Soil Monolith Paper 1

THIONIC FLUVISOL

(Sulfic Tropaquept)

Central Plain Region, Thailand

International Soil Museum - Wageningen - The Netherlands

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Based upon the work of
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International Soil Museum, Wageningen, The Netherlands - 1981

Foreword

This ISM publication forms the first of a planned series of Soil Monolith Papers. Each will deal with a representative example of a soil unit of the legend of the FAO-Unesco Soil Map of the World at a scale of 1:5.000.000.

These examples form also a reference collection, in the form of soil monoliths, at the exhibition section of the ISM in Wageningen, The Netherlands. The essential information on these monoliths is available for visitors and research students in the form of loose hand-out-sheets. It is, however, thought that a more comprehensive description, including detailed information on the regional environmental setting and land suitabilities, can be useful for teaching of soil science at University level, for soil correlation work by survey organizations, and as background material at the establishment of national soil reference collections.

The outline of the Papers takes account of suggestions received from soil scientists in many countries. In part these suggestions were the result of two precursor booklets on ISM soil monoliths. These dealt with a Chromic Luvisol from Botswana and a Haplic Chernozem from the USSR, and were produced in a limited number in 1974, as try-outs for the 10th International Congress of Soil Science in Moscow.

ISM hereby invites further comments and suggestions on the usefulness and formate of the series. Individual soil scientists are very welcome to prepare a Soil Monolith Paper in the projected series during a stay as a guest researcher at its premises.

Wageningen, October 1981

W.G. Sombroek
Director

Contents

	page
Foreword	2
0 Introduction	5
1 General information and setting	5
1.1 General information on the Thionic Fluvisols	5
1.1.1 Central concept of the soil unit	5
1.1.2 Regional and global extension	6
1.1.3 Regional and global agricultural use	6
1.2 Regional environmental setting	6
1.2.1 Climate	6
1.2.2 Geology	11
1.2.3 Physiography and hydrology	12
1.2.4 Vegetation and land use	13
2 Site and soil	14
2.1 Site characteristics and soil pattern	14
2.1.1 Location of the profile	14
2.1.2 Parent material and petrology	14
2.1.3 Physiographic position and drainage conditions	14
2.1.4 Microclimate	15
2.1.5 Surface characteristics	16
2.2 Soil and soil pattern	16
2.2.1 Brief description of the soil	16
2.2.2 Soil pattern	16
3 Soil genesis and classification	19
3.1 Soil genesis	19
3.2 Soil classification	22
3.2.1 Diagnostic characteristics	22
3.2.2 Classification in various systems	23
4 Aspects of land evaluation	23
4.1 Introduction	23
4.2 Land evaluation in Thailand	24
4.2.1 Land capability classification for upland crops (U)	24
4.2.2 Soil suitability groups for paddy (wetland rice) (P)	25
4.2.3 The placement of some associated soils in interpretive classes and groups	29
4.3 Land qualities and land improvement of Thionic Fluvisols in general	29
5 Suggested reading	33
6 Acknowledgements	34
7 References	34

CONTENTS (continued)

		Page
Appendix 1	Soil data	37
	1A Profile description	37
	1B Laboratory data	39
	1C Clay mineralogy	40
	1D Micromorphological description	41
	1E Major characteristics of the soils of the Wang Noi area (after: Van der Kevie and Yenmanas, 1972)	44
Appendix 2	Analytical methods	46
Appendix 3	Description of the slides	48

List of text figures

Figure 1: World distribution of Thionic Fluvisols 7
Figure 2: Location map 9
Figure 3: Agroclimatic map of the Central Plain of Thailand 10
Figure 4: Mean monthly air and soil temperature at various depths in a Calcaric Fluvisol near Lopburi 15
Figure 5: Soil map of the Wang Noi area 17

List of tables

Table 1 : Monthly rainfall, temperature, radiation, relative humidity and evapotranspiration for three selected stations in Central Thailand 8
Table 2 : Guidelines for grouping soils in capability classes for upland crops; range in degree of limitation by classes 26
Table 3 : Guidelines for grouping soils in suitability groups for paddy; degree of limitation by groups 27
Table 4 : Suggested placement of some soils of the Central Plain area in interpretive classes and groups 28

Introduction

This paper describes a Thionic Fluvisol from Thailand, represented by soil monolith nr. T1 of the ISM soil monolith collection. The paper refers to other Thionic Fluvisols as well, especially to other Thionic Fluvisols in Thailand. A number of remarks of a more general nature are made on the Thionic Fluvisols in Southeast Asia, in the tropics and in the world at large.

Sampling of the soil monolith T1 was carried out in 1967 by Mr. W. van der Kevie, at that time FAO soil scientist at the Soil Survey Division of the Thai Department of Land Development.

The same profile was described and discussed in summary form by the late Prof. Dr. F.A. van Baren, former Director of ISM, in the third edition of the well-known textbook on the genesis of tropical soils (Mohr, Van Baren and Van Schuylenborgh, 1972).

1. General Information and Setting

1.1 General information on the Thionic Fluvisols

1.1.1 Central concept of the soil unit

In the legend of the FAO-Unesco Soil Map of the World (FAO-Unesco, 1974) Fluvisols are defined as soils, developed from recent alluvial deposits having no diagnostic horizons other than (unless buried by 50 cm or more new material) an ochric or an umbric A horizon, a histic H horizon, or a sulfuric horizon. As used in this definition, recent alluvial deposits are fluviatile, marine, lacustrine or colluvial sediments.

The soil unit Thionic Fluvisol has been introduced by FAO-Unesco to include Fluvisols, having a sulfuric horizon or sulfidic material, or both, at less than 125 cm from the surface.

A sulfuric horizon forms as a result of drainage and oxidation of mineral or organic materials which are rich in sulfides. It is characterized by a pH less than 3.5 (H_2O, 1:1) and jarosite mottles with a hue of 2.5Y or more and a chroma of 6 or more.

Sulfidic materials are waterlogged mineral or organic soil materials containing 0.75 percent or more sulfur (dry weight), mostly in the form of sulfides and having less than three times as much carbonate ($CaCO_3$ equivalent) as sulfur. Sulfidic materials accumulate in a soil that is permanently saturated, generally with brackish water. If the soil is drained the sulfides oxidize to form sulfuric acid; and the pH which normally is near neutrality before drainage, drops below 3.5. Sulfidic material differs from the sulfuric horizon in that it does not show jarosite mottles (FAO-Unesco, 1974).

Thus, the Thionic Fluvisol unit includes both soils characterized by extreme acidity which are often referred to as actual acid sulfate soils, and soils which are neutral in reaction but will acidify upon drainage and oxidation, and which are therefore called potential acid sulfate soils. The profile T1 is an example of a Thionic Fluvisol with a sulfuric horizon and may be described as an actual

acid sulfate soil.

Apart from acidity or the risk of acidification Thionic Fluvisols in active tidal areas are often affected by salinity.

1.1.2 Regional and global extension

The site of the soil is located in the Bangkok Plain, also known as the Southern Central Plain of Thailand (for exact location see profile description, appendix 1A). Van Breemen (1976) reports a continuous area of acid sulfate soils, covering about 8000 km^2 in the Bangkok Plain.

According to the Soil Map of the World (sheet IX, FAO-Unesco, 1976) Thionic Fluvisols occur in this region as the dominant soil unit in the map unit Jt14-3a. This map unit is composed of the dominant soil with the associated soil unit Gh, Humic Gleysols (mineral soils with hydromorphic characteristics within 50 cm depth and acid organic surface horizon) and inclusions of soil unit Gd, Dystric Gleysols (mineral soils with hydromorphic characteristics within 50 cm and low base saturation). The dominant soil in this region is fine textured and the dominating slope of the map unit is level.

The occurrence of Thionic Fluvisols has been reported in many parts of the world (Figure 1). They are associated with recent marine or brackish water deposits, although under special conditions acid sulfate soils may develop in inland areas (cf. Chenery, 1954). Their largest extension is found in the coastal plains, deltas and mangrove swamps in tropical regions, such as Southeast Asia, North Australia, the Ganges delta, West Africa, Madagascar, the Caribbean and the northeast coast of South America. Globally, Thionic Fluvisols cover an area of about 140.000 km^2. In addition, some 200.000 km^2 of coastal Histosols (peat soils), mainly in Indonesia, are underlain by mineral material of essentially the same character as the Thionic Fluvisols (Van Breemen, 1980).

1.1.3 Regional and global agricultural use

The Thionic Fluvisols of the Central Plain in Thailand are mostly used for the cultivation of rice. In small areas they are used for growing vegetables and even some fruit trees. The soils are then ridged and measures are taken to control the ground water level. Rice is also the main crop in other parts of the tropics, where Thionic Fluvisols are under cultivation, e.g. West Africa. In temperate regions, after reclamation, they are used for pasture and field crops.

In many areas, however, Thionic Fluvisols are not used for agriculture, especially when tidal movements are still active. Here, the existing mangrove forest is an important hatching area for shrimps, fish and shellfish, while the vegetation is often used for timber, thatch, and charcoal production. The forests have a protective function as well because they shelter the hinterland for ravages by cyclones through dampening wave action and reducing wind speed.

1.2 Regional environmental setting

1.2.1 Climate

Climatic data are available from a number of meteorological stations in the Central Plain (Met. Dep., 1974, 1977). Since no climatic data for the site of

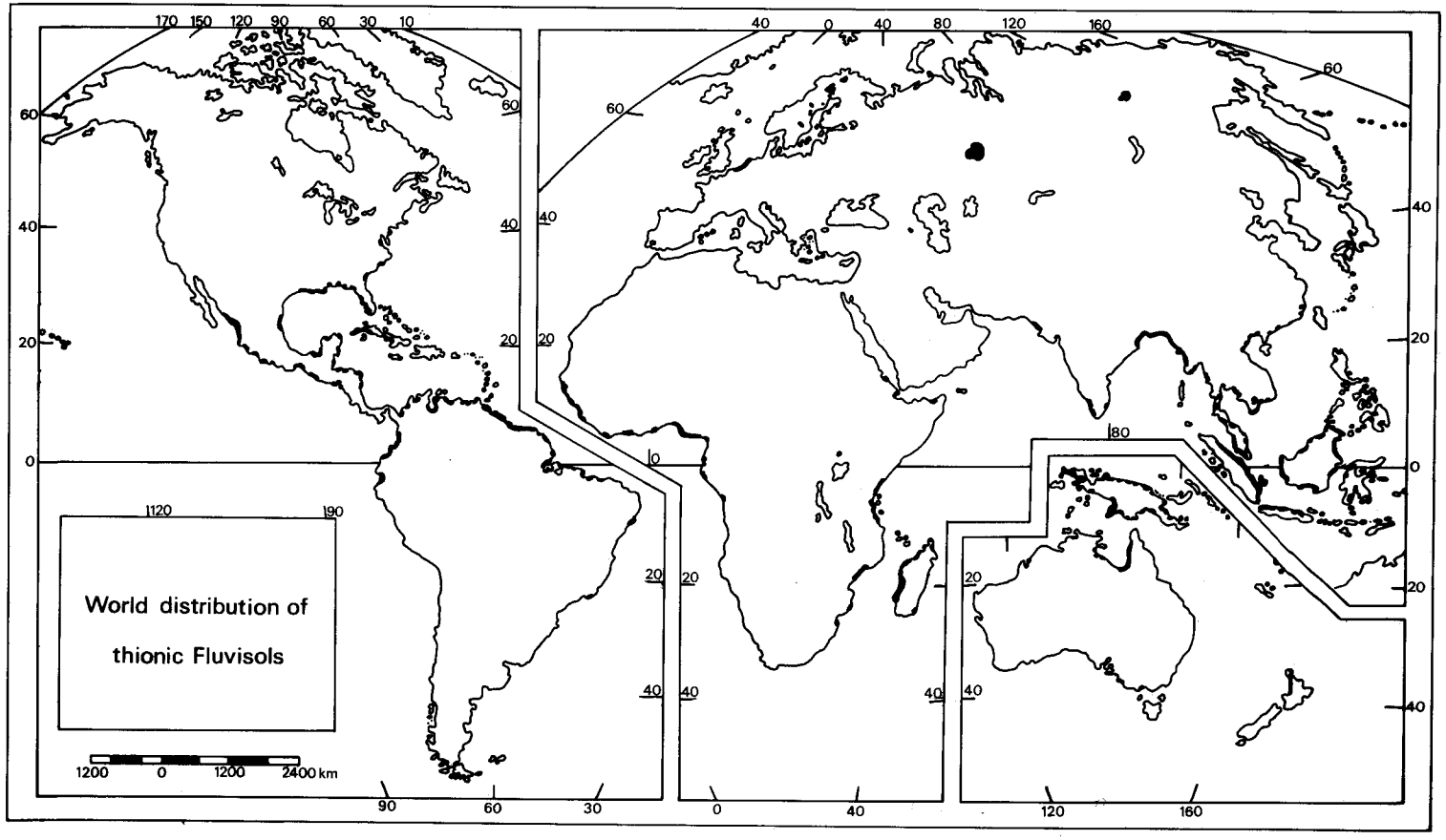


Figure 1. World distribution of Thionic Fluvisols (Kawalec, FAO, 1973)

Table 1. Monthly rainfall, temperature, radiation, relative humidity and evapotranspiration for three selected stations in Central Thailand (After: Meterol. Dept., 1977; Oldeman, 1981)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
	Median rainfall expressed in mm per month												
Lop Buri	0	5	40	75	146	145	172	173	297	158	27	0	1237
Bangkok	1	16	19	64	179	132	165	193	355	219	37	2	1282
Prachin Buri	1	9	74	108	187	271	308	340	383	181	33	0	1895
	Mean monthly temperature in ^{o}Celsius (Average for the three locations)												
Max.	32.3	33.7	35.1	35.9	34.6	33.1	32.4	32.0	31.6	31.6	31.4	31.3	32.9
Min.	19.5	22.1	23.9	25.0	25.1	24.6	24.3	24.2	24.1	23.9	22.1	19.9	23.5
Mean	25.9	27.9	29.5	30.4	29.8	28.8	28.3	28.1	27.8	27.7	26.7	25.6	28.2
	Mean net incoming radiation in kJ/m^2 per day ($x10^2$)												
Lop Buri	195	207	211	236	211	186	180	178	176	193	193	188	197
Bangkok	203	216	226	232	207	193	180	178	174	186	195	190	199
	Mean monthly relative humidity in %												
Lop Buri	58	61	62	64	72	75	77	79	81	77	69	60	70
Bangkok	73	76	77	77	80	80	81	82	84	83	79	74	79
Prachin Buri	60	63	66	70	77	80	81	82	83	78	68	61	72
	Mean potential evapotranspiration in mm per day (modified Penman)												
Lop Buri	4.6	5.2	5.5	6.0	5.5	4.6	4.3	4.3	3.7	4.9	4.6	4.5	1754
Bangkok	4.3	5.0	5.6	5.8	5.3	4.7	4.4	3.8	3.6	4.1	4.2	4.0	1665

the monolith itself are available, three nearby stations were selected, all within a range of 70 km. Lop Buri is located north, Bangkok south and Prachin Buri east of the site (Figure 2).

