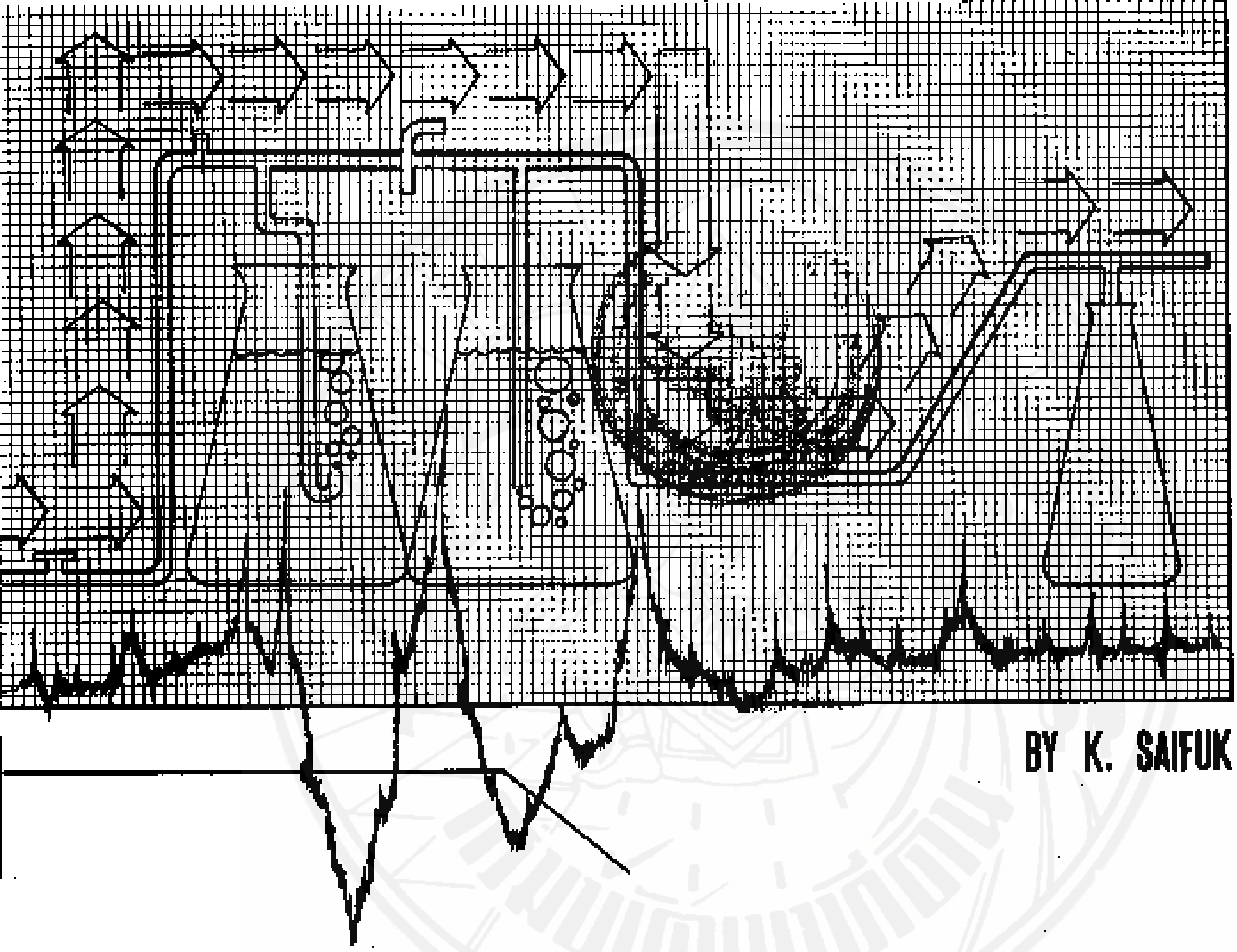
STUDY OF PHYSICAL, CHEMICAL, AND MINERALOGICAL PROPERTIES OF SOILS

erived from Sandstone Sediment in Khon Kaen Province, Northeast Thailand.



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Contents

Study of Physical, Chemical, and Mineralogical Properties of Soils Derived from Sandstone Sediment in Khon Kaen Province, Northeast Thailand.

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Abstract

Korat Renu, and Roi-Et soils are developed on old alluvium under similar climatic conditions.

The dominant soil forming precesses are desilication and in situ clay formation with Kaolinite being the dominant clay mineral in every soil profile.

pH values decrease with depth in all soils from slightly acid to extremely acid.

The fine sand fraction (0.05-0.10 mm) of all soils is composed mainly of quartz in the light fraction and zircon with opaques in the heavy fraction.

Micromorphological features are similar in all soils. Single grain is dominant. Massive, bridge, and alveolar structures also occur. The clay is brownish and isotropic with a few areas being anisotropic.

There is evidence of vigorous termite activity in Korat and Renu soils. There is little or no termite activity in Roi-Et soil, because that soil usually becomes saturated with water every year.

The differences of profile characteristics are due to differences in topography drainage and land management. The differences in profile characteristic of these soils are readily apparent ; viz. colour, mottles, concretions,

etc. The differences are significant because they influence the differences in the classification of these soils.

I. Introduction

The study area is in Khon Kaen Province, which is located in Northeast Thailand. The dominant landforms in that province are high alluvial terrace and fans of old alluvium and colluvium. Soils are Low Humic Gley (32 % of total area of Khon Kaen) and Gray Podzolic (30 %) (Rojanasoonthon 1964).

The geologic formations of the area, as classified by Javanaphet (1969) are the Salt and Kok Kruat Formation and the Pra Wihan Formation. The Salt and Kok Kruat formation is comprised of layers of sandstone, shale, siltstone, rock salt, and gypsum. Maximum thickness of any one gypsum layer is 50 feet. Maximum thickness of this formation is 800 feet. The Kok Kruat or Ban Na Yo formation, characterized by sandstone, shale, siltstone, and nodular limestone, also occurs in areas mapped as the Salt and Kok Kruat Formation.

The Phu Phan and Pra Wihan Formation is characterized by yellowish gray to grayish pink sandstone and conglomerate, and grayish red to olive gray to white massive sandstone with dark reddish brown micaceous shale and grayish red micaceous siltstone.

Three pits for examination and sampling were dug, one each for the Korat series (Gray Podzolic Soils), Roi-Et series (Low Humic Gley Soils) and Renu series (Hydromorphic Gray podzolic Soils) Fig. 1 shows the location of the three pits.

II. Purposes of the study

1. To compare soils developed from the same parent material, Old alluvium, which differ in drainage, topography, and land management.

2. To classify these soils according to a number of different systems including : Soil Taxonomy (U.S.D.A 1975), the F.A.O system, and the system of FitzPatrick.

3. To study the dominant soil forming processes of the study area.

III. Procedure

The pits were approximately 1.5 metres by 3 metres wide and 1.5 metres deep. The profile face was cut vertically, cleaned with a brush, photographed and then sampled.

3.1 Bulk Sampling

Duplicated bulk samples, each of about 5 litres, were collected from each horizon. The lower horizons were sampled first in order to avoid contamination from overlying horizons.

3.2 Thin Section Sampling.

Duplicate samples for thin section preparation were collected from each horizon in Kubiena boxes of size 15 X 8 X 5 cm with lid on top and bottom.

Laboratory methods.

All determinations were performed in duplicated. The average values are presented.

3.3 Preparation of bulk samples.

The bulk samples were dried at room temperature. Stones and plant roots were removed from each sample. The samples were then ground with mortar and pestle. The fine earth (less than 2 mm) was separated by means of seiving, placed in labelled plastic bags and kept for laboratory investigation.

