REPORT ON THE MINERALOGY AND MICROMORPHOLOGY OF THE SOILS
OF SANDAKAN, SABAH, MALAYSIA

BY

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Rozier 44, Gent, Belgium

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- The Department of Agriculture, Sabah, Malaysia
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ACKNOWLEDGEMENTS

THE MINERALOGY AND MICROMORPHOLOGY OF SOME
SOILS FROM SANDAKAN, SABAH, MALAYSIA

1. INTRODUCTION

This report comprises the mineralogy and micromorphology of soils derived from mudstones and sandstones in Sandakan, Sabah, Malaysia. The soil survey of the area has been done by Mr.C. FOLLAND and B.D. ACRES of the Land Resources Division of England for the Government of Sabah. The draft report of the soil survey has been published by the Land Resources Division (FOLLAND and ACRES, 1972).

In September 1970, we had the opportunity to visit the area. We were accompanied by Mr. C. FOLLAND, and Mr. T. LAMB, manager of the oil-palm station at Ulu Dusun. One of the questions for which we were requested to provide laboratory data is, if clay had been translocated in some of these soils. For this reason, Mr. C. FOLLAND sent us undisturbed samples in Kubiena boxes in 1971. The soils as mentionned before are derived from sandstones and mudstones or alluvium thereof. The soils, especially in the lower parts of the landscape, are subject to moisture saturation in some parts of the year. Consequently it was felt that the clay mineralogy and the clay mineral status as a function of drainage would be an interesting study.

Consequent to the field study, a preliminary report of the soils was made in October 1970 by SYS. This mimeographed report gave profile description, classification according to the 7th Approximation and some comments on the profiles studied.

All the analysis of these soils have been performed in the laboratories of the Geological Institute, University of Gent, except when indicated. The profile descriptions and data of the routine physico-chemical analysis are given in Appendix I.

11. Physiography

As more information is given by FOLLAND and ACRES
(1972) in their report on the soil survey of the area, the physio-
graphic conditions will be summarised here. Much of the informa-
tion presented here has been extracted from their report.

The soils are formed on deposits which have been termed
geologically as the Tanjong formation. According to FOLLAND and
ACRES (1972), the formation originated under largely neritic
conditions during the late Miocene. It forms topographically rugged,
subcircular synclinal basins notably in the catchment of the
Kuamut River. The formation consists of mudstone and siltstone
with prominent but generally subordinate beds of sandstone.

During the Survey, FOLLAND and ACRES have recognised
thirteen Soil Associations on this or similar parent material.
The two associations considered in the present study are firstly
the Silabukan Association formed on mudstones and Meliau Associa-
tion on sandstone. The soils of the Silabukan Association are
dominantly Tropudults, ranging from Aquic to Typic subgroups. In
depressions Aquepts may also be present. In the Meliau association
Tropudults ranging from Typic to Oxic and Haplorthods are present.

The climate of the area is uniformly hot and wet. Accor-
ding to the Köppen Classification, the climate is of "Af" or the
Tropical Rainy Type. The climatic data for two stations in the
area is given in table 1. With respect to precipitation, data is
given on total rainfall, evaporation and net loss or gain which
is the difference between the two. Total annual rainfall is high,
being more than 3,100 mm. and no month receives less than 100 mm.
rain. In the "winter"months (October to March), each month receives
more rain than losses by evaporation. In the "summer" months,
evaporation is just equal to or greater than precipitation in
Sandakan. A lesser difference is seen in Ulu Dusun. The differences
between rainfall and losses will become more marked when evapo-
transpiration is considered instead of evaporation alone.

the mean annual soil temperature at these stations is
... . Soil temperatures have also been recorded at Sandakan
... times have been specifically included here because such data
are not usually available. Note that the mean annual soil
temperature is about 1°C higher than mean annual air temperature
and this agrees with similar measurements in other parts of the
Tropics. The mean winter soil temperature (May) is 28°C and
mean summer, 29.4°C and the difference is 1.5°C. At 1.2 m., the
winter soil temperature is 28.9°C and mean summer is 30.3 with a
difference of 1.2°C. This small difference (< 5°C) is characteris-
tic for tropical soils.

With respect to the 5th approximation, the temperature
regime in the area is isohyperthermic. The moisture regime is
Udic though it might be tending towards Ustic...