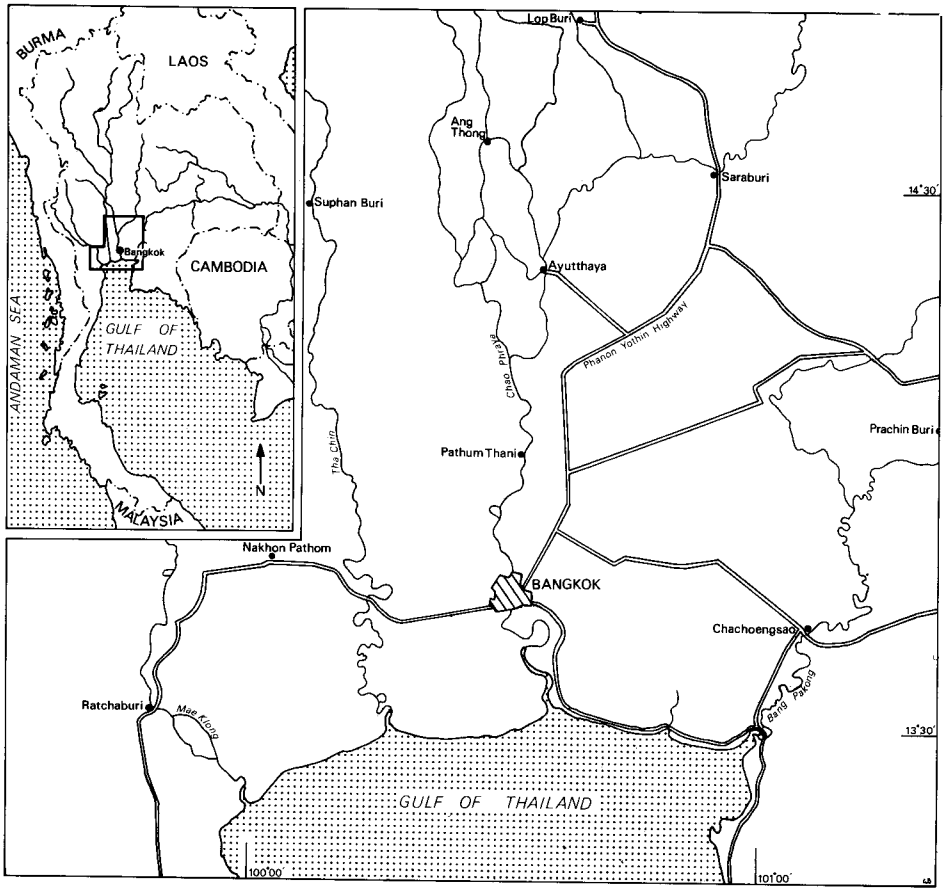
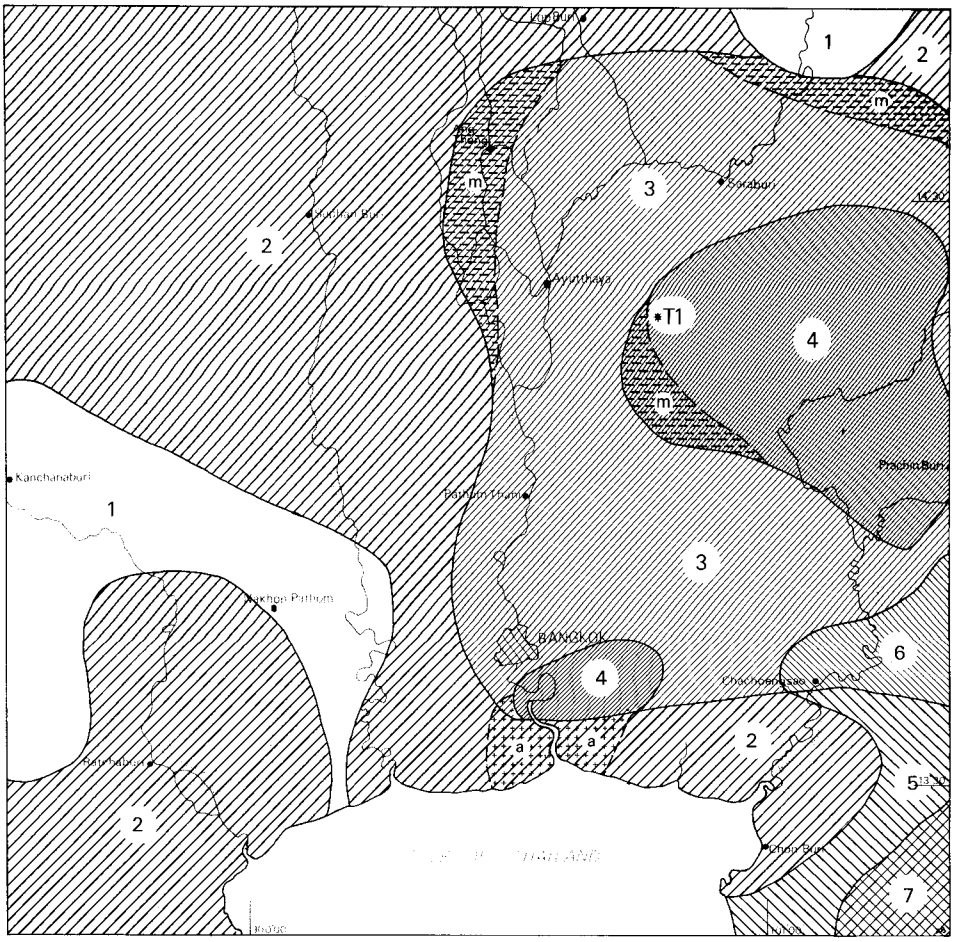


Figure 2. Location map

According to the Köppen system the climate can be classified as tropical savannah (Aw), characterized by temperatures above 18°C throughout the year and a pronounced dry season in winter.

Monthly and annual values of precipitation, temperature, radiation, relative humidity and evapotranspiration for the three locations are shown in Table 1.

Rainfall shows a pronounced seasonal variation. Bangkok and Lop Buri have 5 dry months with less than 50 mm rain from November to March. Rainfall remains erratic from May until mid-July, although monthly means are as high as 150 mm. The highest and most reliable rain falls between mid-July and mid-October with a peak of 300 mm or more (mean value) in September. Prachin Buri has a similar



LEGEND

1	**Growing season 7 months,** less than 3 wet **months.**
2	Growing season 8 months, less than 3 wet months.
3	Growing season 8 months, 3-4 wet months.
4	Growing season 8 months, 5-6 wet months.
5	Growing season 9 months, less than 3 wet months.
6	Growing season 9 months, 3-4 wet months.
7	Growing season 10 months, less than 3 wet months.

a	an additional wet month is possible early in growing period
m	wet period interrupted by one month with 100-200 mm rain
* T1	Site of monolith
	villages
	Rivers

0 75

Fig. 3 An agroclimatic map of the Central Plain of Thailand (After: Oldeman, 1981) approx. scale 1:1,500,000

dry season, but the total rainfall is much higher, especially during June, July and August, which gives, including the peak in September, four real wet months with more than 250 mm rain.

Annual variability of rainfall in the Central Plain is high. In a 15 year period (1954-1968) the maximum rainfall for Bangkok was 1957 mm and the minimum was 876 mm (Van der Kevie & Yenmanas, 1972).

The other climatic features show much less seasonal variation. The mean monthly temperature fluctuates from 25.6°C in December to 30.4°C in April. Mean monthly minimum temperature is just below 20°C in December and January and around 25°C in April and May; mean monthly maximum temperature varies from 31.3°C in December to 35.9°C in May.

The mean radiation is around 17400 kJ/m^2 (415 cal/cm^2) per day in September and increases to 23400 kJ/m^2 (560 cal/cm^2) per day in April. The mean relative humidity is around 80 % from May to October and drops to values of around 60 % between December and March.

Evapotranspiration, calculated with the modified Penman method varies between 3.5 mm per day in September to 5.8 mm per day in March and April. Annual potential evapotranspiration amounts to about 1650 to 1750 mm (Oldeman, 1981). Figure 3 shows the delineation of agroclimatic zones in Southern Central Thailand, based on the length of growing seasons and the number of wet months. A growing season is defined here as the period during the year that rainfall exceeds full evapotranspiration (modified Penman) and it includes additional periods of up to one month at the onset of the growing season when precipitation exceeds half of the evapotranspiration and one month at the end of the growing season to account for evaporation of water stored in the soil. A month is defined as wet if it has more than 200 mm rainfall. Length of growing period and duration of wet period increase from the west to the east. Analysis of rainfall figures of three stations of the Central Plain indicates marked differences in rainfall distribution between Prachin Buri located in its eastern fringe and Lop Buri and Bangkok, situated on the north-south axis of the plain. In the central parts, after the pronounced start of the rainy season in the second half of May, there exists a high risk of relatively dry spells in June and July and to a lesser degree in August. This is of critical importance for the growth of rice in the dryland stage, particularly on purely rainfed locations. This would call for late sowing as to evade eventual dry spells, but if the rice is sown too late the seedlings may be too weak to elongate rapidly enough to keep pace with the rising flood water. Rainfall conditions are much more favourable in Prachin Buri where the occurrence of drought during the rainy is less frequent.

Applying the Thornthwaite method (Grontmij N.V., 1963), water balance calculations for the Wang Noi area result in an actual evapotranspiration of approximately 1100 mm per year, a rainfall deficit of about 600 mm for the period December to May and a precipitation surplus of about 200 mm in August, September and October.

1.2.2 Geology

The Central Plain of Thailand is a syncline filled with Quaternary sediments of fluvial, deltaic and marine origin. The fluvial deposits are found mainly in the northern part, while tidal marsh and marine sediments, underlain by mottled clayey and sandy deposits, prevail in the southern part.

In general, two types of tidal marsh and marine deposits are distinguished in the coastal plain of Thailand. In the inland area, where the site of T1 is located, the sediments have grey to dark grey colours, while along the coast the deposits show more greenish grey colours.

This difference in type of sediment is related to the relative sea-level movements, which have strongly influenced the environment of deposition. In post-glacial times the sea-level rose rather quickly until about 5.000 years B.P., when it nearly reached its present-day level. During this period brackish water swamps extended far inland and thick layers of clayey sediments were deposited. These clays were mixed with poorly decomposed organic matter and had dark grey reduction colours. The anaerobic environment and continuous supply of SO_4 by intruding sea-water caused the simultaneous accumulation of sulfides in the clayey sediments.

After 5.000 years B.P., when the rise of the sea-level became gradually less, the coastline of the Bangkok Plain shifted gradually southward and filling-up of the Gulf of Thailand started. These younger sediments have greenish grey colours, which are due to the presence of green iron silicates, probably formed on a shallow sea floor (Van der Kevie, 1971).

The old coastline is nowadays marked in the field by a broken very low sandy ridge 40-50 km inland, more or less parallel to the present shoreline.

A slight uplift of the Bangkok Plain, most likely due to westward tilting of the Kra Peninsula (Brown et al., 1951), together with a lessening influence of the sea in the swampy area after 3.500 years B.P., caused upheaval of the region above mean sea-level and drainage of the land improved from that time onwards.

1.2.3 Physiography and hydrology

At present, the Central Plain of Thailand is formed by a very level lowland ranging in altitude from 1.5 m near the coast to 15 m inland. Macrorelief is in the order of several metres and is caused by river levees and backswamps in the upper part and, in the lower part, by two elongated areas parallel to the coast, which are probably old barrier islands (Takaya, 1969).

Conspicuous topographical features of the lowlying flat area are numerous, almost circular depressions, about 0.5 m deep and 50 m wide. Locally they are called "elephant-wallows", in the world at large "whale-wallows" or "Carolina bays". Their genesis is rather uncertain, but most likely they can be attributed to the action of tidal swirls.

Three major streams enter the Central Plain, viz. the Chao Phraya River, which is by far the most important river in the area, and the smaller Mae Klong and Bang Pakong Rivers. Together with their tributaries and distributaries they represent a meandering and branching river system. This intricate pattern of larger and smaller streams, typical for a deltaic region, form the natural drainage system of the plain. This has recently been changed by a number of civil engineering measures, in particular by canalization since 1899 and the construction of diversion works and, outside the Central Plain, of high dams (1952-1972) (Nedeco/Ilaco, 1973). Until about 1960 the river flow in the Chao Phraya River followed the seasonal variation of the rainfall with a certain time-lag. At Nakorn Sawan, at the entrance of the Central Plain, river discharges varied from about 40 m^3/s in the dry season to maxima between 1500 and 4000 m^3/s in October (Kasetsart Un., 1972). At present dry season flow is much higher. Between August and September the combined flow of river and rainwater exceeds the total capacity of the drainage system of the Central Plain, especially north of Bangkok, and flooding occurs. Maximum inundation heights vary between 0.1 and 3 m. In the western and central part of the area with older acid sulfate soils flood levels of 0.80 to 2.0 m occur, while in the east they usually do not exceed 0.80 m. South of Bangkok inundation is much less, up to 0.3 m (Van der Kevie and Yenmanas, 1972; Van Breemen, 1976).

1.2.4. Vegetation and land use

Palynological data of subsoil samples from two sites in the former tidal marshes, viz. east of Pathum Thani and southeast of Ayutthaya, indicate that at the time of deposition the vegetation in these marshes consisted dominantly of mangrove species (69-93 %), mainly Rhizophoraceae (Pons and Van der Kevie, 1969), with a subordinate amount of various ferns and grasses. As the influence of the tides lessened, the mangrove forest gave initially way to a fresh water forest (Van der Kevie, 1971). This gradually changed to a vegetation of mainly tall grasses, rushes and sedges, which form the presentday natural vegetation of the Bangkok Plain (Van Breemen, 1976).

Clearing of the natural vegetation commenced about a century ago because of a growing demand for rice, especially from the newly colonized neighbouring countries (Tomosugi, 1966).

At present management practices include ploughing, incidental application of fertilizers, and burning of the straw. Ploughing is done by mechanical or animal traction (water buffaloes).