3.4 Particle size analysis.

The samples were dispersed with calgon solution after the removal of organic matter and sesquioxides. Fine silt and clay fractions were determined by the pipette method at the appropriate time. Sand and coarse silt fractions were separated by using a bank of seives on a Pascall shaker.

3.5 Determination of pH.

The pH was determined in a 1:2.5 soil water mixture using an E.I.L pH meter.

3.6 Determination of organic carbon and total nitrogen.

Total organic carbon was determined by the wet oxidation method of Tinsley (1950). The amount of organic matter was calculated by using the relationship O.M. (%) = Carbon (%) X 1.72. Total nitrogen was determined by the

Kjedahl digestion method of Bradstreet (1965).

3.7 Determination of cation exchange capacity (C.E.C.)

The exchangeable cations are displaced by leaching of the soil sample with 1.0 N. ammonium acetate at pH7.0. Exchange acidity (H^+) was determined by the back titration of the leachate to pH 7.0. Calcium, magnesium, potassium and sodium were determined by atomic absorption of the leachate.

3.8 Separation of samples for mineralogical study

In each soil sample, the clay fraction was dispersed by calgon, the sand and silt fractions were remove by sedimentation, then the clay fraction was reflocculated.

The sand was separated by further sedimentation, dried, and the 0.05-0.10 mm fraction separated by seiving.

3.9 Preparation of the clay samples for x-ray analysis.

Duplicated aliquote were treated with sodium acetate to destroy carbonates and remove exchangeable divalent cations. They were treated with hydrogen peroxide to remove organic matter. One aliquot was separated with Mg, the other with K, and slides were Prepared for x-ray analysis. The following x-ray analysis were run : Mg-saturated at room temperature and 110 C, K-saturated at room temperature, 325°C and 525 C. A glycerol solvated Mg. saturated was done, but because there was no change in the 14°A peak in any of the samples of the three soils the x-ray chart for that

IV. Results

4.1 Korat series

Taxonomic Unit	:	Gray Podzolic Soils (National)
		Oxic Paleustalf (U.S.D.A.)
Location	:	Khon Kaen Province.
Map reference	:	Sheet 5660 IV, series L 708, Coordinate 877352.
Air photo	:	M 86 No. 14497
Topography	:	Flat.
Elevation	:	200 metres
Slope	:	0.2 percent.
Climate	:	Tropical Savannah (Koppen 'AW')
Precipitation	:	1,100 - 2,200 mm.
Temperature	:	26-28 °C
Vegetation	:	Dipterocarp forest.
Parent material	:	Old alluvium.
Land use	:	Shifting cultivation of upland crops, kenaf, maize, cassava and sparse secondary forest.

	(cm)	(moist colours unless otherwise stated)
A_1	0-12	Dark brown to brown (10YR4/3) loamy sand; weak fine subangular blocky breaking to single grain; non sticky, non plastic, loose when moist, soft when dry; common fine interstitial pores; many medium roots; gradual, smooth boundary; pH 6.0.

	(cm)	(moist colours unless otherwise stated)
A_2	12-20	Light yellowish brown (10YR6/4) sandy loam; weak fine subangular blocky; non sticky, non plastic, loose when moist soft when dry; common fine interstitial pores; many medium roots; gradual, smooth boundary; pH 6.0.
B_1	20-70	Light yellowish brown (10YR6/4) sandy loam; weak fine to moderate medium subangular blocky; non sticky, non plastic, friable when moist, firm when dry; common fine interstitial pores; few fine tubular pores; common medium roots; gradual, smooth boundary; pH 5.5.
B_{21}	70-118	Light yellowish brown (10YR6/4) sandy loam; moderate fine to medium subangular blocky; non sticky, non plastic, friable when moist, hard when dry; common fine interstitial and tubular pores; few fine roots; clear, smooth boundary; pH 5.5.
B_{22}	118-140	Brownish yellow (10YR6/6) sandy loam; moderate fine to medium subangular blocky; slightly sticky, non plastic, friable when moist, extremely hard when dry; common fine interstitial and tubular pores; few fine roots; pH 5.0.

Micromorphology

Single grain and bridge structures are dominant in the upper 70 cm with dark brown grading to yellowish brown isotropic clay. Below 70 cm the clay coating is weakly anisotropic with undulose extinction. Frequent bridges form between the grains. Below 70 cm alveolar structure accompanies single grain and bridge structure (Alveolar structure is similar to bridge structure).

In soil having alveolar structure clay and silt are more plentiful than they are in soils having bridge structure. The clay and silt forms the matrix in alveolar structure, whereas in bridge structure the sand grains form the matrix (FitzPatrick, 1971).

Characteristics of Korat soil can be summarized as follows :

1. Mineral grains are dominantly subangular and subrounded quartz in the A horizons, becoming more rounded in the B horizons. Tourmaline and zircon are frequent in the A_2 horizon and decrease slightly with depth.

2. Clay increases slightly with depth until at a depth of 70 cm there is a marked increase.

3. Clay is kaolinite.

4. Clay coatings occupy 0.9 % of the area on slides taken from the B_{21} and B_{22} horizons.

4.2 Renu series

Taxonomic units	:	Hydromorphic Gray Podzolic Soils (National) Paleustult (U.S.D.A.).
Location	:	Khon Kaen Province.
Map reference	:	Sheet 5661 IV, series L 708, Coordinate 972675.
Air photo	:	M86 No. 14576.
Topography	:	Undulating.
Elevation	:	230 metres.
Slope	:	2-4 percent.
Climate	:	Tropical Savannah (Koppen 'AW')
Precipitation	:	1,100 - 2,200 mm.
Temperature	:	26 - 28 °C.
Parent material	:	Old alluvium.
Vegetation	:	Dipterocarp forest.
Land use	:	Maize, kenaf, ground bean, sugar cane, cassava, and paddy rice (if dikes are built to impound rain water).

Note : The soil described on the next few pages more nearly fits the concept of the Satuk series than the Renu series.

	(cm)	(moist colours unless otherwise stated)
A_1	0-9	Dark grayish brown (10YR4/2) sandy loam; weak fine to moderate medium subangular blocky; non sticky, non plastic, friable when moist, soft when dry many fine interstitial pores; many fine and medium roots; clear, smooth boundary; pH 6.0.
A_2	9-20	Light yellowish brown (10YR6/4) sandy loam; weak fine to medium subangular blocky; non sticky, non plastic, friable when moist, soft when dry; common fine and medium roots; clear, smooth boundary; pH 6.0.
B_1	20-35	Yellowish brown (10YR6/6) sandy loam; moderate fine to medium subangular blocky; slightly sticky, non plastic, slightly firm; common fine interstitial and tubular pores; common fine and medium roots; gradual, smooth boundary; pH 5.0.
B_{21}	35-57	Yellowish brown (10YR6/6) sandy clay loam; common fine brown (7.5YR5/4) mottles; moderate fine and medium subangular blocky; slightly sticky, non plastic, firm when moist, slightly hard when dry; few fine interstitial and common fine and medium roots; diffuse, smooth boundary; pH 5.0.
B_{22}	57-90	Yellowish brown (10YR6/6) mixed with light brown (7.5YR6/4) sandy clay loam, few prominent yellowish red (5YR5/6) mottles; weak fine and medium

	(cm)	(moist colours unless otherwise stated)
		subangular blocky; slightly sticky, non plastic, firm when moist, slightly hard when dry; few fine interstitial pores; gradual, wavy boundary; pH 5.0.
B_{23}	90-115	Yellow (10YR7/6) sandy clay loam, few fine prominent yellowish red (5YR5/6) mottles; weak fine and medium subangular blocky; slightly sticky, non plastic, friable when moist, hard when dry; few fine interstitial and common fine tubular pores; few fine roots; abrupt, wavy boundary; pH 5.0.
C	115^{+}	Compact layer of iron and manganese oxide concretion.

