots, compact (27mm), field pH ; 5.5, clear smooth boundary.
B22cn	47-68cm	mottled dark reddish brown (2.5YR 3/4) and grayish yellow (2.5Y 6/2), SiC, weak subangular blocky, firm, *abundant subrounded ironstones* up to 2cm in diameter (about 40% by volume), moist, few medium to large roots, compact (25mm), field pH ; 5.0, gradual smooth boundary.
Cg	68-130cm+	mottled dark red (10R 3/6) and grayish yellow (2.5Y 6/2), SiC, massive, firm, dark red mottles are partly indurated, moist, few fine and medium roots, moderately compact (22mm), field pH ; 5.0.

Profile No.8. Kula Ronghai series (Natraqualf)

Location ; Ban Phon Tong, Amphur Suwanaphum, Roi-et province (Tung Kula Ronghai Land Development Center)
Landuse ; paddy field
Landform ; lower plateau
Relief ; nearly flat Elevation ; 125m
Drainage ; poorly drained
Date ; 15 January 1986
Surveyor ; Saeree, J., Mitsuchi, M., Pichai, W. and Tanongsak, S.
Profile description ;

Apg	0-13cm	grayish brown (7.5YR 4/2), SL, massive, hard, common fine distinct mottles (7.5YR 5/6), few iron concretions up to 5mm in diameter, dry, few fine roots of rice, very compact (30mm), field pH ; 5.5, abrupt wavy boundary.
B21tg	13-46cm	grayish brown (7.5YR 6/2) changing downward to light brownish gray (7.5YR 7/2), CL, subangular blocky, friable, many fine distinct mottles (10YR 5/6), common iron concretions up to 10mm in diameter, moist, compact to very compact (28-29mm), field pH ; 5.0, gradual smooth boundary.
B22tg	46-69cm	grayish yellow brown (10YR 6/2), CL, *weak very coarse prismatic,* firm, common medium mottles (10YR 5/6) and few fine mottles (7.5YR 5/6), common iron concretions up to 10mm in diameter, moist, moderately compact (23 mm), *field pH ; 8.0,* gradual wavy boundary.
B23tg	69-140cm+	grayish yellow brown (10YR 6/2), CL-LiC with sand lens, *weak very coarse prismatic,* firm, many medium mottles (10YR 5/6) and common fine mottles (7.5YR 5/6), moist, moderately compact (20-25mm), *field pH ; 8.0.*

Profile No.9. Udon series (Halaquept)

Location ; Ban Non Somboon, Amphur Muang, Udon Thani province
Landuse ; barren
Landform ; lower plateau
Relief ; gently undulating
Drainage ; somewhat poorly drained
Date ; 14 February 1986
Surveyor ; Saeree, J., Pichai, W. and Laksamee, R.
Profile description ;

Apg	0–17cm	mottled grayish brown (7.5YR 4/2), brownish black (7.5YR 3/2) and dull brown (7.5YR 6/3), LS, weak fine to medium subangular blocky, friable, non-sticky, non-plastic, common fine distinct mottles (5YR 5/6), benzidine test +, moist, common fine to very fine roots, moderately compact (22mm), field pH ; 7.0, clear smooth boundary.
ABg	17–41cm	grayish brown (7.5YR 6/2), SCL, weak fine to medium subangular blocky, firm, slightly sticky, slightly plastic, common fine mottles (7.5YR 5/6), benzidine test ++, moist, many fine and few medium roots, compact (27mm), field pH ; 6.5, gradual smooth boundary.
B21g	41–86cm	light brownish gray (7.5YR 7/2), SL, weak fine to medium subangular blocky, friable, non-sticky, slightly plastic, few fine mottles (7.5YR 4/4), benzidine test ++, moist, many fine and few medium roots, moderately compact (23 mm), *field pH ; 8.0,* clear smooth boundary.
B22g	86–109cm	light brownish gray (7.5YR 7/2), SL, weak fine to medium subangular blocky, friable, non-sticky, slightly plastic, many medium mottles (10YR 6/8), benzidine test ++, common iron nodules in top few centimeters, moist, moderately compact (22mm), *field pH ; 8.0,* clear smooth boundary.
IICg	109cm+	light brownish gray (7.5YR 7/2) and dull orange (7.5YR 7/3), LS, weak fine subangular blocky, friable, non-sticky, non-plastic, common fine mottles (10YR 7/8), benzidine test +, moist, moderately compact (20mm), *field pH ; 8.0.*

Note ;
1. *Nearly 50% of land was covered with salt encrustation.*
2. Mottles in the 1st through 3rd horizons are thread-like and those in the 4th and 5th horizons are spot-, or cloud-like in shape.