Most of the area is now under cultivation. In the low-lying and yearly flooded former tidal flat area mainly broadcast, deep water rice is grown.

Rice is sown broadcast in the early rainy season, after the land has been plowed twice. It grows as a rainfed crop until August, when the area is flooded with fresh water mainly through overflow of the rivers. The rice plants elongate with the rising water level and flower around November. Flowering generally coincide with the highest water level. Harvesting takes place after the water has retreated, usually between the second half of December and the later part of January. In general no second crop is planted.

Notwithstanding the apparent similarity of the soils, production levels differ considerably on the acid soils of the Central Plain. Yields are relatively high (up to 3000 kg/ha) in the western, central and southern areas, but they are decreasing toward the east, where they may be as low as 750 kg/ha. The major factor involved in these large differences is probably the stronger acidity of the eastern soils during the growing season, while only minor pH differences are found on dried samples of acid sulfate soils from the eastern and western parts of the Central Plain. Possible reasons for the higher acidity under field conditions may be the absence of gypsum in the soil, the lateness of the flood, the low flood level and the low quality of the flooding water, all of which characterize the eastern area (Van der Kevie and Yenmanas, 1972).

In areas with very low flood levels (e.g. river levees; areas south of Bangkok) transplanted rice is often grown on bunded fields, relatively small parts are planted with dryland crops like sugar cane, maize, beans or groundnuts.

When fertilizers are applied, this is usually liming in order to raise the pH and to limit the Al-toxicity of the soils. Fertilization with duck manure containing shell fragments is done for growing vegetables on the ridged soils (Van der Kevie and Yenmanas, 1972). On the site of T1 no fertilizers are applied.

In the active tidal zone along the Gulf of Thailand mangrove forest still occurs, but not anymore in its natural state. Trees are planted and used for charcoal production while the leaves of the Nipa palm are used for thatching. On the inland side of the tidal area, where drainage is better and the soils are more ripened, the vegetation consists of salt tolerant mangrove trees or of sparse ground cover with large bare spots, depending on the degree of salinity. All over the tidal area salt pans and fish ponds have been constructed while in some places slightly brackish tidal land has been ridged for coconut growing.

2. Site and Soil

2.1 Site characteristics and soil pattern

2.1.1 Location of the profile

The approximate geographical coordinates of the soil profile are 14°15' N and 100°15' E. The location is about 5 km northwest of Wang Noi in the Province of Ayutthaya (topographical sheet nrs. 5153 I and IV of the AMS Topo Map Series L. 708) and about 80 km north of Bangkok.

2.1.2 Parent material and petrology

The inland tidal marsh deposits, in which the soil has developed, are clayey, non-calcareous sediments. The substratum contains 1-2.5 % sulphur in the form of pyrite, very finely divided in the matrix, and the content of organic carbon ranges from 2-8 % (Van Breemen, 1976). The clay mineralogy has a mixed character of kaolinite, muscovite/illite and smectite (see Appendix 1C). The organic matter occurs as poorly decomposed plant remains, probably originating from the mangrove vegetation and is more or less orientated parallel to the sedimentary strata.

At the surface an admixture with fresh water sediments may occur due to the yearly overflow during the wet season.

2.1.3 Physiographic position and drainage conditions

The sampling site is situated in a very flat area which has a very gentle overall dip towards the west. Slopes are less than 1 %.

External drainage is restricted to a number of small channels contributing to the Chao Phraya River about 15 km west of the sampling site. Due to the very level topography, surface runoff is very slow. Locally some small lakes and ponds occur.

Internal drainage is poor and the soil remains wet for a long period. At the time of collection, which was at the end of the dry season (May 1967), the soil was still wet below 60 cm depth.

Permeability data of some Thionic Fluvisols are available from investigations at the Rangsit Acid Sulfate Soil Experimental Station near Thanyaburi, about 15 km southeast of the sampling site (Vlek, 1971; Van Breemen, 1976). The data are from a toposequence formed by the Rangsit series on the higher parts and the Thanyaburi series on the lowest parts, the latter forming the middle of an elephant wallow. The topsoil of all soils has a very low permeability of about 0.15 m/day. Maximum permeabilities occur between 0.5 and 1.5 meter depth in the profile. There is considerable variation, which is probably a reflection of a varying root distribution pattern under the original fresh water swamp forest vegetation. Nevertheless, there appears to be a relation between elevation and average permeability: subsoil permeability is highest (up to 5 m/day) at a depth of about 1 meter at the intermediate elevation, it is lowest (1 m/day) in the lowest area and intermediate but steadily increasing with depth in the highest parts of the catena.

2.1.4 Microclimate

Because of the physiographic environment, the microclimate on the sampling site will not deviate strongly from the overall climatological conditions, except for the soil temperature regime. Night frost does not occur and dew is insignificant.

Soil temperatures at various depths have been measured in a number of soils in Thailand (Rice, 1969). Although data on Thionic Fluvisols are not available, an insight in the soil temperature regime can be obtained from similar soils under comparable physiographic and hydrological conditions.

As example may be taken the soil temperature regime of a clayey Calcaric Fluvisol (locally called Tha Tako series) near Lop Buri, developed in a depression in alluvial deposits. This soil is poorly drained and flooded or saturated with water during the wet season. Like the Thionic Fluvisol, the soil is generally used for paddy rice growing (Dent and Cheuthongdee, 1966; Rice, 1969).

The data for the period 1964-1965 show mean soil temperatures of 27.0°C in the topsoil (4 cm depth) and 29.3 and 27.3°C in the subsoil (19 and 42 cm depth respectively). Seasonal variation amounts to 6.2°C for the topsoil and 4.3 and 3.9°C in the subsoil (Figure 4). Mean winter and mean summer temperatures at 42 cm depth differ by 1.6°C.

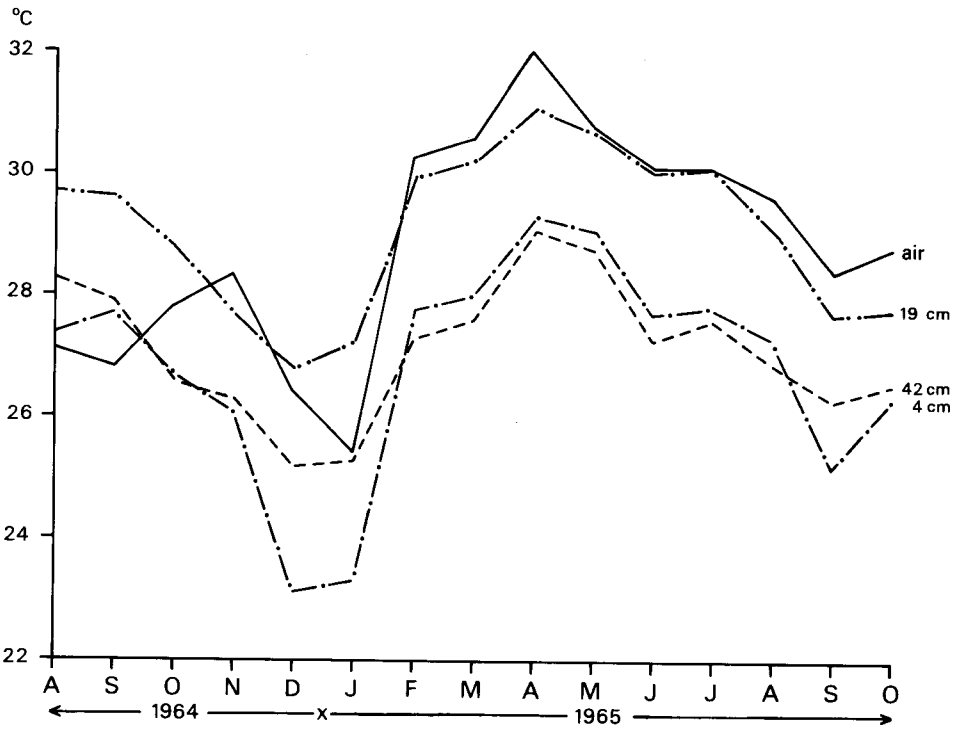


Figure 4. Mean monthly air and soil temperature at various depths in a Calcaric Fluvisol near Lop Buri (after: Rice, 1969)

2.1.5 Surface characteristics

Microrelief occurs locally and consists of shallow furrows and low ridges, caused most probably by ploughing. Cracking of the soil is common in the dry season when narrow cracks of not more than 1 cm wide develop, which penetrate into the soil down to a depth of 20-30 cm. Sealing or crusting of the surface has not been observed.

2.2 Soil and soil pattern

2.2.1 Brief description of the soil

The field description of the profile is given in Appendix 1A. Slide nr. 2 shows the profile in the field, while slide nr. 3 and the photograph inside back cover shows the soil monolith, in which the top 10 cm have not been retained.

The profile shows a clayey soil with clear horizonation due to conspicuous colour contrasts. The structure is moderate angular blocky in the upper part and weak to very weak in the lower part of the profile. The Apg horizon, 27 cm thick, is black with common (3-5 %) fine strong brown and yellowish red mottles, mainly associated with pores and root channels. The actual plow layer is about 15 cm thick, but not very clear in this particular profile and has therefore not been described separately in the field.

The Apg horizon is underlain by brown to greyish brown coarse and medium mottled Bg horizons. Mottles have red, strong brown, reddish yellow and yellow colours. Red mottles are dominant in the Bg1 horizon, whereas prominent yellow mottles prevail in the Bg3 horizon, also known as "cat clay" horizon. In the field very few fine gypsum crystals have been observed in the Bg1 and Bg2.

The underlying brown Bg4 horizon (below 93 cm) has only very few fine mottles associated with pores. This horizon (Bg4) is called "soap clay" horizon in the field.

2.2.2 Soil pattern

A soil map at scale 1:200,000 of the Wang Noi area is shown in Figure 5. This map is based on the Detailed Reconnaissance Soil Map of the Southern Central Plain area at scale 1:100,000 (Van der Kevie and Yenmanas, 1972). Soils on the Wang Noi map are shown both according to the FAO-Unesco legend of the Soil Map of the World and to the Thai National Soil Classification System (soil series).

In the latter soil classification system several series have been recognized based on a number of morphological, chemical and physical land and soil properties. The legend of the soil map of the Wang Noi area contains series, phases, variants, and associations. A summary of the major soil characteristics and diagnostic criteria of the mapping units is given in Appendix 1E. The distribution pattern of the mapping units reflects more or less the sedimentological and hydrological history of the area.

A subdivision is introduced in the legend, based on physiography and parent materials, which are closely related in this area. Distinction has been made between soils developed in former tidal flat deposits and those developed in flood plain deposits.

The soils in the former tidal flat deposits show a rather simple distribu-

Fig. 5 Soil Map of the Wang Noi area

LEGEND

Symbol and name of soil mapping unit			Landform and Parent Material	
FAO-Unesco	Thai Soil Survey			
Jt THIONIC FLUVISOLS	Ay	Ayutthaya	former tidal flat marine and brackish water deposits	acid
	Ay/Ma	Ayutthata/Maha Phot complex		
	Ok	Ongkharak		
	Rs	Rangsit		
	Se	Sena		
	Se/Rs	Sena/Rangsit complex		
Gm MOLLIC GLEYSOLS	Bl	Bang Len		non-acid
	Bl-O	Bang Len, overwash phase		
Ge EUTRIC GLEYSOLS	Cc	Chachaoungsao clay		
Ge EUTRIC GLEYSOLS	Bin	Bang Pa-in	floodplain recent river alluvium	
	Rb	Ratchaburi		
	Sin-b	Sing Buri acid substratum		

soil boundary, FAO mapping unit

soil boundary, Thai mapping unit

* T1 site of T1 profile

Scale 1 : 200.000

1 0 5

Rivers (if dotted intermittent)

Lakes

Canals

Wang Noi Villages

Main roads

Railway

tion pattern. Most of the area is occupied by Thionic Fluvisols with locally Mollic and Eutric Gleysols (in the US Soil Taxonomy Sulfaquepts or Sulfic Tropaquepts, Typic Haplaquolls and Typic Tropaquepts respectively). The Gleysols occur in valley floors and in places with brackish water deposits without sulfur. The location of these deposits is possibly related to originally fresh water drainage ways on the former tidal flat.

In the southeastern part the Ongkharak (Ok) and Rangsit (Rs) series prevail, characterized by the occurrence of the yellow mottled "cat clay" horizon at shallow (< 40 cm) or moderate (40-100 cm) depth and the absence of gypsum (Van der Kevie and Yenmanas, 1972). Towards the Chao Phraya River the Sena (Se) and Ayutthaya (Ay) series have been mapped, in which gypsum is present and the "cat clay" horizon occurs at moderate depth or deeper than 1 m. Obviously, these soils are somewhat deeper drained than the Ongkharak and Rangsit series due to a closer proximity to the main river. The proximity to the river may also explain the presence of gypsum in these soils. For the latter a supply of calcium, e.g. in the form of lime, is needed; it is likely that the sediment load of the Chao Phraya River, deposited during high floods, forms the source of this calcium, as calcium bicarbonate from river-water cannot account for the accumulation of gypsum (Van Breemen, 1976).

The soil pattern along the Chao Phraya River is determined by a system of natural levees and backswamps. Drainage conditions and textural variation have been the main differentiating criteria for subdivision of the soils in those parts. The mapped series form a toposequence from fine textured somewhat poorly drained soils on the levees to very fine textured poorly drained soils in the backswamps. All levee soils belong to the Eutric Gleysols (FAO/Unesco) or to Aeric and Typic Tropaquepts (USDA). In addition, soils occur which are developed in former tidal flat deposits, and are buried under shallow recent fluvial deposits of a thickness of up to 1 m.

3. Soil Genesis and Classification

3.1 Soil genesis

The major soil forming processes that have been active at the site are related to drainage and aeration of the sediment. The processes involve a number of physical, chemical, mineralogical and biological changes together termed "initial soil formation" or "ripening" (Pons and Zonneveld, 1965). The processes may be categorized as follows:

Physical ripening

a. Dehydration and (partly irreversible) shrinkage of the sediment
b. Development of cracks
c. Increase in permeability
d. Change from soft consistency to friable or hard
e. Development of pedal structure
f. Subsidence of the surface

Chemical ripening

a. Oxidation and humification of organic matter
b. Oxidation of mineral compounds that are stable under reduced conditions (e.g. pyrite)
c. Desalinization with a change in ionic composition and concentration of interstitial water
d. Change in composition of adsorbed cations
e. Weathering of less and of more stable minerals (in addition to oxidation mentioned under b. e.g. dissolution of calcite, hydrolysis of mica and feldspars)
f. Formation of precipitates and new minerals (e.g. ferric oxides and hydroxides, jarosite, gypsum)

Biological ripening

This comprises processes like withdrawal of water by plant roots and oxidation of organic matter by micro-organisms. Hence, they are processes contributing to physical and chemical ripening.