Micromorphology

This soil has an alveolar structure with yellowish brown (10YR5/6) isotropic clay showing undulose extinction in the B_1 horizon. Below 35 cm depth the clay is brownish yellow (10YR6/6) with irregular anisotropic areas. Distinctive features observed under the microscope are :

1. Clay increases until 65 cm depth and then decreases slightly whereas the sesquioxide concretions increase in the lower horizons.

2. The mineral grains are predominantly quartz with lesser amounts of zircon, tourmaline, and opal.

3. Clay is kaolinite.

4. Clay coatings reach a maximum of 0.8 percent at the 20-35 cm horizon and decrease slightly with depth.

4.8 Roi-Et series

Taxonomic unit	:	Low Humic Gley Soils (National).
		Aeric Paleaquult (U.S.D.A).
Location	:	Khon Kaen Province.
Map reference	:	Sheet No. 5560 I, series L 708, coordinate 798338
Air photo	:	M76 No. 12504
Topography	:	Flat
Elevation	:	150 metres.
Slope	:	0-2 percent.
Climate	:	Tropical Savannah (Koppen 'AW').
Precipitation	:	1,100-2,200 mm.
Temperature	:	26 - 28°C.
Vegetation	:	Rice.
Parent material	:	Old alluvium.
Land use	:	Paddy-field.

	(cm)	(moist colours unless otherwise stated)
Apg	0-13	Light brownish gray (10YR6/2) sandy loam; common fine distinct yellowish brown (10YR5/6) mottles; weak fine subangular blocky and massive; non sticky, non plastic; loose, many fine interstitial pores; many fine roots; clear, smooth boundary; pH 6.0.

	(cm)	(moist colours unless otherwise stated)
B_{1g}	13-39	Grayish brown (10YR5/2) to light brownish gray (10YR6/2) sandy loam; common fine faint dark yellowish brown (10YR5/8) mottles; weak fine to medium subangular blocky; non sticky, non plastic, friable when moist; common fine interstitial and tubular pores; few very fine roots; diffuse, smooth boundary; pH 5.0.
B_{21g}	39-72	Light yellowish brown (10YR6/4) sandy loam, many fine distinct yellowish brown (10YR5/8) mottles; weak fine and medium subangular blocky; slightly sticky, non plastic, slightly firm when moist; common fine tubular pores; clear, smooth boundary; pH 5.5.
B_{22g}	72-120	Pale brown (10YR6/3) to light yellowish brown (10YR6/4) sandy clay loam; many fine distinct yellowish brown (10YR5/6) mottles; weak fine and medium subangular blocky; slightly sticky, slightly plastic; common fine tubular pores; pH 5.5.

Micromorphology

Massive and laminar structure with yellowish brown (10YR5/6) isotropic clay in the Apg. Below 13 cm depth structure is massive. Secondary growth of ferri-argillans is evident in the B_{22g}. The vertical cleavages in the clay coatings suggest that these coatings may be formed in situ.

The soil has the following important features :

1. Clay coatings range from 0.2 percent in the B_{1g} and reach their maximum of 3.1 percent in the B_{22g}.

2. Clay is kaolinite.

3. Mineral grains are dominantly quartz with lesser amounts of zircon, tourmaline and opal.

4. Iron/manganese oxide concretions occur below 50 cm and increase slightly with depth.

V. Discussion

5.1 Clay minerals

Korat series : This soil is dominated by kaolinite in every horizon, characterized by the presence of diffraction spacing at 7.15 angstroms (°A) and 3.57°A in K-saturated and Mg-saturated air dried clay samples. The peaks are stable at 325°C, but characteristically they disappear when heat at 525°C. Mica (illite) is present as a trace and characterized by the presence of a 10°A basal reflection in both K and Mg-saturated samples and stable at 525°C. Vermiculite is differentiated from montmorillonite by the Mg-saturated, glycerol solvated, treated sample, because the 14°A basal reflection did not expand to 18°A at room temperature.

Non clay minerals are quartz, characterized by very sharp, high peak at 3.34 °A in the K-saturated samples, stable at 525°C, trace amounts of K-feldspar with 3.26°A basal reflection of the Mg and K-saturated, air dried samples and stable at 525°C.

Renu series : This soil is dominated by kaolinite with very small amounts of vermiculite and traces of chlorite. Chlorite is characterized by the presence of 14 °A basal reflection after heating at 525°C. Traces of micas were also found throughout the profile.

Non clay minerals are dominantly quartz with traces of K-feldspar.

Roi-Et sereis : Kaolinite is dominant accompanied by small amounts of vermiculite and traces amounts of micas.

Non clay minerals are quartz and trace amounts of K-feldspar.

The detrital grain mineral species and the clay minerals suggest that the three soils developed from the same parent material i.e. sandstone which is wide spread in the area. An interesting phenomenon is that occurence of vermiculite and chlorite appears to be associated with wet soil conditions.

The possible processes of weathering of silicates and aluminosilicates should be as follow (Gerasimov and Glazovskaya, 1960) :

$$K_2Al_2Si_6O_{16} + H.HCO_3 \longrightarrow K.H.Al_2Si_6O_{16} + KHCO_3$$

ORTHOCLASE — SERICITE OR SECONDARY MUSCOVITE

At the first stage of weathering there forms an acid Potassic aluminosilicate sericite - a secondary mica, or in the case when crystals are large, secondary muscovite. In the further decomposition of sericite free aluminosilicate acid arise which is rapidly decomposed into kaolinite and hydrous silica (opal).

$$K.HAl_2Si_6O_{16} + H.HCO_3 \longrightarrow H_2Al_2Si_6O_{16} + KHCO_3$$

$$H_2Al_2Si_6O_{16} + nH_2O \longrightarrow H_2Al_2Si_8O_8 \cdot 2H_2O + 2SiO_2 \cdot nH_2O$$

KAOLIN — OPAL

However, the formation of opal in the upper soil horizons of the Roi-Et and Renu soils can also be attributed to the decomposition of siliceous plant tissue and the subsequent hydration of the SiO_2.

The presence of chlorite in the Renu soil suggests that this soil is the youngest, if we consider the pathway biotite $\longrightarrow$ chlorite $\longrightarrow$ vermiculite $\longrightarrow$ kaolinite. However, chlorite is present only in trace amounts in the Renu soil, and biotite can go directly to vermiculite. The

Roi-Et soil has trace amounts of vermiculite, which could conceivably have weathered directly from biotite without going through the chlorite stage. So it is not certain that the Renu soil is the youngest of the three soils, or that it is younger than the Roi-Et soil.

5.2 <u>Particle size Distribution</u>

Examination and comparision of particle size distribution patterns of the three soils show the dominance of the sand fraction (2.0-0.05 mm) viz : 72.4 to 77.8 percent in Korat, 48.2 to 55.8 percent in Roi-Et, and 49.3 to 63.7 percent in the Renu soil. A distinct phenomenon is the presence of some fractions that constitute the majarity of the soil. In Korat soil, the fraction of 0.02 to 0.5 mm constitutes 81.0 to 86.2 percent of the soil. In Roi-Et and Renu the 0.02 to 0.2 mm fraction is dominant; 53.4 to 76.0 in the Roi-Et and 62.7 to 78.5 percent in the Renu.

The dominance of one particle size range in each of these soils suggests an alluvial origin. These soil derived from sediment carried by the overflow of slow moving streams.