Appendix II. Some physical properties of soils of the Northeast Thailand

Soils (location)		Depth cm	Three Phases V % air	water	solid	Dry bulk density g/cm	Water permeability K20 cm/sec.	Hard-ness	Remark
Chok Chai	A	(0-22)	29.6	25.5	44.9	1.22	-	15	26/Jul./85
(Chok Chai, NR)	B21	(22-52)	28.9	21.9	49.2	1.37	-	28	monolith profile
	B22	(52-110)	41.9	17.8	40.3	1.16	-	20	
	B23	(110^{+})	34.2	19.9	46.0	1.31	-	24	
Pak Chong	Ap	(0-14)	33.4	20.2	46.4	1.21	-	23	27/Jul./85
(Pak Chong, NR)	B21t	(14-42)	30.4	22.4	47.2	1.25	-	29	monolith profile
	B22t	(42-70)	27.8	25.3	46.9	1.26	-	32	
	B3	(70^{+})	26.1	24.9	49.0	1.31	-	34	
Yasothon	Ap	(0-16)	14.0	23.0	63.0	1.60	-	17	9/Aug./85
(Ban Ham Hae, KL)	B1	(16-45)	15.3	20.8	64.0	1.67	-	17	monolith profile
	B21t	(45-98)	19.2	20.8	60.0	1.58	-	15	
	B22t	(98^{+})	13.9	23.3	62.7	1.64	-	21	
Yasothon	Ap	(0-22)	40.7	9.4	49.9	1.39	2.0×10^{-3}	-	27/Oct./86
(Mor Din Daeng, KK)	B1	(22-41)	34.9	5.8	59.4	1.58	1.1×10^{-3}	-	IBSRAM profile
	B21t	(41-67)	37.6	7.1	55.3	1.54	1.6×10^{-3}	-	
	B22t	(67^{+})	41.7	6.5	51.9	1.46	2.7×10^{-3}	-	
Warin	Ap	(0-20)	36.9	7.6	55.5	1.49	-	8	25/Apr./85
(Mor Din Daeng, KK)	A3	(20-31)	38.0	3.6	58.5	1.53	-	24	monolith profile
	B1	(31-44)	37.7	3.5	58.8	1.57	-	33	
	B21t	(44-100)	36.7	5.0	58.3	1.42	-	33	
	B22t	(100^{+})	41.6	4.4	54.0	1.46	-	27	
Warin	Ap	(0-19)	26.0	12.7	61.3	1.66	7.9×10^{-4}	-	27/Oct./86
(Mor Din Daeng, KK)	B1	(19-43)	28.2	7.3	64.6	1.75	2.2×10^{-4}	-	IBSRAM profile
	B21t	(43-99)	34.7	8.5	56.9	1.55	2.5×10^{-3}	-	
	B22t	(99-150)	32.4	10.0	57.6	1.52	2.5×10^{-3}	-	
Warin	Ap	(0-20)	32.0	9.7	57.6	1.56	2.9×10^{-3}	-	15/Mar./86
(Mor Din Daeng, KK)	B1	(20-41)	35.4	5.5	59.1	1.61	9.1×10^{-4}	-	
	B21t	(42-52)	32.6	6.5	60.9	1.61	1.3×10^{-3}	-	
	B22t	(52^{+})	35.6	7.5	56.8	1.55	2.5×10^{-3}	-	
Satuk	Ap	(0-20)	13.8	27.6	58.7	1.52	-	15	27/Aug./85
(Ban Kud Nam Sai, KK)	B1	(20-38)	9.8	28.6	61.5	1.63	-	20	monolith profile
	B21t	(38-71)	12.8	25.5	61.7	1.63	-	20	
	B22t	(71^{+})	11.0	24.3	64.5	1.69	-	20	
Korat	A	(0-18)	19.1	22.1	58.8	1.54	-	12	23/Aug./85
(LDS, KL)	B21t	(34-74)	9.1	25.5	65.4	1.70	-	13	monolith profile
	B22t	(74-110)	16.2	22.1	61.7	1.62	-	14	
	B23t	(110^{+})	20.7	19.8	59.5	1.56	-	12	
Korat	A	(0-18)	14.3	20.0	65.7	1.74	-	22	3/Sep./85
(Ban Non Kong, UR)	B21	(18-56)	12.0	21.6	66.3	1.69	-	18	monolith profile
(Muang)	B22	(56-94)	24.7	16.6	58.8	1.58	-	14	
	IIB3	(94^{+})	18.7	17.5	63.8	1.58	-	12	
Nam Phong	Ap	(0-26)	27.6	11.1	61.3	1.67	9.8×10^{-4}	-	27/Oct./86
(Mor Din Daeng, KK)	A 21	(26-41)	34.4	8.0	57.6	1.56	2.0×10^{-3}	-	IBSRAM profile
	A22	(41-88)	35.7	4.6	59.7	1.61	8.9×10^{-4}	-	
	B21t	(88-122)	30.4	8.9	60.5	1.64	9.8×10^{-4}	-	
	B22t	(122^{+})	24.5	14.6	60.9	1.65	1.1×10^{-3}	-	
Nam Phong	Ap	(0-15)	39.2	7.0	53.8	1.44	-	9	30/May/85
(NERAD Project, KK)	A/C	(15-64)	32.1	10.8	57.1	1.52	-	21	monolith profile
	C1	(64-95)	22.3	15.0	62.7	1.63	-	17	
	C2	(95-115)	29.3	14.3	56.4	1.51	-	16	
	C3	(115^{+})	18.9	18.1	63.0	1.63	-	16	