From Serawak is reported, that mud lobsters are proliferous in the coastal swamps. The lobsters build large mounds out of potentially acid subsoil material, which acidifies strongly upon aeration and oxidation (Andriesse et al., 1973).

The present profile shows evidence of most of the mentioned processes. The ripening has resulted in a strong gleying of the profile while some more progressive pedogenesis is reflected by the dark Ap horizon and by hydrolysis of jarosite to goethite higher up in the B horizon.

The degree of physical ripening can be expressed by the so-called n-value which is derived from the water holding capacity of the clay fraction (Pons and Zonneveld, 1965). Because of the (partly) irreversible character of the dehydration the water holding capacity of a "ripe" clay will be lower than that of an "unripe" clay. For a similar profile of the Rangsit series, Van Breemen (1976) determined the n-values for the different horizons. Comparison with the present profile indicates that this soil is "ripe" to a depth of about 50 cm (approximately down to the Bg2 horizon), then decreases in ripeness ("nearly ripe") to about 95 cm (Bg4 horizon) below which the material can be classified as "half ripe".

The immaturity of the profile is also expressed by the clay mineralogy and the elemental composition which show no appreciable change throughout the profile, apart from the mineralogy of the red and yellow mottles of the B horizon (see Appendices 1B and 1C).

Micromorphologically, the B horizon still shows a predominantly unistrial fabric, i.e. an overall single direction of preferred orientation of the plasma grains throughout the whole of the material, which is characteristic for aqueous sediments (Brewer, 1976). The amount of argillaceous material with unistrial fabric is estimated at 60 % in the Bg1 and increases with depth (see Appendix 1D).

The Apg horizon contrasts strongly with the underlying horizons. Finely grained organic matter is thoroughly mixed with the clay, resulting in a dark coloured soil material. Strongly developed plasmic fabrics, infillings of darker coloured soil material and irregular zones where both coarse and fine grains show pronounced preferred orientation patterns with various directions, indicate that strong (mechanical) disturbance under wet conditions has occurred. Nodules are abundant and have yellow, reddish yellow and yellowish red colours. They show a great variety of sphericity and roundness and have sizes up to 500 µm.

The major part of the nodules consists of clay impregnated to a greater or lesser extent with ferric iron compounds. Many have sharp external boundaries, some however are diffuse which indicates that they are autochtonous. The Apg horizon also contains prominent, obviously allochtonous nodules. These nodules, containing ferric iron compounds and jarosite, have sharp external boundaries in contrast to the autochtonous nodules many of which are faint or diffuse. The allochtonous nodules are considered to be broken concretions originally occurring around voids in the upper part of the B horizon. Their presence also points to strong (mechanical) disturbance in the topsoil.

The profile shows the typical features of a normal or ground water gley: a reduced subsoil, while in the gley zone the inner part of the structural elements is largely reduced and the outer part shows oxidation features in the form of ferric precipitates.

The very low content of gypsum throughout the profile is in accordance with the absence of lime in the parent material. Pyrite has not been found in the profile to the depth studied and was probably all oxidized. The original content may already have been low, only a few percent (Van Breemen, 1976).

The form, distribution and mineralogy of the ferric precipitates throughout the profile need some discussion. In the lower part of the solum, the Bg3 horizon, these precipitates are goethite and jarosite. Their presence is indicated in the X-ray diffractograms. Jarosite can be readily observed in thin sections

as small (2-3 μm) colourless crystals, forming thin halos around narrow pores in the argillaceous material (neojarositans). The root channels and large planar voids contain large infillings of jarosite and on some of the walls of the voids thick neojarositans occur.

The thin neojarositans are free of ferric oxides whereas the thick neojarositans show appreciable accumulations of ferric (hydr-)oxides, often to the extent that no jarosite can be discerned. This suggests that neojarositans are being transformed to neoferrans by hydrolysis. This is in accordance with the fact that jarosite is thermodynamically unstable relative to goethite above a pH value of zero (Mohr, Van Baren and Van Schuylenborgh, 1972). The presence of SO_4 as soluble anion (see Appendix 1B) may also point to this, since pyrite as a source of sulfate has been depleted at these depths.

In some places the neoferrans, associated with the large planar voids and root channels have been transformed into quasiferrans, that is, there is a zone adjacent to the wall of the void which is almost devoid of ferric oxides. This suggests that during a reduction phase iron was mobilized and removed. Voids with quasiferrans often have thin skins of newly precipitated jarosite (jarositans), which indicates that after the removal of iron oxides oxidative conditions have favoured the formation of jarosite. This corroborates with the observation that less stable phases (like jarosite) in the soil can be formed before the more stable ones (like goethite), because of the former's lower nucleation energies (Langmuir, 1971). Thus, the occurrence of quasiferrans in combination with jarositans are witnesses of alternating phases of oxidation and reduction.

In the Bg1 and Bg2 horizons, which are pedogenetically older than the Bg3, jarosite is less prominent while hematite is clearly present and occurs as cutans and infillings, enveloping goethite accumulations. Apparently, the transformation of jarosite to ferric oxides, occurring already in the Bg3, continues and will, eventually, result in the disappearance of this mineral.

The presence of hematite is somewhat unexpected. In general, under gleyic conditions in the presence of organic matter and at low pH, goethite is considered to be the favoured phase (Schwertmann and Taylor, 1977). It seems to be formed directly when by slow hydrolysis of Fe^{3+} salts the relatively low solubility product of goethite is exceeded. The formation of hematite is considered to be indirectly, with ferrihydrite as an essential precursor. However, ferrihydrite is only formed by fast hydrolysis of Fe^{3+} salts, whereby the relatively high solubility product of ferrihydrite is exceeded.

In an acid sulfate soil with pronounced dry and wet seasons both slow and rapid hydrolysis will occur at certain times, leading to the formation of goethite as well as hematite, whereby goethite is favoured as indicated before. However, the transformation of hematite to goethite by rehydration is not considered feasible for kinetic reasons (Langmuir, 1971). Therefore the hematite content will, perhaps slowly, increase, unless all hematite (as well as goethite) is reduced and dissolved during a reduction phase. In addition, it is generally accepted that the coarser grained hematite (> 0.1 μm) is stable relative to the finer grained goethite (Berner, 1969; Langmuir, 1971; Ferrier, 1966, as quoted by Schwertmann and Taylor, 1971). Thus, since freshly precipitated goethite is of very small grain size and formed during each reduction/oxidation cycle, the increase in hematite content can also be enhanced in this way. The relatively low oxalate soluble iron content as compared to dithionite soluble iron (see Appendix 1B) indicates that ferrihydrite does not accumulate.

The chemistry of the formation of acid sulfate soils is rather complicated because of the combination of the presence of pyrite, organic matter and a microflora in a sediment with extreme and varying hydrological conditions. Both components of pyrite, FeS_2, can be oxidized and reduced within the stability range of water and many (intermediate) compounds can be formed as a result of

the almost continuously changing redox potential. For further details the reader is referred to Mohr et al. (1972) and Van Breemen (1976). Some of the main reactions involved are:

$$4FeS_2 + 15O_2 + 10H_2O = 4FeOOH + 8H_2SO_4$$
pyrite goethite sulfuric acid

$$\text{illite} + 6FeOOH + 4H_2SO_4 = 2KFe_3(SO_4)_2(OH)_6 + \text{kaolinite} + SiO_2$$
jarosite

$$KFe_3(SO_4)_2(OH)_6 + H_2O = 3FeOOH + 2H_2SO_4 + KOH$$

$$2FeOOH - H_2O = Fe_2O_3$$
goethite hematite

3.2 Soil Classification

3.2.1 Diagnostic characteristics

Diagnostic horizons

The characteristics of the Agp horizon meet the requirements for structure, consistency, colour, base saturation, organic matter, thickness and phosphorus content of the *umbric A horizon* (Legend of the Soil Map of the World; FAO-Unesco, 1974) and of the *umbric epipedon* (U.S. Soil Taxonomy; Soil Survey Staff, 1975). It has a moderate medium and coarse angular blocky structure, and is hard when dry. The colour is black (10YR 2/1 when moist) while the underlying horizon has a colour value of 5 (7.5YR 5/2). The base saturation is 39 %. The organic carbon content is more than 1 %. It has a thickness of 27 cm.

The Bg3 horizon qualifies as a *sulfuric horizon* according to both the Legend of the Soil Map of the World and Soil Taxonomy. The pH (H_2O 1:1) is 3.4 and the jarosite mottles have a hue of 2.5Y and a chroma of 6.

The Bg horizon would seem to meet all requirements of a cambic B horizon, because of its texture, structure, amount of weatherable minerals and evidence of alteration. However, microscopic observations indicate that in more than half of the volume the horizon has rock structure (remnants of the sedimentary structure) rather than soil structure. In addition, the organic carbon content decreases irregularly with depth. Therefore the Bg horizon does not qualify as cambic B horizon.

Diagnostic properties

The soil moisture regime, diagnostic for the classification according the Soil Taxonomy, is *aquic*. The soil is saturated and flooded for a prolonged period of the year (6-7 months). This results in a reducing environment during this time, which is essential for an aquic moisture regime (Soil Survey Staff, 1975, p. 54).

Soil temperature measurements in similar soils (see 2.1.4) show mean soil temperatures of 27.3°C at about 40 cm depth. Seasonal variation at this depth amounts to about 1.6°C. This set of temperature data indicates an *isohyperthermic* soil temperature regime.

The presence of sulfidic materials within a depth of 125 cm could not be established since the soil samples had been dried prior to laboratory analysis. In similar soils (e.g. the Rangsit series, as described by Van Breemen) sulfidic materials have been found only below 140 cm.

3.2.2 Classification in various systems

The set of characteristics described above qualifies the soil as an oxidized *Thionic Fluvisol* according to the Legend of the Soil Map of the World.

The umbric epipedon classifies the soil as an Inceptisol in the Soil Taxonomy. Because of the aquic moisture regime, the isohyperthermic temperature regime and the presence of a sulfuric horizon below 50 cm, the soil keys out as a *Sulfic Tropaquept* on subgroup level. Additional information on family level is: *very fine* for the textural class, *mixed* for the mineralogy class, and *acid* for the reaction class. Similar soils under non tropical climates would be classified as Sulfic Haplaquepts. Oxidized Thionic Fluvisols with a sulfuric horizon within 50 cm depth are Typic Sulfaquepts according to Soil Taxonomy. Reduced Thionic Fluvisols are classified either as Typic Sulfaquents (if sulfidic material within 50 cm depth) or Sulfic Fluvaquents (if sulfidic material between 50 and 100 cm depth).

No appropriate characterization of Thionic Fluvisols can be given according to the French "Classification des sols" (CPCS, 1967). In the "Projet de classification des sols" (ORSTOM, 1979), however, the oxidized Thionic Fluvisols are classified as "Selsols sulfoniques" or "Sulfosols" (if sulfuric horizon (= sulfon) is within 60 cm depth) or as "sulfonique" subclasses of other soils (if sulfon is present at greater depth). The reduced Thionic Fluvisols are classified as "Selsols thioniques" or "Thiosols" (if sulfidic materials (= thion) is within 60 depth) or as "thionique" subclasses of other soils (if thion is present at greater depth).

The higher levels of the national classification system in Thailand are based on the "Major Soils of South East Asia" (Dudal and Moormann, 1964). Subdivision of these "Great Soil Groups" is made on a number of land and soil characteristics. According to this system, the soil is classified as a *Hydromorphic Alluvial Soil, Rangsit series* (Van der Kevie and Yenmanas, 1972).

In the former American classification system (Baldwin et al., 1938; Thorp and Smith, 1949) the soil belongs to the Alluvial Soils (1938) or to the Low-Humic Glei soils (1949).

Other commonly used names, not related to classification systems, are "katteklei" (Dutch), cat-clay, acid sulfate soil, mangrove soil and "Maibolt" (German).

4. Aspects of Land Evaluation

4.1 Introduction

Mapping and classification of soils is normally followed by an assessment of the suitability of the land concerned for relevant types of agricultural use, through application of an appropriate methodology of "soil suitability assesment", "land capability classification", or "land evaluation". The scope of this paper does not warrant a comprehensive evaluation of all lands with Thionic Fluvisols. Such an evaluation would require a balanced comparison of soil-related land qualities with land qualities that are derived from physiographic conditions (complexity of soils pattern; topography; hydrologic regime, etc.), from agro-climatic conditions (length of growing seasons; frosts; storms, etc.) and from socio-economic conditions (present land use; farming practises; availability of labour; capital inputs, etc.). These non-soil conditions vary from region to

region.

Even a number of soil-related land qualities may vary substantially within one soil classification unit, certainly if it is defined only at a high categoric level. This applies to aspects like nutrient status in the topsoil; workability and tilth; susceptibility to erosion and surface sealing.
In view of the above, only the placing of the soil in the land evaluation system as applied to the area of occurrence of the particular soil profile -i.e. the Central Plain of Thailand- will be given, as an example.
This will be followed by some general statements on soil-related land qualities of the classification unit as a whole, some observations on land improvement possibilities, and references to relevant literature.

4.2 Land evaluation in Thailand

The comprehensive approach to land evaluation is relatively new and provides only a framework. In many countries or projects detailed systems of "land capability classification" have been developed in the course of years, catering specifically for one or a few agro-climatic situations and one set of socio-economic conditions. This holds also for Thailand, where the Land Classification Division published a "Soil Interpretation Handbook for Thailand" (1973), which is a revised and expanded version of the "Soil Survey Interpretation Handbook for Northeast Thailand", by Gallup et al. (1967). Its methodology draws substantially from the USDA system of land capability classification by Klingebiel and Montgomery (1961). Separate evaluations are presented for various kinds of land use. Reference is made here to (1) land capability classification for upland crops; and (2) soil suitability grouping for paddy (wetland rice). The Handbook defines land capability as being of a more general nature than soil suitability, but essentially the procedures for their assessment are the same.

4.2.1 Land capability classification for upland crops (U)

This classification is the grouping of soils according to their general suitability for upland crops[1]. It takes into account a number of soil properties and environmental data. The grouping is based on adverse properties that present limitations (management requirements and risk of crop damage) when used for crop production under present conditions.