The fact that these soils were all derived from sandstone suggests that they are related genetically. Silt/clay ratios indicate the evolution of the soil profiles. In the Korat profile there is an abrupt change in the silt/clay ratio from 4.0 to 1.8 at a depth of 70 cm thus the eluvial horizon in fact begins at a depth of 70 cm. Analytical data show this eluvial horizon to be quite thick-58 cm. In the field however, the only eluvial horizon that is possible to distinguish is that between 12 and 20 cm.

In the Renu profile, there is an abrupt decrease in the silt/clay ratio below a depth of 20 cm from approximately 3.5 to 1. The ratio of around 1 suggests that either the translocation of clay is not vigorous or the clay coating is being destroyed by some means.

5.3 Exchange Properties

Total exchangeable base (T.E.B.) of the three soils are quite similar : about 1.2 me in the subsoil and around 2 at the surface horizons. The C.E.C.'s of the three soils are very low but the base saturation percentages vary considerably due to the fluctution of the exchange acidity. These are indeed Low Activity Clay (LAC) soils. The exchange of a few mili-equivalents of H^+ greatly alters the percentage base saturation.

In this investigation the Al^{+++} was also determined by atomic absorption but in none of the horizons was the value greater than 0.05 milli-equivalents.

As an example of the disproportionate influence of a slight change in H^+ concentration of the Korat soil. In the horizon 20-70 cm, the H^+ is 2.48 me. and T.E.B. is 1.13, so the base saturation is 31.3 percent. In the horizon from 70-118 cm, the H^+ is 1.43 m.e., T.E.B. is 1.20 me., so that base saturation is 51 percent. A decrease of only 1.05 me. of H^+ caused an increase in base saturation of 16.7 and 20.2 percent respectively.

Thus using percentage base saturation as a basis for differentiating these soils at the order level is ambiguous. It does not give an accurate idea of the base status of these soils.

One significant feature of these soils is the high content of exchangeable sodium despite the intense weathering and leaching of parent material. This phenomenon may be explained by the prolonged dry, hot season during which sodium moves upward through capillary action.

5.4 Classification

Korat series

U.S.D.A. (1975) : In this soil, the clay in some pores and the clay bridging the sand grains (it is single grain structure) is oriented. It also has a significant clay increase in lower horizons. All these facts indicate the presence of an argillic horizon. However, no sample at the 1.8 metre depth was available, so the soil may be either Alfisol or Ultisol. The increase percent base saturation with depth make it likely that at the depth of 1.8 metres, percent base saturation is high enough to classify this soil as an alfisol. Therefore it can be classified as an Oxic Paleustalf since clay content remains constant with depth and C.E.C. is less than 24 m.e.q/100g clay.

FAO/UNESCO (1974) : This soil is an Eutric Nitosol due to the high base saturation.

FitzPatrick (1971) : This is a $Vk_{12}Ae_{58}(AeAr)_{48}(AeFvAr)_{22}$ of the arenosols, characterized by the presence of the arenon.

Roi-Et series

U.S.D.A. (1975) : This soil is a Paleaquult because it has an argillic horizon and it fall into the subgroup of Aeric Paleaquult because the high Chroma of the subsoils.

FAO/UNESCO (1974) : It is a Dystric Nitrosol because it has an argillic horizon with a C.E.C. less than 24 m.e.q./100 g clay.

FitzPatrick (1971) : This soil is a $Mi_{13}Pn^{+}_{107}$ of the planosols, characterized by the presence of the planon indicating the wet condition.

Renu series

U.S.D.A. (1975) : This soil with alveolar structure, has oriented clay in some pores and oriented clay bridging the sand grains. Thus plus a sufficient clay increase indicate the presence of an argillic horizon. This is a Typic Paleustult.

FAO/UNESCO (1974) : Like the Roi-Et, it is a Dystric Nitosol.

FitzPatrick (1971) : This soil is a $(MuMo)_9Zo_{11}(AeFvZh)Ar_{15}(AeFvZh)^{+}$ of the luvisols.

5.5 Genesis

Genitically, these soils have much in common with each other. Most of the important factors are the same in all soils : parent materials, temperature regime, rainfall, etc. One important difference between the Roi-Et soil and the Korat and Renu soils is position in landscape. The difference is important enough to have given rise to two different evolutionary sequences.

The evolutionary sequence for the Korat and Renu soils is as follows :

1. Deposition of alluvium.
2. Leaching of iron and aluminium.

3. *In situ* formation of kaolinite

4. Formation of concretions.

The evolutionary sequence for Roi-Et so s follows :

1. Deposition of alluvium.

2. Gleization.

3. Leaching of iron and aluminium

4. *In situ* formation of kaolinite.

5. Formation of concretions.

TABLE 1 Percentage of light and heavy minerals in 50-100 μm fraction of Korat series.

Depth (cm)	Horizon symbol	Light minerals (%)	Heabyminerals (%)
0-12	A_1	99.0	1.0
12-20	A_2	99.3	0.7
20-70	B_1	98.7	1.3
70-118	B_{21}	98.4	1.6
118-140	B_{22}	99.8	0.2

TABLE 2 Percentage of light and heavy minerals in 300 grains of Korat series.

Depth (cm)	0-12	12-20	20-70	70-118	118-140
Light minerals					
Quartz	97.3	97.4	98.0	98.4	97.8
Coated grains	1.3	1.6	1.0	1.0	1.3
Weathered grains	1.3	1.0	0.3	0.3	0.3
Bioite	-	-	0.7	0.3	0.6
Heavy minerals					
Zircon	57.9	53.4	63.4	56.7	60.3
Opaque grains	34.1	31.8	29.8	33.7	28.3
Tourmaline	7.4	14.3	6.5	9.3	10.7
Hornblende	0.6	0.7	0.3	0.3	0.3
Weathered grains	-	0.8	-	-	-

TABLE 3 Percentage of light and heavy minerals 50-100 μm fraction of Roi-Et series.

Depth (cm)	Horizon symbol	Light minerals (%)	Heavy minerals (%)
0-13	Apg	99.9	0.1
13-39	B_{1g}	99.8	0.2
39-72	B_{21g}	99.8	0.2
72-120	B_{22g}	99.6	0.4

TABLE 4 Percentage of light and heavy minerals in 300 grains of Roi-Et series.

Depth (cm)	0-13	13-39	39-72	72-120
Light minerals				
Quartz	95.7	92.7	94.0	97.4
Coated grains	0.7	3.0	1.6	1.6
Weathered grains	1.3	3.0	4.1	0.7
Biotite	2.3	0.3	-	-
Opal	-	1.0	0.3	0.3
Heavy minerals				
Zircon	47.0	52.7	32.1	43.9
Opaque grains	33.1	31.7	55.1	45.5
Tourmaline	19.2	14.7	11.5	9.6
Hornblende	0.7	0.6	0.6	0.3
Biotite	-	0.3	0.6	0.7

TABLE 5 Percentage of light and heavy minerals in 50-100 μm fraction of Renu series.

Depth (cm)	Horizon symbol	Light minerals (%)	heavy minerals (%)
0-9	A_1	99.6	0.4
9-20	A_2	99.0	1.0
20-35	B_1	99.8	0.2
35-57	B_{21}	99.5	0.5
57-90	B_{22}	99.7	0.3
90-115	B_{23}	99.3	0.7

TABLE 6 Percentage of light and heavy minerals in 300 grains of Renu series.