Continued

Soils (location)		Depth cm	Three Phases V % air	water	solid	Dry bulk density g/cm	Water permeability K20 cm/sec.	Hard-ness	Remark
Nam Phong	Ap	(0-15)	46.1	2.1	51.8	1.44	1.6×10^{-3}	-	14/Mar./86
(NERAD Project, KK)	C1	(15-30)	40.3	5.1	54.6	1.50	1.5×10^{-3}	-	
	C2	(30-50)	40.1	7.3	52.6	1.45	1.0×10^{-3}	-	
	C3	(50^{+})	38.9	9.0	52.1	1.45	1.1×10^{-3}	-	
Phon Phisai	A	(0-20)	25.2	25.9	49.0	1.50	-	24	22/Jul./85
(Ban Mahachai, NP)	B1cn	(20-47)	21.5	21.7	56.8	1.83	-	27	monolith profile
	B2cn	(47-68)	7.9	29.4	62.7	1.82	-	25	
	Cg	(68^{+})	3.3	34.2	62.6	1.60	-	22	
Udon	Apg	(0-17)	15.6	19.1	65.3	1.53	-	22	14/Feb./86
(Ban Non Somboon, UT)	ABg	(17-41)	4.5	25.3	70.2	1.82	-	27	monolith profile
	B1g	(41-86)	4.9	25.6	69.5	1.83	-	23	
	B2g	(86-109)	1.9	28.7	69.5	1.84	-	22	
	IICg	(109^{+})	1.3	34.9	63.7	1.68	-	20	
Tha Tum	Apg	(0-14)	33.8	3.5	62.7	1.61	-	25	16/Jan./86
(Tung Kula Ronghai	B11g	(14-32)	15.7	14.6	69.7	1.75	-	27	monolith profile
LD Center, RE)	B12g	(32-56)	11.6	21.9	66.6	1.69	-	26	
	B21tg	(56-110)	2.3	32.4	65.3	1.67	-	26	
	B22tg	(110^{+})	1.9	34.9	63.2	1.66	-	25	
Kula Ronghai	Apg	(0-13)	30.6	3.5	65.9	1.63	-	30	15/Jan./86
(Tung Kula Ronghai)	B21tg	(13-46)	16.5	20.4	63.1	1.66	-	28	monolith profile
LD Center, RE)	B22tg	(46-69)	0.9	31.3	67.7	1.74	-	23	
	B23tg	($69\text{-}140^{+}$)	6.8	29.7	63.5	1.79	-	22	

KK=Khon Kaen, KL=Kalasin, UR=Ubon Ratchathani, NR=Nakon Ratchasima, NP=Nakon Phanom, UT=Udon Thani, RE=Roi-et

Photo.1. **Gully erosion dissecting mottled and pallid zones in gently undulating plateau, Nakon Phanom province**

Photo.2. **Selective erosion at Mahasarakam Field Crop Experiment Station (6 September 1984)**

Photo.3. **Salt-damaged paddy field, Amphur Phen, Udon Thani province**

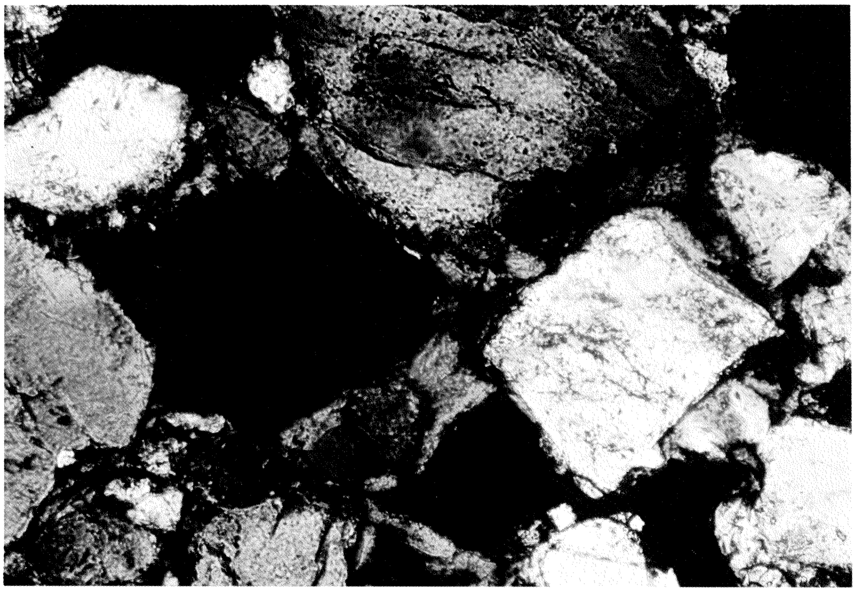

Photo.4. **Microphotograph showing grain argillans connecting skeleton grains to each other in lamellae of illuviated clay in Quartzipsamment, Udon Thani province**