According to the degree of limitation eigth capability classes are recognized ranging from very well suited (U-I) to poorly suited (U-IV), while classes U-V through U-VIII are considered unsuited. Class U-V concerns land with no erosion hazard, but having other limitations that are impractical to remove, and classes U-VI, U-VII and U-VIII have increasingly severe limitations related to erosion hazard (steepness, shallowness, rockiness, etc.).

The soils within each class are subdivided into subclasses according to the dominant kind of limitation. Nine capability subclasses for upland crops are distinguished:

[1] The term "upland crops" includes all crops commonly grown in areas with a monsoonal climate, except wetland rice, tree crops and vegetables.

e - erosion hazard or past erosion damage
s - soil limitation in the root zone
m - lack of moisture for plant growth during growing season
f - risk of flooding, either flash floods or prolonged deep flooding
d - impeded drainage
x - salinity or alkalinity
a - soil acidity
cl - excessively humid climate
t - topographic limitations

The guidelines for grouping soils in capability classes for upland crops are presented in Table 2. Application of these guidelines for the classification of the Rangsit soil series, which is the specific subject of this paper, gives the following: severe limiting factors are flooding, acidity and drainage. The series is characterized by a pH (H_2O 1:1) in its topsoil of 4.0 to 4.5 and by poor drainage. This would meet the criteria for the subclass U-IVad, but the flooding is considered to be the limiting factor that is dominant, hence the classification becomes U-Vf. The Rangsit very acid phase with pH below 4.0 falls in subclass U-Va. While the Handbook (1973) suggests to place the Rangsit series in class U-Vf, Van der Kevie and Yenmanas (1972) propose subclass U-IVf, stating that the soils are too wet until well into the dry season, but that some crops can be grown in the dry season if water is available.

4.2.2 Soil suitability groups for paddy (wetland rice) (P)

This classification system aims to show the relative suitability of soils for the cultivation of wetland rice without irrigation. Five suitability groups are recognized. The first four range from very well suited (P-I) to poorly suited (P-IV). Group P-V includes all soils that are generally not suited for paddy, due to severe limitations which cannot be corrected. The system puts great emphasis on the availability of sufficient water and the possibility to control flooding. The specific requirements for rice has as a consequence that the definition of subgroups for paddy is different from the definition of subclasses for upland crops. Altogether six suitability subgroups for paddy are distinguished:

s - soil limitations in the root zone
m - lack of water, resulting from lack of rain or from lack of rain and streamflow
f - risk of damage caused by flash floods or excessively deep and prolonged flooding
t - unfavourable topography
x - salinity or alkalinity
a - soil acidity

There are no subgroups for erosion, impeded drainage or excessively humid climate. The guidelines for grouping soils in suitability groups for paddy are presented in Table 3. This set of guidelines implies, that soil acidity is the dominant limiting factor for acid Thionic Fluvisols, while flooding would be the second limiting factor. Thus the Rangsit series is classified as P-IIIa (pH between 4.0 and 4.5) and its very acid phase as P-IVa.

Table 2. Guidelines for grouping soils in capability classes for upland crops; range in degree of limitation by classes[1)]

Limiting factor	U-I	U-II	U-III	U-IV	U-V	U-VI	U-VII	U-VIII.
Depth to laterite, bedrock, etc.	> 100 cm	> 75 cm	> 50 cm	> 25 cm	-	> 25 cm	> 25 cm	-
Texture of surface 30 cm	loam, to clay loam	sandy loam to clay	loamy sand to clay	-	-	-	-	-
Permeability of subsoil	moderate	mod. slow to mod. rapid	slow to rapid	-	-	-	-	-
Upper slope limit[2)]	1 to 2%	3 to 6%	8 to 12%	15 to 20%	-	25 to 35%	-	-
Erosion and erodibility	none	none to slight	none to moderate	none to severe	none	none to severe	none to very severe	-
Gravel, stones, rocks % by volume in topsoil	< 5%	< 15%	< 50%	< 50%	-	< 90%	< 90%	-
Fertility or nutrient status	high to moderate	high to moderate	high to mod. low	high to low	-	-	-	-
Risk of damage by drought	low	low to moderate	-	-	-	-	-	-
Excessively wet climate	no restrictions	restriction	-	-	-	-	-	-
Available water holding capacity[3)]	high > 15 cm	high to medium; > 10 cm	high to low > 5 cm	-	-	-	-	-
Soil drainage class	well to mod. well	well to mod. well	somewhat exc. to mod. well	somewhat exc. to poorly	very poorly	exc. to mod. well	exc. to mod. well	-
Flooding[4)]	never	1 year in 5	2 years in 5	1 year in 2	more than 1 year in 2	-	-	-
Salinity; EC5 x 10^6	< 1000	< 2000	< 2000	< 3000	-	-	-	-
Reaction within 30 cm pH (1:1H_2O)	5.5-8.0	4.5-8.3	4.5-8.5	4.0-8.5	-	-	-	-

[1)] Dash indicates that limitation is not class determining

[2)] Depending on soil erodibility

[3)] Available water holding capacity to 1 meter or to restricting layer

[4)] Frequency of severe damage by flooding

From: Soil interpretation handbook for Thailand (1973)

Table 3. Guidelines for grouping soils in suitability groups for paddy: degree of limitation by groups[1]

Limiting factor	P - I	P-II	P - III	P - IV	P - V
Effective soil depth	> 50 cm	> 50 cm	> 25 cm	> 25 cm	–
Texture of surface soil	clay loam and sandy clay to clay	sandy clay loam to clay	sandy loam to clay	loamy sand to clay	–
Permeability of subsoil	< 0.5 cm/hr, slow	slow to mod. slow, < 1.5 cm/hr	slow to moderate < 5 cm/hr	slow to mod. rapid; < 15 cm/hr	–
Fertility; nutrient status	high to moderate	high to moderately slow	high to low	high to low	–
Reaction of surface soil pH (1:1 H_2O)	5.0-7.5	4.5-8.0	4.0-8.0	3.5-8.5	
Salinity EC $5x10^6$	< 1500	< 2500	< 2500	< 4000	–
Slope	< 1%	< 2%	< 3%	< 5%	
Area % of smooth land	> 80%	> 80%	> 50%	> 40%	–
Leveling required	little	little	moderate	much	
Gravel etc. in topsoil	none	none to slightly gravelly	none to slightly gravelly	none to gravelly	–
Frequency of moderate damage by water shortage	no damage	occasional slight damage	< 4 years in 10; occasional severe damage	< 6 years in 10; occasional complete loss	–
Soil drainage class	somewhat poorly to poorly	somewhat poorly to poorly	somewhat poorly to very poorly	well to very poorly	–
Risk of moderate damage by floods[2]	< 1 in 10 years	< 3 in 10 years	< 4 in 10 years	< 6 in 10 years	–

[1] Dash indicates that limitation is not class determining

[2] Flash floods, quickly rising water, saline water

From: Soil interpretation handbook for Thailand (1973)

Table 4. Suggested placement of some soils of the Central Plain area in interpretive classes and groups (after Soil Interpretation Handbook for Thailand (1973) and Van der Kevie and Yenmanas (1972))

soil series mapping unit	upland capability class and subclass	paddy (wetland rice) suitability group and subgroup	paddy (wetland rice) current yield level ton/ha (1)	Remarks
Bang Pakong	U-Vx	P-Vx	-	potentially acid mud; poorly ripened, strongly saline soils on active tidal flat
Cha-am	U-Va	P-IVa	0,6	partly ripened, extremely acid, slightly saline soils on former tidal flat
Bangkok	U-IVf, U-IVd(1)	P-I	2,5	partly ripened, non-acid soils on former tidal flat
Chachoengsao	U-IVf	P-IIa	1,5-2,2	nearly ripe, strongly acid soils on former tidal flat
Ayutthaya	U-IVf	P-IIa	1,2-2,2	nearly ripe, strongly acid soils on former tidal flat
Sena	U-IVf	P-IIa	1,2-1,9	nearly ripe, strongly acid soils on former tidal flat
Rangsit	U-Vf, U-IVf(1)	P-IIIa	0,9-1,5	nearly ripe, very strongly acid soils on former tidal flat
Rangsit, high phase	U-IVf(1)	P-IIIa(1)	0,9-1,5	nearly ripe, very strongly acid soils on former tidal flat
Rangsit, very acid phase	U-Va(1)	P-IVa(1)	0,6-0,9	nearly ripe, extremely acid soils on former tidal flat
Ongkharak	U-Vf, U-Va(1)	P-IVa	0,6-1,2	nearly ripe, extremely acid soils on former tidal flat
Ridged acid soils	U-IIIt(1)	P-Vt(1)	-	slightly acid man-made soil over (potentially) acid subsoil
Bang Len	U-IVf	P-IIf,P-I(1)	2,5-3,0	non-acid soils close to creeks in former tidal flat
Bang Pa-in	U-IIIf(1)	P-I(1)	2,5	non-acid soils on floodplain

(1) rating by Van der Kevie and Yenmanas (1972), if different from or not included in Handbook

4.2.3 The placement of some associated soils in interpretive classes and groups

For comparison's sake, the classification as suggested in the Handbook (1973) is given in Table 4 for some characteristic soils of the Central Plain, including both Thionic Fluvisols and associated soils. As wetland rice is practically the only crop that is grown on most of these soils the classification for upland crops is necessarily rather hypothetical, while the suitability grouping for paddy can be directly tied to the actual level of paddy yields. An interesting case of interpretation is formed by those Thionic Fluvisols (including Rangsit soils) that have been reclaimed for horticulture by ridging. Such soils are classified as U-IIIt and P-Vt. The dominant limitation for upland crops is the narrowness of the ridges (3 to 5 meters), preventing the use of heavy machinery. At the same time the ridging has rendered the land unsuitable for wetland rice. However, the land may be class I or II for horticulture.

It should be noted that the chemical soil fertility plays only a minor role in the Thai suitability classification. The evaluation of the overall soil fertility is based on the relative rating of the following soil characteristics: organic matter content, cation exchange capacity, base saturation, phosphorus content, and, in case of cat clay within one meter, soil reaction (pH). These ratings are condensed into one rating for natural fertility (with five class levels) ranging from very low to very high but without specifying the kind of limitations.

Finally, like all land evaluation procedures that are based on the rating of limiting factors, the Thai classification tends to focus on adverse properties, while other favourable soil characteristics do not receive the attention they may deserve in describing land use potential.

4.3 Land qualities and land improvement of Thionic Fluvisols in general

This paragraph deals with the appraisal for agricultural use of Thionic Fluvisols in general on the basis of land qualities as defined in the Framework for Land Evaluation (FAO, 1976). Emphasis is on the soil-related land qualities as distinct from those related to other environmental conditions and to the socio-economic setting.

As indicated earlier (1.1.1) the unit Thionic Fluvisols encompasses soils of two stages of soil development with completely different properties and management implications. They are the reduced stage (potential acid sulfate soils or Sulfaquents) and the oxidized stage (actual acid sulfate soils or Sulfaquepts), the latter being the result of natural or artificial improvement of drainage. Furthermore, there are numerous intermediate situations where a topsoil of varying thickness is oxidized and acidified, and has a firm consistency ("ripe"), but the subsoil is still in a reduced status, with a soft and soapy consistency ("unripe"). The latter is in fact the case for the Rangsit profile.

The above complicates any discussion on land qualities and land improvement.

Soil related land qualities, that differentiate the suitability of Thionic Fluvisols for agricultural use are:

- soil acidity and soil toxicities
- soil salinity
- nutrient availability
- oxygen availability
- trafficability, workability
- moisture availability

The relationship between soil conditions and land qualities will be discussed and their importance of major kinds of land use along with the possibilities and consequences of changing or improving the land qualities.

Soil acidity and soil toxicities

Acidity is the most prominent soil characteristic that contributes to the suitability assessment of Thionic Fluvisols. Young oxidized Thionic Fluvisols with a sulfuric horizon or sulfidic materials at shallow depth are generally more acid than older acid Thionic Fluvisols in which such horizons are found at greater depths. Extreme acidity occurs notably soon after aeration of the soil, e.g. following a lowering of the groundwater table. At pH values below 4.5 the aluminium concentration in the soil solution may become toxic for plant growth.

It has been reported from Vietnam and Kalimantan that surface water coming from acid Thionic Fluvisol areas contains toxic concentrations of aluminium, thus creating damage to downstream crops on non-acid soils (Moormann and Van Breemen, 1978).

Other reported ills of acid sulfate soils include the strong acidity per se, which has probably adverse effects on plant growth, and toxic concentrations of iron in solution, of hydrogen sulfide and of total electrolyte. These adverse conditions are frequently more severe in young acid Thionic Fluvisols than in deeper developed older soils (Van Breemen and Pons, 1977; Moormann and Van Breemen, 1978).

For the improvement of Thionic Fluvisols in the sense of diminishing soil acidity three approaches may be distinguished:

- keep the soil saturated with water
- neutralize the soil with lime
- drain, aerate and leach the soil

From experience it is known that economically sound management of strongly acid soils is usually based on the first approach with additionally some liming and leaching.

By saturating the soil with water a reducing environment is created in which a further oxidation of pyrite is stopped and the existing soil acidity is attenuated. The reduction process, caused by respiration of facultative anaerobic and anaerobic bacteria is favoured by a high organic matter content and the presence of easily reducible iron. The raise in pH is also influenced by the quality of the flooding water. The Al-toxicity is eliminated at higher pH. On the other hand, in the reducing conditions the concentration of ferrous ions may become toxic. This depends on the amount of easily reducible iron in the soil, which is much higher in younger than in older Thionic Fluvisols. Iron toxicity may appear some weeks after flooding of young Thionic Fluvisols. However, the release of the ferrous ions in older Thionic Fluvisols occurring in the Central Plain of Thailand is usually not so high as to become toxic (Van Breemen, 1976).

The management requirement of keeping the soil in waterlogged condition by submerging the land or by maintaining the ground watertable above the horizon that contains sulfur compounds, is often partly met under natural conditions, in which Thionic Fluvisols occur. This is for instance the case for the older, deeply developed Thionic Fluvisols in Thailand, subject to seasonal flooding. Deep water rice is the only crop adapted to this environment. Improvements should be primarily concerned with water management, notably control of depth and duration of flooding and supplementary irrigation, which can only be achieved by major engineering works. It is doubtful whether such land improvement projects are economically feasible, and if so, whether they are technically possible on a large scale in view of the need to dispose of the excess river flow in the wet season. In addition, there should be sufficient fresh water in the dry season. Under improved water management the range of crops could be broadened. The best adapted next crop would be common (short straw) wetland rice, including high yielding varieties which could be grown twice a year. The suitability for dryland annual crops would depend on the resulting acidity of the topsoil and the depth

of the horizon that contains sulfur compounds. Perhaps pineapple, sugarcane and soybean could be grown. From Malaysia it is reported that oil palms are grown on Thionic Fluvisols, where the watertable is carefully maintained at shallow depth.