Depth (cm)	0-9	9-20	20-35	35-57	57-90	90-115
Light minerals						
Quartz	95.6	91.5	99.0	98.7	98.5	98.7
Coated grains	1.7	1.0	0.3	-	0.6	0.3
Weathered grains	1.3	0.3	0.3	0.3	0.6	0.3
Opal	1.3	7.2	0.3	1.0	0.3	0.6
Heavy minerals						
Zircon	50.7	51.1	39.4	54.2	45.7	41.9
Opague grains	35.7	37.1	44.7	31.6	46.3	40.3
Tourmaline	13.3	11.1	15.7	14.3	8.1	17.1
Hornblende	-	0.3	0.3	-	-	0.3
Biotite	0.3	0.3	-	-	-	0.3

TABLE 9 PHYSICAL PROPERTIES OF ROI-ET SERIES.

DEPTH (cm)	HORIZON SYMBOL	PARTICLE SIZE DISTRIBUTION (μm) 2000 – 1000	1000 – 500	500 – 200	200 – 100	100 – 50	50 – 20	20 – 10	10 – 5	5 – 2	2 – 1	1 – 0.5	∠0.5	SAND 2000 – 50	SILT 50 – 2	CLAY ∠2	TEXTURE	200 – 20 μm	SILT CLAY RATIO	SESQ OXIDE (%)	H.G. MOISTURE (%)	COATING (%)
0-13	Apg	0.05	0.8	8.6	19.4	26.9	23.7	7.5	4.0	4.0	1.3	0.3	2.5	55.8	39.2	4.1	SL	70	9.6	0.1	0.4	-
13-39	B_{1g}	0.10	1.2	10.7	19.6	20.7	19.8	7.3	4.0	5.3	1.0	1.0	7.3	52.3	36.4	9.3	SL	60.1	3.9	0.2	0.9	0.2
39-72	B_{21g}	0.44	1.7	10.4	18.4	22.0	17.2	6.1	4.0	6.1	3.8	0.5	7.6	52.9	33.4	11.9	SL	57.6	2.8	0.2	0.8	0.4
72-120	B_{22g}	0.39	1.9	10.0	16.5	19.4	17.5	6.1	4.3	5.3	2.5	1.0	14.0	48.2	33.2	17.5	L	53.4	1.9	0.2	1.6	3.1

TABLE 10 CHEMICAL PROPERTIES OF ROI-ET SERIES.

DEPTH (cm)	pH 1:2.5	EXCHANGE PROPERTIES (me %) H	Ca	Mg	K	Na	T.E.B.	C.E.C SUM	BS (%)	ORGANIC MATTER C x1.72	C (%)	N (%)	C/N
0-13	5.4	2.20	1.00	0.20	0.09	0.53	1.82	4.02	45.3	0.9	0.55	0.04	13.4
13-39	5.6	1.80	1.33	0.28	0.09	0.41	2.11	3.91	54.0	1.0	0.58	0.04	14.5
39-72	5.4	2.55	0.50	0.08	0.09	0.38	1.05	3.60	39.2	0.5	0.27	0.03	9.0
72-120	5.5	4.20	1.20	1.20	0.16	0.45	1.93	6.13	31.5	0.5	0.27	0.03	9.0

TABLE 7 PHYSICAL PROPERITES OF KORAT SERIES

DEPTH (cm)	HORIZON SYMBOL	PARTICLE SIZE DISTRIBUTION (µm)												SAND	SILT	CLAY	TEXTURE	500	SILT	SESQ	H.G.	COAT-
		2000 – 1000	1000 – 500	500 – 200	200 – 100	100 – 50	50 – 20	20 – 10	10 – 5	5 – 2	2 – 1	1 – 0.5	0.5	2000 – 50	50 – 2	/2		– 20 µm	CLAY RATIO	OXIDE (%)	MOIST TURE	ING (%)
0-12	A_1	0.24	2.9	24.6	30.8	19.3	10.8	1.3	1.8	1.8	0.8	1.0	2.5	77.8	15.7	4.3	LOAMY SAND	85.5	8.7	0.2	0.4	–
12-20	A_2	0.15	2.0	20.4	30.1	21.3	18.7	3.5	1.0	2.5	2.0	0.8	2.8	74.0	20.7	5.1	SANDY LOAM	85.5	4.1	0.1	0.2	–
20-70	B_1	0.25	2.4	22.6	30.7	19.6	13.3	2.5	2.0	2.0	0.8	0.8	3.3	75.6	19.8	4.9	"	86.2	4.0	0.2	0.2	–
70-118	B_{21}	0.26	3.0	22.5	28.4	18.2	11.9	4.0	0.3	1.3	1.0	1.5	7.0	72.4	17.5	0.5	"	81.0	1.8	0.1	0.4	0.9
118-140	B_{22}	0.21	2.7	22.1	29.1	19.3	11.3	2.5	0.8	2.5	0.5	0.8	8.8	72.6	17.1	10.1	"	83.0	1.7	0.1	0.5	0.9

TABLE 8 CHEMICAL PROPERTIES OF KORAT SERIES.

DEPTH (cm)	pH 1.25	EXCHANGE PROPERTIES (me %)							BS (%)	ORGANIC MATTER			
		H	Ca	Mg	K	Na	T.E.B	C.E.C SUM		C x1.72	C (%)	N (%)	C/N
0-12	6.1	2.55	1.25	0.25	0.05	0.53	2.08	4.63	44.9	2.8	1.64	0.07	23.4
12-20	6.0	2.40	0.63	0.20	0.05	0.42	1.30	3.70	35.1	1.1	0.65	0.04	16.3
20-70	6.1	2.48	0.50	0.12	0.07	0.44	1.13	3.61	31.3	0.4	0.21	0.04	5.3
70-118	5.8	1.43	0.50	0.27	0.08	0.47	1.32	2.75	48.0	0.4	0.21	0.03	7.0
118-140	5.5	1.43	0.50	0.18	0.08	0.40	1.20	2.33	51.5	0.3	0.15	0.02	7.5

TABLE 11 PHYSICAL PROPERTIES OF RENU SERIES.

DEPTH (cm)	HORIZON SYMBOL	PARTICAL SIZE DISTRIBUTION (μm) 2000-1000	1000-500	500-200	200-100	100-50	50-20	20-10	10-5	5-2	2-1	1-0.5	∠0.5	SAND 2000-50	SILT 50-2	CLAY ∠2	TEXTURE	200-20 μm	SILT: CLAY RATIO	SESQ OXIDE (%)	H.G. MOIST (%)	COAT-ING (%)
0-9	A_1	0.13	0.5	4.3	26.5	29.4	22.7	4.8	2.8	0.5	0.8	0.3	5.8	60.8	30.8	6.9	SL	78.6	4.5	0.3	0.7	–
9-20	A_2	0.26	0.3	3.8	29.2	30.1	19.2	4.3	2.3	1.5	0.8	0.3	7.5	63.7	27.3	8.6	SL	78.5	3.2	0.2	0.5	0.1
20-35	B_1	0.12	0.5	4.0	24.5	25.3	17.3	4.8	1.8	1.0	0.8	0.5	18.5	54.4	24.9	19.8	SL	67.1	1.3	0.3	1.1	0.8
35-57	B_{21}	2.28	0.5	3.6	28.3	24.6	16.7	4.3	2.3	0.1	1.3	0.8	20.3	54.3	23.4	22.4	SCL	64.6	1.0	0.3	1.4	0.6
57-90	B_{22}	0.30	0.5	3.9	21.7	24.4	16.6	3.6	1.8	2.3	0.5	1.0	22.1	50.8	24.3	23.6	SCL	62.7	1.0	0.3	1.6	0.6
90-115	B_{23}	0.67	0.6	2.9	20.3	24.8	19.1	5.1	1.0	2.5	0.5	1.5	20.7	49.3	27.7	22.7	SCL	64.2	1.2	0.3	1.0	0.2

TABLE 12 CHEMICAL PROPERTIES OF RENU SERIES.

DEPTH (cm)	pH 1:2.5	EXCHANGE PROPERTIES (me %) H	Ca	Mg	K	Na	T.E.B	C.E.C SUM.	BS (%)	ORGANIC MATTER C x 1.72	C (%)	N (%)	C/N
0-9	5.6	3.35	0.92	0.46	0.05	0.38	1.81	5.16	35.1	4.0	2.34	0.07	33.4
9-20	5.1	3.00	0.17	0.39	0.08	0.37	1.01	4.01	25.2	1.5	0.85	0.04	21.3
20-35	5.0	4.51	0.10	0.73	0.11	0.58	1.47	5.98	24.5	1.2	0.67	0.04	16.8
35-57	5.0	4.96	0.10	0.74	0.16	0.52	1.52	6.48	23.5	1.1	0.62	0.04	15.5
57-90	5.0	4.96	0.10	0.41	0.09	0.52	1.12	6.08	18.4	0.8	0.47	0.04	11.8
90-115	4.9	4.66	0.10	0.33	0.10	0.70	1.23	5.89	20.9	0.7	0.43	0.04	10.8

TABLE 13 Comparision of the data from the three soils.

Series	Depth (cm)	Sand 500 – 50	Silt 50 – 2	Clay /2 μm	Coating %	pH	H^+ me %	CEC me %	B.S. %	CLAY MINERALS KT	BT	MI	CT
Korat	0-12	74.7	15.7	4.3	-	6.1	2.6	4.6	44.9	D	-	Tr	-
	12-20	71.8	20.7	5.1	-	6.0	2.4	3.7	35.1	D	-	Tr	-
	20-70	72.9	19.8	4.9	-	6.1	2.5	8.6	31.3	D	Tr	Tr	-
	70-118	69.1	17.5	9.5	0.9	5.8	1.4	2.8	48.0	D	Tr	Tr	-
	118-140	69.7	17.1	10.1	0.9	5.5	1.4	3.3	51.5	D	Tr	Tr	-
Roi-Et	0-13	54.9	39.2	4.1	-	5.4	2.2	4.0	45.8	D	S	Tr	-
	13-39	51.0	36.4	9.3	0.2	5.6	1.8	3.9	54.0	D	S	Tr	-
	39-72	50.8	33.4	11.9	0.4	5.4	2.6	3.6	29.2	D	S	Tr	-
	72-120	45.9	33.2	17.5	3.1	5.5	4.2	6.1	31.5	D	S	Tr	-
Renu	0-9	60.2	30.8	6.9	-	5.6	3.4	5.2	35.1	D	S	Tr	-
	9-20	63.1	27.3	8.6	0.1	5.1	3.0	4.0	25.2	D	S	Tr	Tr
	20-35	53.8	24.9	19.8	0.8	5.0	4.5	6.0	24.5	D	S	Tr	Tr
	35-57	51.5	23.4	22.4	0.6	5.0	5.0	6.5	23.5	D	S	Tr	Tr
	57-90	50.0	24.8	23.6	0.6	5.0	5.0	6.1	18.4	D	S	Tr	Tr
	90-115	48.0	27.7	27.7	0.2	4.9	4.7	5.9	20.9	D	S	Tr	Tr

D = dominant S = small amount Tr = trace

Fig.2. X-RAY ANALYSIS OF KORAT SERIES

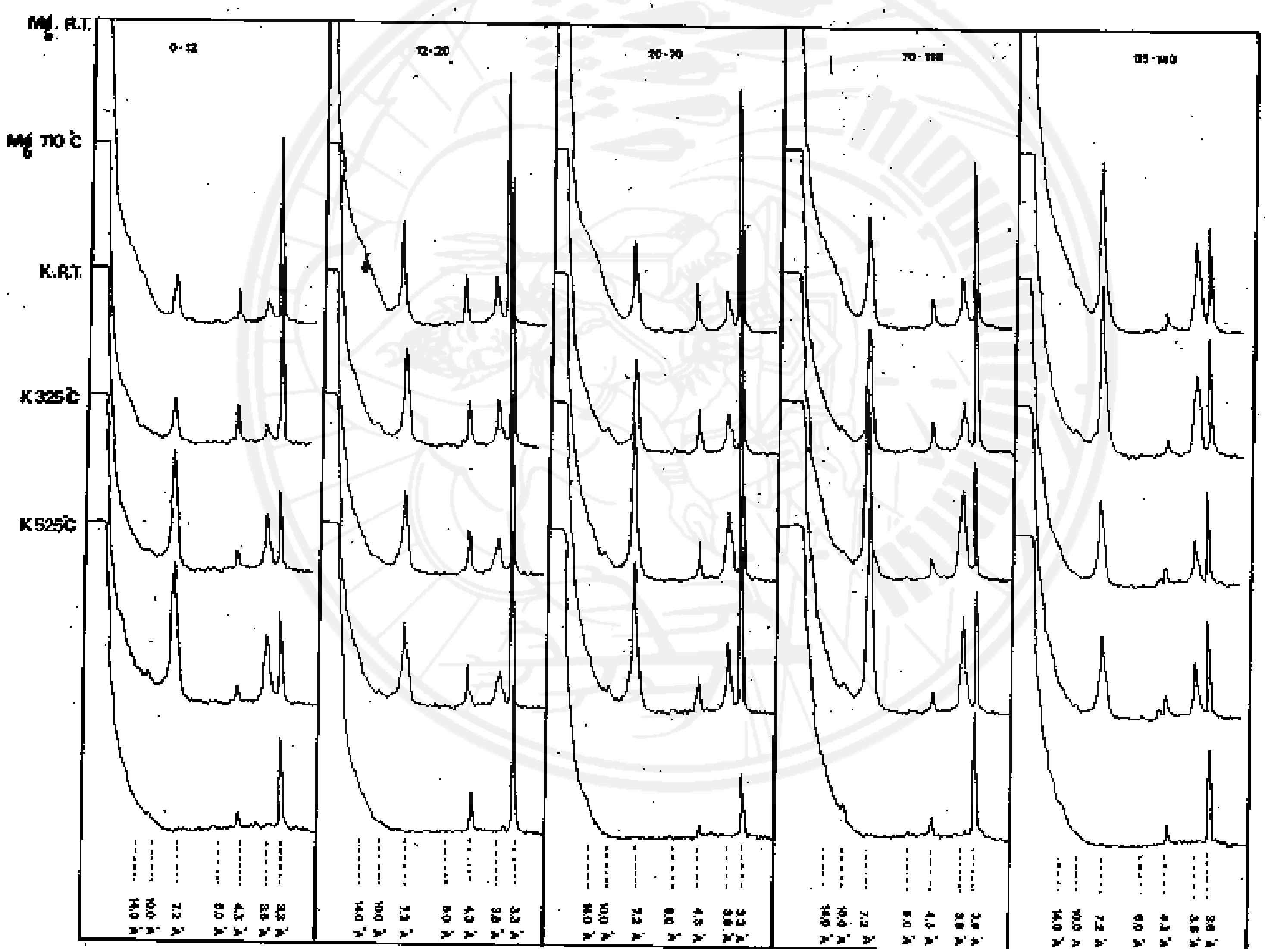


Fig 1. Topography of the Study area, Khon Kaen province. (Scale 1 : 750,000)