The second way to overcome soil acidity problems is by liming. However, the amounts of lime necessary to neutralize the soil are usually prohibitively high; quantities of 30 tons up to 300 tons per hectare would be needed for treatment (ILRI, 1972). Empirical formulas have been developed for reclamation in the Netherlands. Application of such a formula gives about 200 ton lime per hectare for a soil with similar properties as the Thai Rangsit soil. Yet, field trials in Thailand have shown that relative small applications of three to six ton lime per hectare have given positive effects on rice yields including residual effects lasting several years. Van Breemen (1976) explains this as the result of the precipitation of aluminium.

Similarly, flood water carrying lime in its sediment or in solution may have a neutralizing effect in the long run on acid Thionic Fluvisols, under the formation of gypsum. In general, additional liming is required during the process of improving acid Thionic Fluvisols by either the waterlogging or the leaching approach.

The third approach to suppress acidity is by leaching after drainage and aeration. This approach is generally considered impractical, especially where the pyritic substratum occurs at shallow depth. This is because leaching is too slow to remove an appreciable and relatively immobile fraction of the soil acidity from most of the soil within an acceptable time (Van Breemen, 1980). Time spans of a few years to a few decennia or even a century are mentioned (Brinkman and Pons, 1972).

A special leaching technique has been applied in experiments in Sierra Leone (Bloomfield and Coulter, 1973). Leaching with sea water is followed by leaching with fresh water. The sea water provides bases to substitute the exchange acidity, the fresh water is needed for subsequent desalinization.

Yet, while leaching is usually not recommended as reclamation method, some leaching is always associated with the method of keeping the soil saturated, in order to remove some of the acidity that has risen from the subsoil.

In short, the key for improving Thionic Fluvisols lies in the possibility to control soil acidity. Improvement methods include good water management, liming and fertilization. The question of which method should be applied in a given situation depends both on the particular soil propeties as well as on the environmental and socio-economic setting. Possibilities for increasing agricultural productivity are usually present for deeper developed older Thionic Fluvisols. On the other hand, from experiences in many countries it can be concluded that in general no projects should be undertaken to empolder potentially acid or young acid Thionic Fluvisols from coastal swamps. If no priority is given to nature conservation, then the exploitation of its natural vegetation (usually mangrove forest) is often a viable kind of land use.

A special kind of land use that has proved to be economically feasible is the breeding of fish and shrimp in ponds. A pond can be constructed by building a dike around a field. The contact between the acid or potentially acid subsoil and the water should be as limited as possible to avoid acidification of the water to levels that are toxic for fish. It must be possible to refresh the water in the pond at any time with non-acid water. In coastal areas also salt can be produced on leveled, bunded fields, that serve as evaporation pans.

Soil salinity

Soil salinity is detrimental to plant growth, because it weakens the plants by the high osmotic pressure of the soil solution and it may induce other toxicities, e.g. by increasing the iron and aluminium content in solution.

Salinity problems are common in tidal marshes with reduced Thionic Fluvisols where intrusion of sea water occurs. The only way to improve the soil is to remove the excess salt by ponding with fresh water. If sufficient fresh water is available, rice can be grown on the flooded fields. In several marine estuaries of West African rivers, salinization of mangrove lands occurs during the dry season, followed by desalinization during the rainy season, as a result of flooding with fresh river water. In such conditions, reasonably good rice yields can be obtained from potentially acid, periodically saline Thionic Fluvisols. Prevention of sea water intrusion in potentially acid saline swamps by empoldering may still increase their productivity, provided that the soils can be kept in waterlogged condition.

Nutrient availability

Thionic Fluvisols have generally high clay contents and are commonly well supplied with plant nutrients adsorbed by appreciable amounts of 2:1 clay minerals and organic matter. Yet, a wide range of variations exists in clay mineralogy, organic matter content, cation exchange capacity and base saturation. Phosphorus deficiency is common on older Thionic Fluvisols. On such soils rice hardly responds to lime or nitrogen unless phosphate is applied. The benefits of lime and phosphate application may in part be due to increased supply of nitrogen by stimulation of ammonification and microbial fixation of nitrogen (Van Breemen and Pons, 1977).

In general, improvements of the nutrient status of Thionic Fluvisols by fertilization will only be effective if acidity is kept under control.

Oxygen availability

Thionic Fluvisols are naturally poorly drained and periodically inundated. The aeration of the soil depends on the degree of physical ripening and depth of the ground watertable. By definition oxygen is absent under reduced soil conditions as prevailing in many Thionic Fluvisols. Apart from the natural vegetation, only rice is adapted to such wet conditions, but even rice grows poorly on soils that are permanently water-saturated, as is the case in soils of depressions and in unripe soils. A temporary improvement of drainage will be beneficial for a subsequent crop of rice. However, such an aeration can only be allowed to a depth that the resulting acidification will remain within repairable limits.

Aeration of the root zone is an essential requirement for the growth of non aquatic plants. In younger Thionic Fluvisols this can only be fulfilled after reclamation, which is usually not economic. The feasibility of aeration of older Thionic Fluvisols depends on the depth of the horizon that contains sulfur compounds.

Trafficability

The land quality "trafficability" describes the fitness of land for movements of man, animals and machinery. It refers to bearing capacity and not to

problems posed to traffic by flooding. The bearing capacity depends on the degree of ripening of the soil and drainage conditions. In flooded rice fields a traffic pan may contribute to the bearing capacity, but in the usually very clayey Thionic Fluvisols a pronounced pan formation is not to be expected (Moormann and Van Breemen, 1978). Low bearing capacities are a problem in young, unripe Thionic Fluvisols.

Measures to improve the bearing capacity by allowing the soil to dry are incompatible with the requirement to control acidification by saturation with water. Yet, ripening of the topsoil must have taken place before farming operations become practical. Soils that are ripe to a depth of 50 cm, as is the case in the older Thionic Fluvisols of Thailand have sufficient bearing capacity for farming purposes, though they present problems for civil engineering.

Moisture availability

In Thionic Fluvisols the availability of moisture is a land quality that is even more crucial for acidity control than for plant growth. The amount of available water depends on rainfall, and the inflow from ground water, run-off, flooding and irrigation, less evapotranspiration and outflow.

Management of Thionic Fluvisols requires a high degree of water control, which is easier to achieve in very humid climates and where sufficient fresh river water is available throughout the year than in regions with strong seasonal rainfall and river flow patterns. In places and in periods that the growth of crops depends on rainfall for their water supply, droughts may quickly result in complete crop failure due to aggravation of toxicities rather than to moisture deficiency per se.

5. Suggested Reading

Recent research on Thionic Fluvisols is concentrated in tropical regions, especially in Southeast Asia, coastal West Africa, and, to a lesser degree, in Latin America. Information should be available from the national soil survey institutions, but it may not always be readily available.

Comprehensive information on many aspects of Thionic Fluvisols, ranging from soil genesis to plant growth and to farming practices, has been brought together at two International Symposia on Acid Sulphate Soils, of which the first was held in Wageningen in 1972 and the second in Bangkok in 1981. The proceedings of both symposia are published by the International Institute for Land Reclamation and Improvement (ILRI) in Wageningen as ILRI Publications 18 and 31, edited by Dost (1973) and by Dost and Van Breemen (1981) respectively. As the present Soil Monolith Paper on Thionic Fluvisols was already drafted before the Bangkok symposium was held, no reference could be made to its proceedings. Following the Bangkok symposium, it was recommended that an international working group on acid sulfate soils be established under auspices of the International Society of Soil Science (ISSS), with the following tasks:

- To pool and evaluate information about both innovative and traditional management systems, some of which are not capital intensive and do not require massive application of engineering, soil amendments and fertilizers.
- To formulate alternative management strategies for acid sulfate soils.
- To scrutinize technical proposals in soil characterization and classification;

formulate criteria for recognition of acid sulfate problems; and to prepare guidelines for experimental methods and characterization of experimental sites, in the context of their physical and social environment.
- To disseminate their findings, not just as bulletins, but to explore contacts with development agencies and land users at various levels.
- To convene a third symposium, in four years time, in West Africa.

Thus, it may be expected that the flow of information on Thionic Fluvisols will continue for many years to come.

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Appendix I. Soil Data

In this Appendix the profile description is presented and the results are given of the physical, chemical, mineralogical and micromorphological analyses. Soil samples were taken from the Apg, Bg1, Bg3 and Bg4 horizons. A description of the analytical methods is given in Appendix 2.

1A PROFILE DESCRIPTION

Information on the site sampled

Local soil name: Rangsit series

Higher category classification:
Alluvial soil on recent brackish water alluvium, acid sulphate soil (Moormann and Rojanasoonthon, 1968)
Thionic Fluvisol (FAO-Unesco, 1974)
Sulfic Tropaquept (Soil Survey Staff, 1975)

Date of examination: May 8, 1967

Author: W. Van der Kevie

Location: Wang Noi District, Ayutthaya Province, Central Plain Region, Thailand. Approx. coordinates 14°15' N and 100°45' E.

Elevation: 2 m above sea level

Landform:
- physiographic position: old tidal flat
- landform of surrounding country: flat
- microtopography: nil

Slope: nil

Land use: broadcast "floating" rice; ploughing with animal traction or tractors; no fertilizers are applied

Climate: tropical savannah; annual rainfall 1300 - 1400 mm of which 85 % from May to October; mean temperatures: April (hottest month) 30°C, December (coolest month) 25.5°C.

General information on the soil

Parent material: brackish water alluvium

Drainage: poor

Flooding: annually flooded by rain and river water for 7-8 months

Moisture conditions at time of collecting: top 30 cm more or less dry, 30-60 cm moist, below wet

Depth of ground-watertable: 1.20 m at time of collecting

Presence of surface stones or rock outcrops: nil

Evidence of erosion: nil

Presence of salt or alkali: few gypsum crystals

Human influence: a 15 cm deep plough layer can be observed

Cracking of the soil: narrow, 1 cm wide and 20 cm deep cracks at time of description. May be as deep as 40 cm

Description of the individual soil horizons

Horizon / Depth / Description

Apg 0-27 cm, black (10YR 2/1, moist) clay; common fine prominent strong brown (7.5YR 4/8) and yellowish red (10YR 4/8) mottles; moderate medium and coarse angular blocky; sticky and plastic when wet, firm when moist, hard when dry; few very fine tubular and few very fine interstitial pores; common fine roots; pH 4.8; clear and smooth boundary to

Bg1 27-48 cm, brown (7.5YR 5/2, moist) clay; many medium and coarse prominent red (10R 4/6) and common medium distinct strong brown (7.5YR 5/8) mottles; some inclusions of black material; moderate fine angular blocky; sticky and plastic when wet, firm when moist, hard when dry; few small slickensides; few very fine and fine tubular and few very fine interstitial pores; black cutans along some fine pores; few very fine roots; very few fine gypsum crystals; pH 4; clear and smooth boundary to

Bg2 48-64 cm, brown (7.5YR 5/2, moist) to greyish brown (10YR 5/2, moist) clay; common medium prominent red (10YR 4/8) and many medium prominent reddish yellow (7.5YR 6/8) mottles; some large inclusions of black material, probably filled-up cracks; weak fine and medium angular blocky; sticky and plastic when wet, firm when moist; common very fine tubular and common very fine interstitial pores; black cutans along some pores; few very fine roots; very few fine gypsum crystals; pH 4; clear and smooth boundary to

Bg3 64-93 cm, brown (7.5YR 5/2, moist) to greyish brown (10YR 5/2, moist) clay; many medium and coarse prominent reddish yellow (7.5YR 6/8) and yellow (2.5Y 8/6) mottles; weak fine and medium angular blocky; sticky and plastic when wet; many very fine and few fine tubular pores; many very fine interstitial pores; black cutans along some fine pores; few very fine roots; pH 4; clear and smooth boundary to

Bg4 93-150 cm+, brown (7.5YR 4/2, moist) clay, slightly darker in some spots; very weak medium angular blocky; sticky and plastic when wet; few fine tubular and few very fine interstitial pores; very few very fine roots; pH 4;

Note:

- Bg3 is "cat clay" horizon, Bg4 is "soap clay" horizon
- pH figures determined with a Hellige-Truog test kit

1B LABORATORY DATA

Hor.	Sample depth cm	Particle size distribution (µm in weight %) >2 mm	2000 200	200 50	50 20	20 2	< 2	pH H_2O 1:2.5	pH H_2O 1:1	pH KCl
Apg	0- 15	-	<1	2	7	24	67	4.1		3.5
Bg1	27- 48	-	5	3	14	17	61	3.6		3.1
Bg3	64- 93	-	<1	5	6	25	64	3.6	3.4	3.1
Bg4	93-120	-	-	<1	10	20	70	3.8		3.2

Hor.	Sample depth cm	Org. matter C %	N %	C/N	Extractable Fe_2O_3 Dithion.	Pyroph.	Oxal.	Gypsum %	Total sulfur %
Apg	0- 15	2.1	0.17	12	3.5	0.3	0.5	0.13	0.1
Bg1	27- 48	1.0	0.07	15	9.6	0.3	0.3	0.33	0.1
Bg3	64- 93	0.9	0.06	14	7.2	0.2	0.3	0.26	1.0
Bg4	93-120	1.5	0.06	25	0.3	0.3	0.1	0.23	<0.1

Hor.	Sample depth cm	Exch. cations Ca	Mg	K	Na	Sum meq/100 g	CEC Soil	CEC Clay	BS %	Extract. acidity meq/100 g
Apg	0- 15	7.2	4.1	0.4	-	11.7	30.2	45.1	39	23.3
Bg1	27- 48	6.3	3.8	0.4	-	10.5	28.1	46.1	37	23.7
Bg3	64- 93	5.6	4.1	0.4	-	10.1	27.9	43.6	36	21.3
Bg4	93-120	5.6	4.8	0.6	-	11.0	31.9	45.6	34	24.6

Hor.	Sample depth cm	Water soluble salts Ca	Mg	K	Na	CO_3	HCO_3	Cl	SO_4 meq/100 g	EC (mS/cm) 1:2.5
Apg	0- 15	1.0	0.7	tr	0.7			-	2.4	1.17
Bg1	27- 48	0.9	0.6	0.1	0.6			-	2.2	0.82
Bg3	64- 93	0.6	0.5	0.1	0.5			-	1.7	0.68
Bg4	93-120	0.5	0.5	0.1	0.6			-	1.7	0.63