Fig. 4 X-RAY ANALYSIS OF RENU SERIES

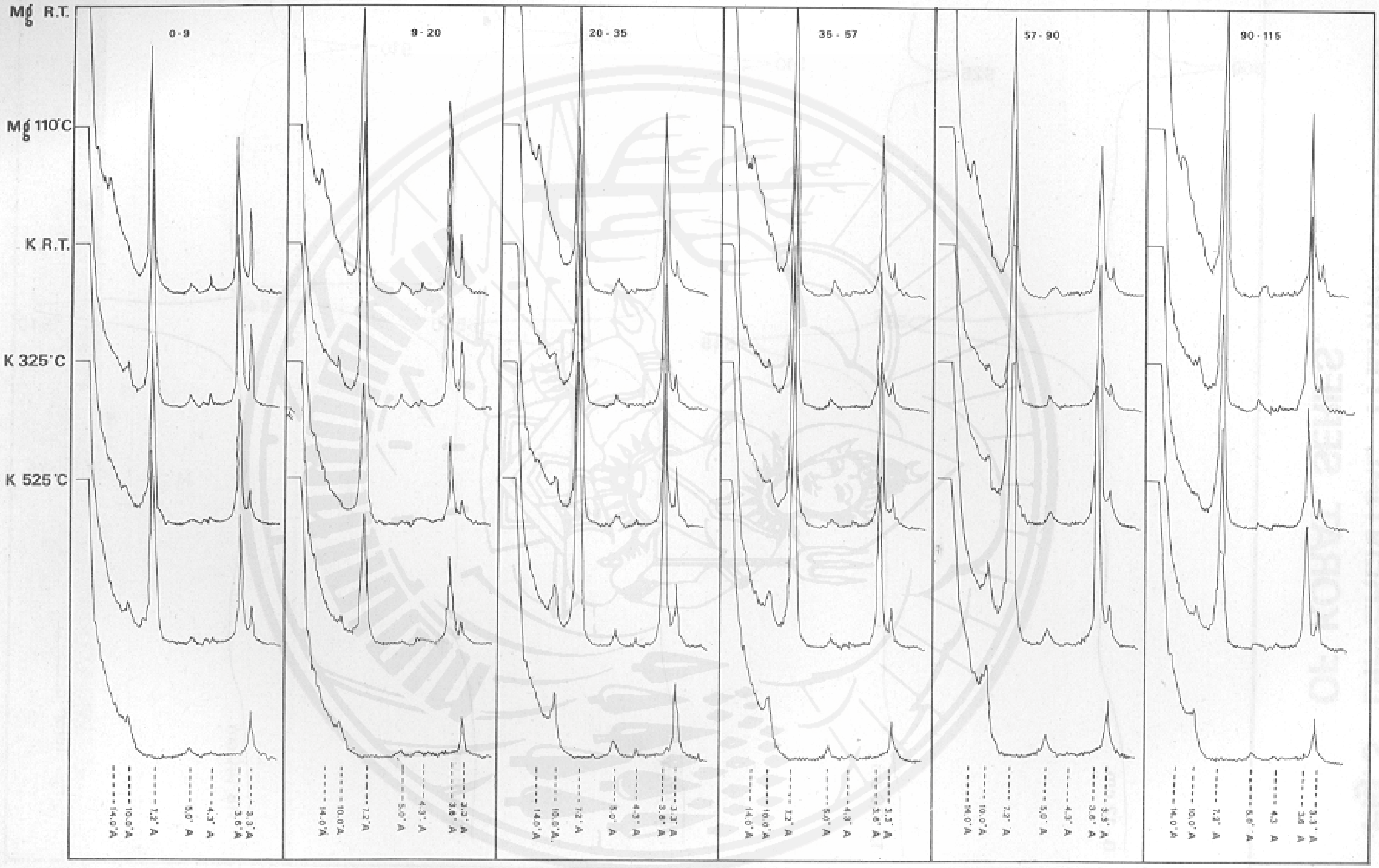


Fig.5 DIFFERENTIAL THERMAL ANALYSIS OF RENU SERIES.

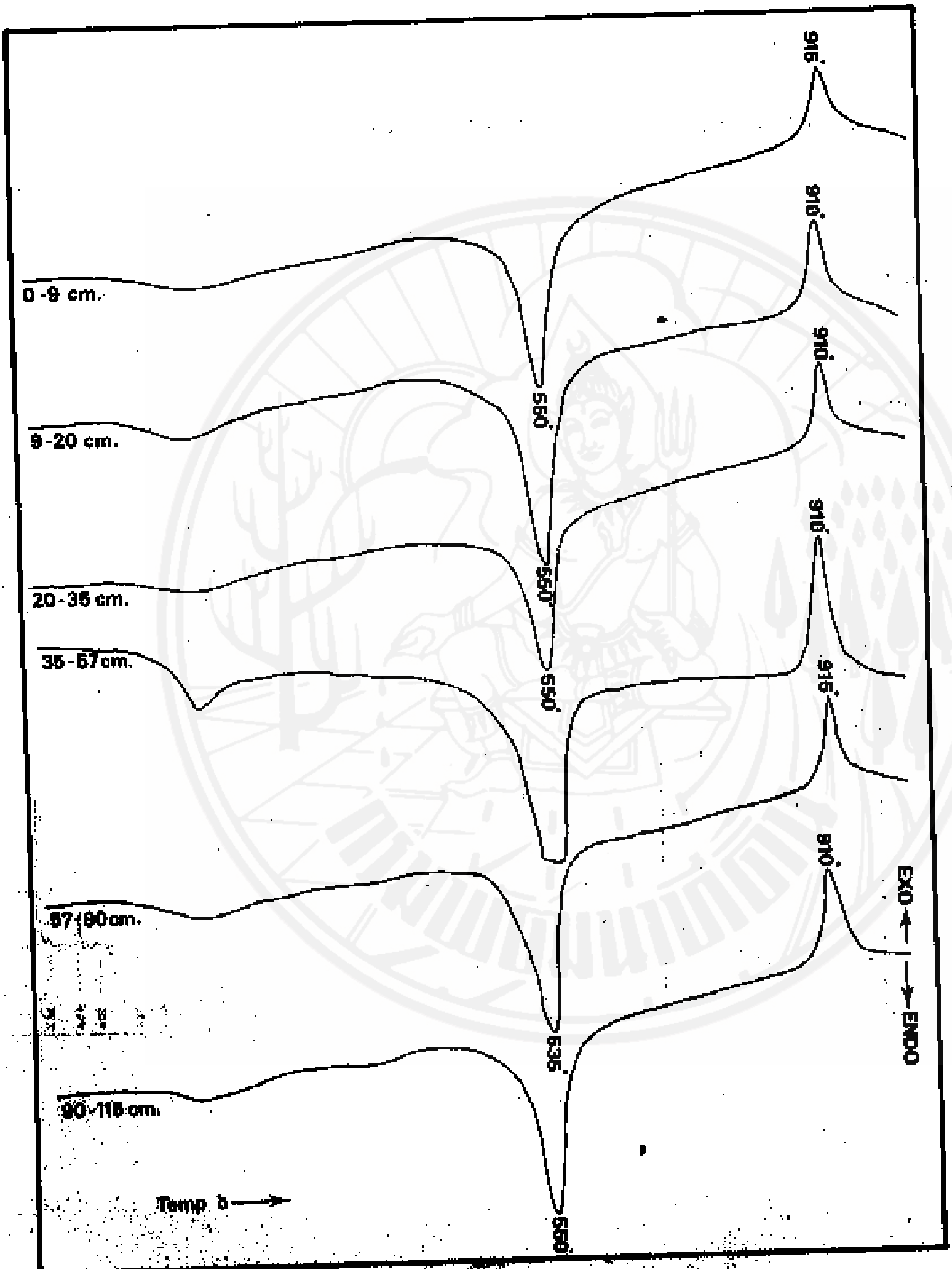


Fig.6 X-RAY ANALYSIS OF ROI-ET SERIES.