Hor.	Sample depth cm	Elemental composition of the total soil (weight %) SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	Ign. Loss
Apg	0- 15	60.1	20.4	5.7	0.3	0.7	1.2		0.9	tr	0.1	0.1	11.6
Bg1	27- 48	52.6	18.5	15.5	0.2	0.8	1.6		1.0	tr	tr	0.1	10.3
Bg3	64- 93	53.4	18.3	11.8	0.2	0.6	2.3		0.9	tr	tr	0.1	12.4
Bg4	93-120	62.5	21.9	3.1	0.2	0.9	1.8		1.1	tr	tr	0.1	9.5

1B Laboratory data (continued)

Hor.	Sample depth cm	Elemental composition of the clay fraction (weight %) SiO_3	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na2O	TiO_2	MnO	P_2O_5	Ign. loss
Apg	0- 15	54.2	26.7	4.3	0.1	0.8	1.5		1.0	-	0.1	9.7
Bg1	27- 48	51.4	25.3	7.4	-	0.9	2.0		1.0	-	0.1	9.2
Bg3	64- 93	47.5	23.7	9.9	0.1	0.9	2.4		0.9	-	0.1	11.8
Bg4	93-120	56.9	25.0	3.5	0.1	0.9	2.0		1.1	-	0.1	8.5

		Molar Ratios							
		Soil				Clay			
		$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
Apg	0- 15	5.0	27.9	4.2	5.6	3.4	33.3	3.1	9.7
Bg1	27- 48	4.8	9.0	3.1	1.9	3.5	18.4	2.9	5.3
Bg3	64- 93	5.0	12.1	3.5	2.4	3.4	12.8	2.7	3.8
Bg4	93-120	4.8	52.9	4.4	10.9	3.9	43.4	3.5	11.2

Blank: not determined; -: not detected; tr: trace (less than 0.05)

1C CLAY MINERALOGY

Depth cm	Horizon	Kaol	Mi/III	Verm	Chlor	Smec	Mix	Quar	Feld	Gibb	Goeth	Hem[1]	Jaros[1]
0- 15	Apg	++	+		tr	+	+	x					
27- 45	Bg1	++	+		-	+	+	x			x	x	xx
64- 93	Bg3	++	+		+	+	+	x			x	tr	xxx
93-120	Bg4	++	+		tr	+	+	x					

[1] Bg1: red mottle; Bg3: yellow mottle

1D MICROMORPHOLOGICAL DESCRIPTION

The description is based on four large-sized (15 x 8 cm) thin sections, representative for the Apg, Bg1, Bg3 and Bg4 horizons respectively. Each horizon description is preceeded by macroscopic observations on the thin section. Micromorphological terminology follows that proposed by Brewer (1976), unless otherwise stated.

Apg horizon

Macroscopic observations

The soil material is dark brown, homogeneous, fine textured and apedal. There are few, about 2 cm wide, vertically oriented infillings of slightly darker coloured material. Voids are few, mostly channels and planar voids. There are few very fine roots and many very dark brown, very fine (< 0.05 cm) glaebules.

Microscopic observations

- S-matrix:
  The soil material consists of light yellowish brown clay with very few silt-sized quartz grains. Dark field examination shows that the clay contains only very small amounts of fine disperse ferric (hydr-)oxides.
  The related distribution pattern is porphyroskelic (Stoops and Jongerius, 1975: C/f: Open porphyric sili/pel; Eswaran and Baños, 1976: Plasmic NRDP).
  The plasmic fabric is insepic and weak to moderate skel-bimasepic (slide 4).
  In some parts the constituents of the s-matrix show striated patterns, mostly vertically oriented, suggesting disturbance under wet conditions.
- Voids:
  There are few irregular planar voids and channels. Some of the channels contain fresh roots.
- Organic matter:
  Organic matter is abundant and consists of very dark brown to opaque, very fine (< 25 µm) fragments, randomly distributed and intimately mixed with the clay. A part of the organic matter occurs as pigment of the clay.
  There are few roots which are commonly associated with neoferrans. Hyphae and sklerotia are common.
- Pedological features:
  Nodules are abundant and have yellow, reddish yellow and yellowish red colours. They have sizes up to 500 µm.
  The major part of the nodules are more or less spherical and consist of clay which is impregnated to a greater or lesser degree with ferric (hydr)oxides but which still retains the original plasmic fabric of the s-matrix. Many of these nodules have sharp external boundaries and are surrounded by oriented plasma ("skelsepic fabric"), suggesting that they are somewhat cemented; some have diffuse or very diffuse boundaries. These nodules are assumed to have been formed under the present hydromorphic conditions.
  A minor part of the nodules is highly ferruginous. These nodules have irregular internal fabrics, similar to those of the accumulations of ferric compounds

in the B horizon. This suggests that these nodules have been derived from the underlying soil. This is in concurrence with the X-ray analysis which indicates the presence of jarosite in the nodules.

Opal phytoliths and diatom frustules are common.

Infillings are mostly vertically oriented, have either distinct or diffuse external boundaries and differ from the other soil material in the following:
- darker colours, due to a higher content of fine organic substance,
- nodules occur in banded zones, and
- the plasmic fabric is very strong masepic.

The characteristics of these infillings suggest strong disturbance under wet conditions.

There is no clear evidence of animal activity.

Bgl horizon

Macroscopic observations

The soil material is light yellowish brown, fine textured and divided in developed-medium blocky aggregates, which are separated by horizontal and vertical planar voids. The horizon has wide (3-12 mm), mostly vertically oriented, discontinuous streaks of dark reddish brown material. Fine, distinct, sharp and diffuse reddish yellow and strong brown mottles are commonly associated with the streaks.

Microscopic observations

- S-matrix:
  The s-matrix of the blocky aggregates consists of pale yellow, very homogeneous clay with very few silt-sized quartz grains. Dark field examination shows that the clay is virtually devoid of fine disperse ferric (hydr)oxides. The related distribution pattern is porphyroskelic (Stoops and Jongerius, 1975: Open porphyric sili/pel; Eswaran and Baños, 1976: Plasmic NRDP). The plasmic fabric is strong to moderate vo-masepic, superimposed on unistrial fabric.
- Voids:
  The blocky aggregates are separated by horizontal and vertical planar voids. Intrapedal channels (diameter 100-500 µm) and planar voids are common.
- Organic matter:
  There is no discernable organic matter in the s-matrix except for few very fine (< 10 µm) fragments and few very thin (< 5 µm) bands occurring locally.
- Pedological features:
  The streaks are pseudomorphic features after roots, surrounded by neoferrans. The original root channels contain:
  1. root remnants, which are almost beyond recognition as they are strongly decomposed and replaced by ferric (hydr)oxides.
  2. abundant very dark yellowish brown and very dark reddish brown accumulations of ferric (hydr)oxides.
  3. few accumulations of fine (3-5 µm) jarosite crystals.

4. few infillings of material derived from the Apg horizon.

The neoferrans bordering the root channels have reddish yellow, dark reddish brown or black colours and they are prominent and very thick (up to 1000 µm). They are commonly disrupted resulting in an intricate pattern of glaebules. Some of the reddish yellow neoferrans contain fine (3-5 µm) jarosite crystals, randomly distributed.
In some places the neoferrans have been transformed into quasiferrans, i.e. there is a zone adjacent to the wall of the root channel which is devoid of iron compounds. This suggest that mobilization and removal of ferric (hydr)-oxides has taken place after the formation of the neoferrans (slide 5).
Using reflected light the accumulations of ferric (hydr)oxides appear to consist of either a reddish yellow or a red variety. There is evidence from X-ray analysis that the reddish yellow variety is goethite with various admixture of jarosite and that the red variety is hematite. The latter occurs as skins and infillings, enveloping the goethite in many places. This suggests that the hematite was formed after the goethite formation (slide 6).

There are few animal burrows in the root channels.

Bg3 horizon

Macroscopic observations

Essentially similar to the Bg1 horizon but differing in the following:
1. Blocky structure has weaker grade and is medium to coarse.
2. Streaks are less common and consist of yellowish brown, strong brown and yellow materials.
3. The fine mottles are strong brown.

Microscopic observations

- S-matrix:
  Similar to Bg1 horizon but vo-masepic plasmic fabric is less developed and unistrial fabric is more evident.
- Voids:
  Essentially similar to Bg1 horizon but planar voids are less.
- Organic matter:
  Similar to Bg1 horizon.
- Pedological features:
  Essentially similar to Bg3 horizon but differing in the following:
  1. The pseudomorphic character of the root remains is more obvious.
  2. Accumulations of ferric (hydr)oxides in the streaks have reddish yellow, yellowish red and dark yellowish brown colours.
  3. Common occurrence in the streak of prominent, large (up to 10 mm) pale olive brown to grey subtanslucent accumulations and cutans of jarosite (slide 7). Using high magnifications these accumulations appear to consist of masses of fine (3-5 µm) colourless crystals.
  4. Most intrapedal channels in the blocky aggregates have neojarositans (slide 8).
  5. In some places the jarosite accumulations and the neojarositans have

yellowish brown and reddish brown colours, suggesting the transformation of jarosite into ferric (hydr)oxides.

The proportion of reddish yellow neoferrans with fine jarosite (as compared to the darker coloured neoferrans devoid of jarosite) is higher than in the Bg1 horizon. In addition neojarositans occur, some of them pure, but mostly slightly coloured by iron compounds. This suggests that first neojarositans were formed, which afterwards were gradually transformed into neoferrans.

Bg4 horizon

Macroscopic observations

Essentially similar to Bg3 horizon but lacking streaks and mottles. Poorly developed medium angular blocks separated by irregular discontinuous planar voids.

Microscopic observations

- S-matrix:
  Similar to Bg horizon.
- Voids:
  Similar to Bg3 horizon, but planar voids are irregular and few.
- Organic matter:
  Similar to Bg3 horizon.
- Pedological features:
  Few weakly developed neoferrans along channels and planes.

1E MAJOR CHARACTERISTICS OF THE SOILS OF THE WANG NOI AREA (after: Van der Kevie and Yenmanas, 1972)

All acid soils of the former tidal flat are flat, very deep, poorly drained, clay or silty clay; colour profile is usually dark grey over mottled greyish brown over grey; they are flooded during 4-5 months, surface soil is wet during 6-7 months, subsoil is wet during 10-11 months; in the upper 30 cm of the soil the organic matter content varies from moderately low to moderately high (1.0-3.5 %); the base saturation ranges from 25 to 50 % (low to medium); the CEC from 20 to 40 me/100 gr soil (high to very high), the available phosphorus (ppm of P, Bray No. 2) varies from very low (less than 3) to moderately low (up to 10), the available potassium (ppm of K. Ammon. Acetate) is high to very high (90-120 and over 120), actually ranging from 100 to 350, and, of course, acidity is strong (pH 4.0-5.0). The fertility of these soils is described as moderately low to moderate.

The non acid soils of the former tidal flat differ from their acid counterparts mainly by a higher base saturation, which ranges from 50 to 95 % and a higher pH (6.0-8.0); their fertility is rated as high.

The soils of the floodplains are much alike the non acid soils of the former tidal flat, but are generally somewhat better drained and more brownish in colour; they are not completely flat; duration of flooding varies from 2 to 5 months, depending on topographic position; available phosphorus is medium (10-15 ppm). pH ranges from 5.0 to 7.0 and overall fertility is considered high to moderately high.

Other soil characteristics, that are used as diagnostic criteria for the distinction of the mapping units are given in the following table.

Diagnostic criteria for the distinction of the soils of the Wang Noi area

Mapping unit			presence of yellow mottles and depth	in lower A and upper B horizons presence of red mottles	in lower A and upper B horizons presence of gypsum crystals	depth of reduced substratum	soil reaction pH (1:1 H_2O) surface	soil reaction pH (1:1 H_2O) subsoil
former tidal flat	acid	Ay	below 100 cm	yes	yes	below 150 cm	5.0-5.5	4.0-4.5[1)]
		Ma	below 100 cm	yes	no	below 150 cm	4.5-5.5	4.0-4.5[1)]
		Ok	within 40 cm	yes	no	below 100 cm	3.5-4.5	3.5-4.5[1)]
		Rs	below 40 cm and within 100 cm	yes	no	below 100 cm	4.0-5.0	3.5-4.5[1)]
		Se	below 40 cm and within 100 cm	yes	yes	below 100 cm	4.5-5.0	3.5-4.5[1)]
	non-acid	Bl	no	no	yes	below 120 cm	6.0-6.5	6.0-8.0
		Bl-O	no	no	yes	below 150 cm	6.0-6.5	6.0-8.0
		Cc	few, below 100 cm	yes	few	below 150 cm	4.5-5.5	5.0-8.0
floodplain		Bin	no	yes	yes	-	5.5-6.0	4.5-5.5
		Rb	no	no	no	-	5.5-6.0	6.0-7.0
		Sin	no	yes	yes	-	5.5-6.0	4.5-5.5

1) increasing to pH 6.0 in the very deep subsoil

Appendix II. Analytical Methods

Particle size distribution

About 20 g of soil (fine earth, < 2 mm) was treated with 30 % H_2O_2 in a 1 N NaOAc pH 5 buffer (15 ml of each). They were left for one night in the cold (in waterbath at room temperature) and then heated to 80°C on the waterbath. Small increments of H_2O_2 were added until completion of the treatment. Dispersion was effected with a short treatment in a milkshaker (1 min.). The resulting suspension was sieved through a 50 µm sieve. The fraction passing through the sieve was washed by sedimentation and siphoning followed by centrifuge washing. Final dispersion was achieved by adding sodium pyrophosphate. Clay and silt were determined with the pipette method.

The sand was washed out on the 50 µm sieve and, after drying, fractionated by a range of sieves.

pH

The pH-H_2O was measured in a 1:2.5 air-dry soil: water (wt/wt) suspension after overnight mechanical shaking.

The pH-KCl was similarly measured using a 1 N KCl solution instead of water. To comply with the Soil Taxonomy requirement pH-H_2O of the surface horizon was also measured in a 1:1 suspension.

Carbon

Organic C was determined according to the method by Begheijn (1976) in which the CO_2 liberated by wet combustion of the sample in a H_2SO_4/H_3PO_4 mixture (after removal of carbonates) is absorbed and precipitated in a $NaOH/BaCl_2$ solution. After dissolving $BaCO_3$ with Na_2-EDTA the pH of the solution is measured. The pH is related to the amount of CO_2 present by means of a calibration graph.

Nitrogen

Total nitrogen was determined with the micro-Kjeldahl technique.

Free iron oxides

To determine different forms of "free" iron oxide extractions were made with three different extractants (reviewed by Andriesse, 1979).