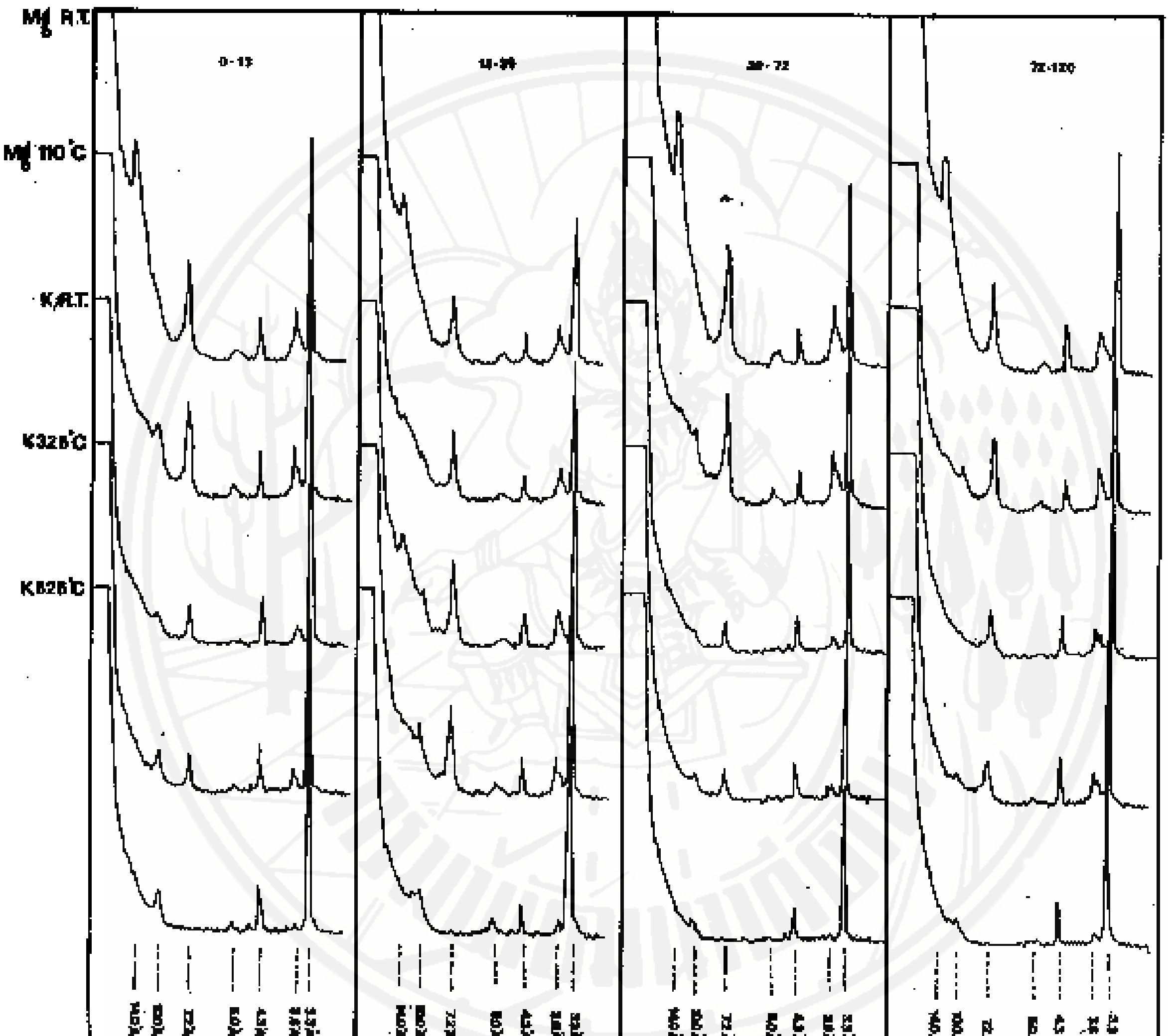
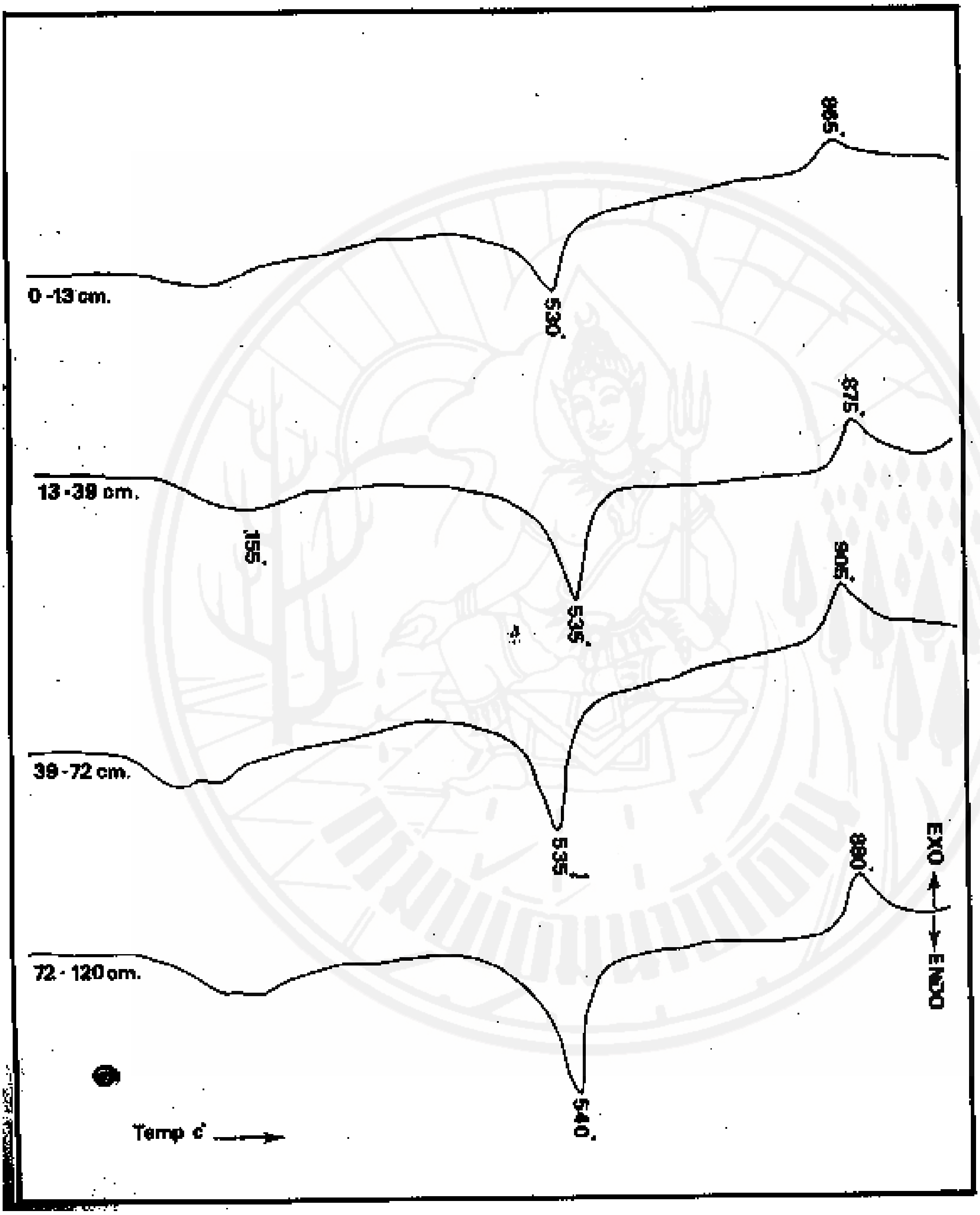


Fig.7 DIFFERNTIAL THERMAL ANALYSIS OF ROI-ET SERIES



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