Diothionite (Holmgren, 1967). 2 g of air-dry fine earth is shaken overnight with a sodium citrate/sodium dithionite mixture and then centrifuged.

Pyrophosphate. Similar to the dithionite extraction, but 200 ml 0.1 M $Na_4P_2O_7.10H_2O$ solution is used.

Oxalate. 2 g air-dry fine earth is shaken for 4 hours in 200 ml Tamm's solution (0.2 M ammonium oxalate pH 3, i.e. acidified with ca. 20 g oxalic acid per litre) and then centrifuged.

In all cases superfloc was added prior to centrifugation and Fe was determined by AAS.

Exchangeable cations

Percolation of a 5 g sample with ammonium acetate (pH 7), determination of Ca, Mg, K and Na by AAS.

CEC

Above NH_4-saturated sample was leached with 1 N sodium acetate (pH 7) and washed free of salt. The sample was then leached with 1 N ammonium acetate (pH 7) and Na was measured in leachate by AAS.

Extractable acidity

Percolation of a 5 g sample with KCl-TEA (pH 8.2) and titration of the leachate.

Electrical conductivity

Measured in the 1:2.5 pH-H_2O suspension.

Water soluble salts

A 40 g sample was shaken with 200 ml water for 2 hours and then filtered. Ions were measured in the filtrate (1:5 extract): Ca, Mg, K and Na by AAS; chloride with a Chlorocounter titrator and sulphate by turbidimetry.

Gypsum

Precipitation with acetone from 1:5 extract. Measurement by conductivity of re-dissolved precipitate.

Elemental composition

By X-ray fluorescence analysis. Samples are ignited at 900°C, then 0.6 mg sample is molten with 2.4 g lithium tetraborate at ca. 1200°C. The obtained tablet was analyzed on a Philips XRF assembly.

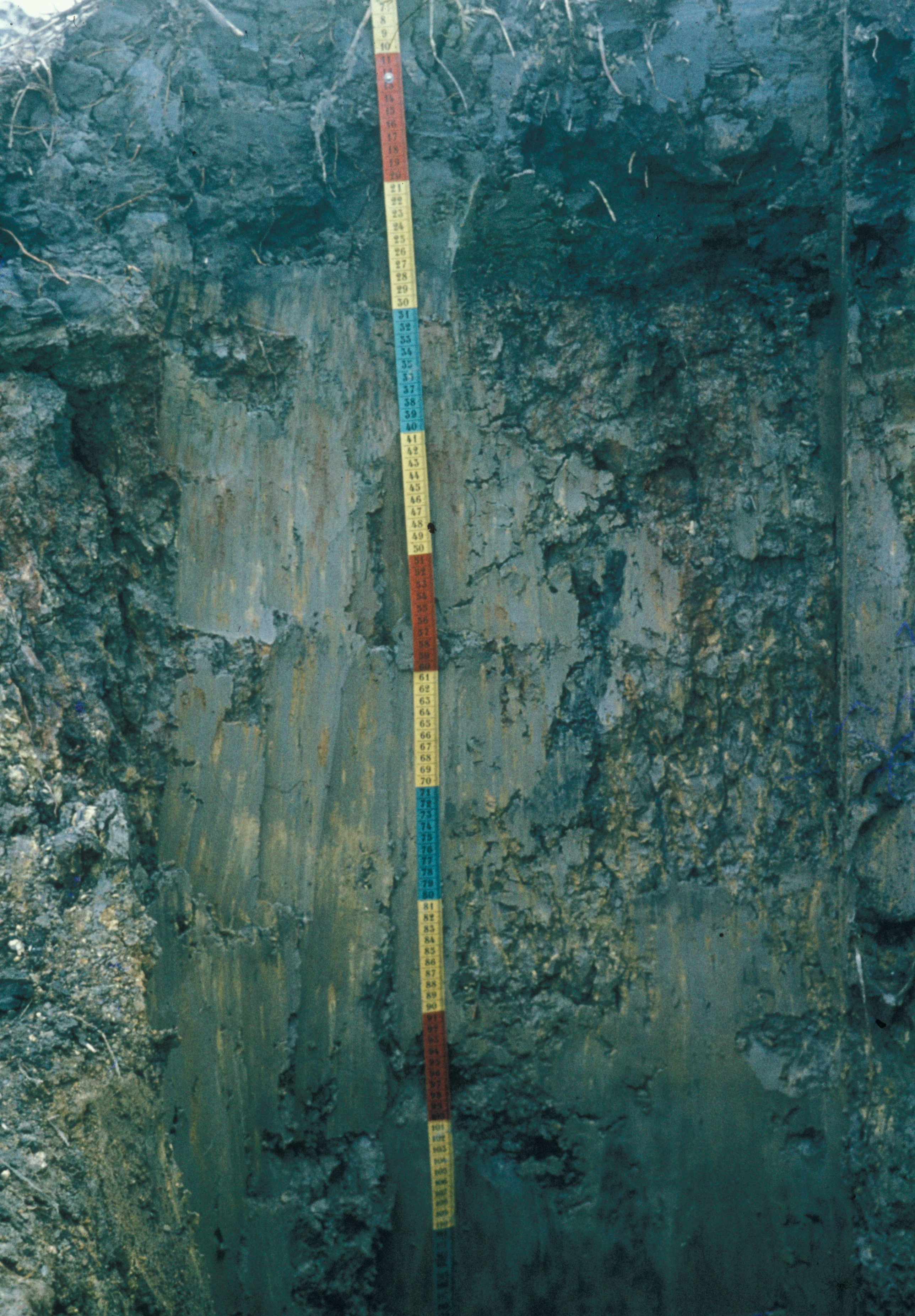
For elemental analysis of the clay fraction, clay was separated as indicated for particle size analysis (without addition of pyrophosphate), after centrifuge washing and freeze-drying the sample was further treated as above.

Clay mineralogy

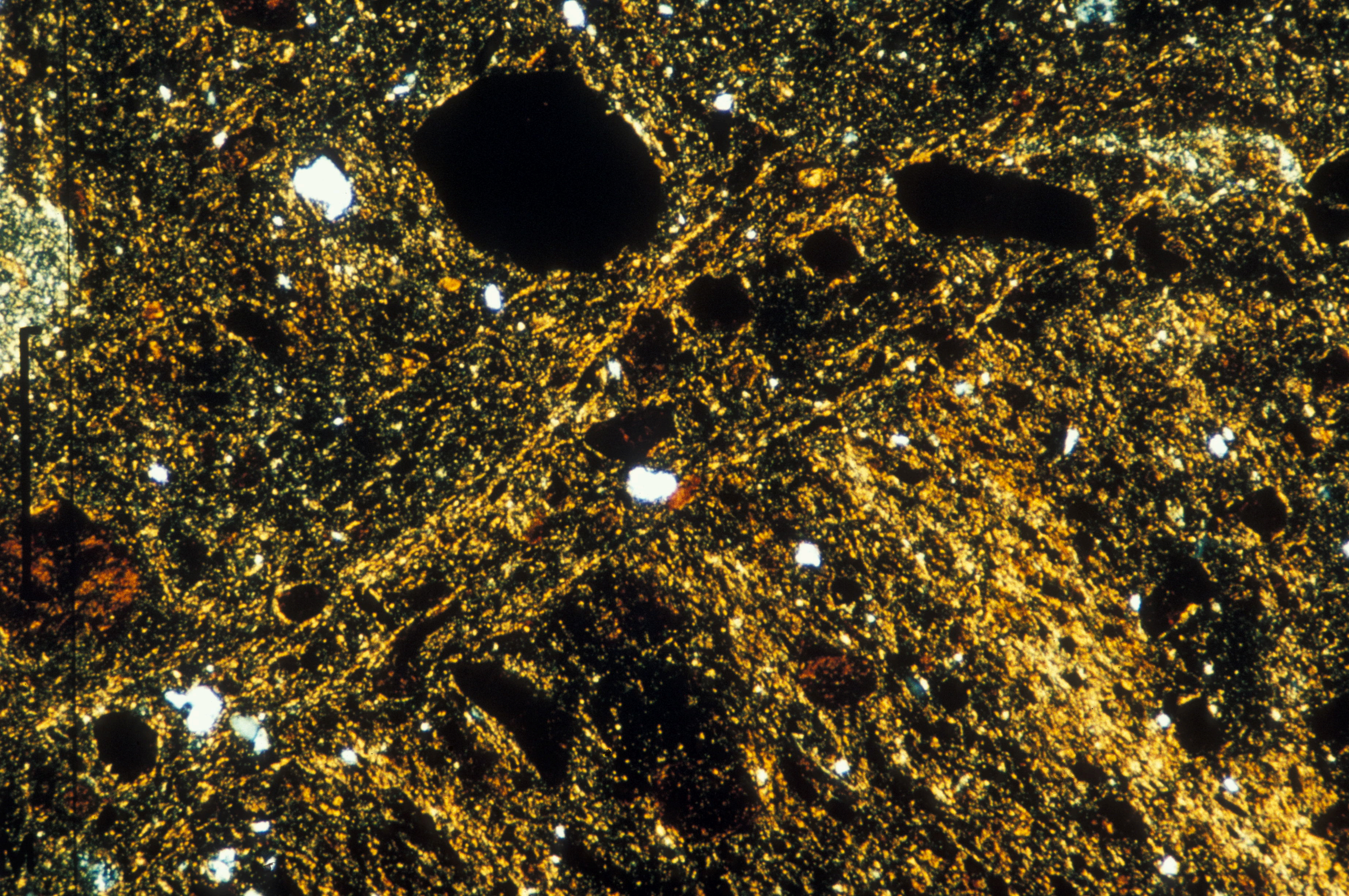
Clay was separated as indicated for particle size analysis (without addition of pyrophosphate). Ca. 10 mg clay was brought onto a porous plate by suction and the specimens were analysed on a Philips diffractometer. For better identification of the non-phyllosilicates Guinier photos were taken of some mottles and concretions.

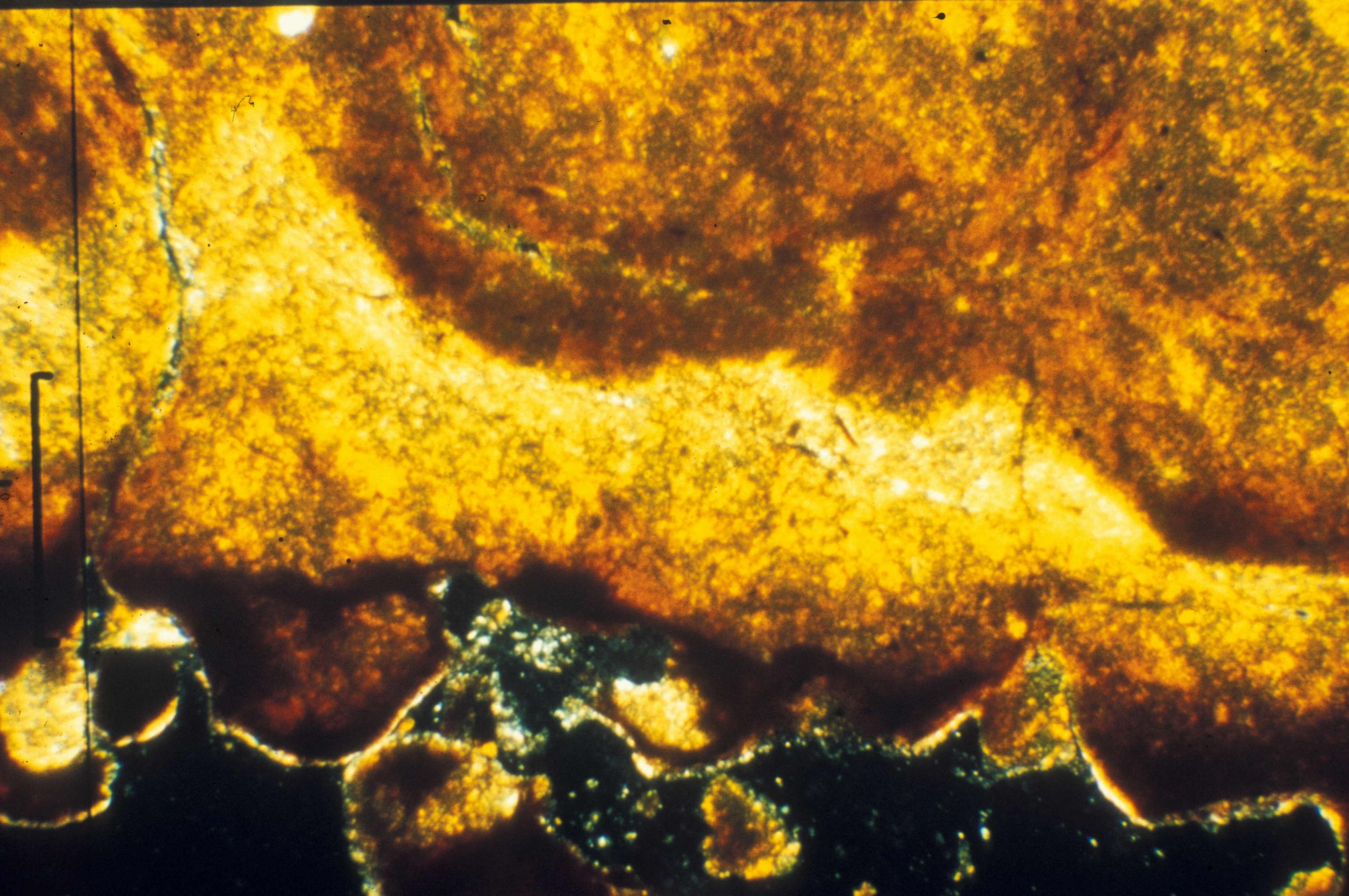
Appendix III. Description of the Slides

Slide 1	Landscape.
Slide 2	Soil profile in the field.
Slide 3	Soil monolith. Upper 10 cm have not been retained. Note cracks in the subsoil, which consisted of soft half ripe clay under field conditions.
Slide 4	Ap horizon, crossed polarizers. Moderate skel-bimasepic plasmic fabric. Some yellowish red iron nodules.
Slide 5	Bg1 horizon, crossed polarizers. Neoferrans and quasiferran.
Slide 6	Bg1 horizon, same as slide 5 but darkfield + incident light. The yellowish goethite-neoferran has a thin red hematite-ferran.
Slide 7	Bg3 horizon, plain light. Prominent greyish brown jarosite accumulations along voids.
Slide 8	Bg3 horizon, plain light. Intrapedal channels with and without neojarositans.



T 1





SM

500 µm

ISM