12. Soils on mudstones and sandstones.

In their short report FOLLAND and ACRES have described
and analysed more than fifty profiles on mudstones and sandstones.
These results together contain an enormous amount of information on such
parent materials and will indicate the range of properties of such
soils. The comparison will in some cases be made with the objective
of providing a base for the new profiles that have been studied
in greater detail in this report.

In these mudstone and ... profiles the texture of the soil
depends on if the profiles are derived from mudstone or sandstone
and to what extent they are mixtures of one by the other. The clay content
varies from 20 to 60% in the ... horizon of these profiles.

Mineralogically, the cation exchange capacity is high,
ranging from 20 to 40 m.e. per 100 g. Consequently there
are no Oxisols and Oxic subgroups are rare. The high CEC indicates
the presence of 2:1 lattice clays which is confirmed by some clay

Mean or total	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
SANDAKAN												
Rainfall (cm) 312.7	46.7	25.2	20.1	11.9	15.0	19.1	18.3	22.1	24.6	26.7	36.8	47.0
Evaporation (cm) 188.0	13.5	14.2	19.1	20.1	18.3	16.8	16.0	16.3	16.5	14.5	12.2	10.2
Net (cm) +124.7	+33.2	+12.0	+1.0	-8.2	-3.3	+2.3	+2.3	+5.8	+8.1	+10.2	+20.1	+36.8
Temper. (°C) 26.7	26.1	26.1	26.7	26.7	27.8	27.2	27.2	27.2	27.2	27.2	26.7	26.1
Soil Temp.												
At 30-5 cm 28.9	27.2	27.2	28.9	30.0	30.0	29.4	28.9	28.9	28.9	28.9	28.3	27.8
At 120 cm 29.4	28.3	28.3	29.4	30.6	30.6	30.6	30.0	30.0	30.0	30.0	29.4	28.9
ULU DUSUN												
Rainfall (cm) 327.7	46.7	28.4	18.3	14.2	25.7	26.9	15.5	25.9	26.4	23.4	32.0	52.8
Evaporation (cm) 177.6	10.9	10.2	13.5	14.0	18.3	17.5	15.7	17.3	17.5	16.8	13.2	12.2
Net (cm) 150.1	+35.8	+18.2	+4.8	+0.2	+7.4	+9.4	-0.2	+8.6	+8.9	+6.6	+18.3	+40.6
Temp. (°C) 26.7	25.6	26.1	26.1	26.7	26.7	26.7	26.7	26.7	26.7	26.7	26.1	26.1

Table 1 - Climatic data for Sandakan and Ulu Dusun and Soil Temperature data for Sandakan (After FOLLAND and ACRES, 1972).

The mean annual air temperature in both stations is
28.7°C. Soil temperatures have also been recorded at Sandakan
and these have been specifically included here because such data
are not usually available. It is seen that the mean annual soil
temperature is about 1°C higher than mean annual air temperature
and this agrees with similar measurements in other parts of the
Tropics. The mean winter soil temperature at 30 cm is 28°C and
mean summer, 29,4°C and the difference is 1,3°C. At 1,2 m., the
winter soil temperature is 29,1°C and mean summer is 30,3 with a
difference of 1,2°C. This small difference (< 5°C) is characteris-
tic for tropical soils.

With respect to the 7th Approximation, the temperature
regime in the area is isohyperthermic. The moisture regime is
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12. Soils on mudstones and sandstones

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These results provide an enormous amount of information on such
parent materials and will indicate the range of properties of such
soils. The properties will be summarised here with the objective
of providing a base for the few profiles that have been studied
in greater detail in this report.

In the autotochtonous profiles the texture of the soil
depends on if the profiles are derived from mudstone or sandstone
and the extent of the mixture of one by the other. The clay content
varies from 20 to 60% in the "C" horizon of these profiles.

Characteristically, the cation exchange capacity is high,
ranging from 20 to 100 m.eq. per 100 g. clay. Consequently there
are no Oxisols and Oxic subgroups are rare. The high CEC indicates
the presence of 2:1 silicate clays which is confirmed by some clay

analysis provided by FOLLAND and ACRES. The base saturation is
essentially a function of the internal drainage of the soils in
this Udic moisture regime. The well drained profiles have a base
saturation of less than 35% and when such soils have an argillic
horizon, they qualify for the Order of Ultisols. With imperfect
drainage conditions, the base saturation reaches very high levels
and in some cases the substratum is saturated. Considering the
exchangeable cations in the latter soils, the most striking feature
is the high amount of magnesium which in some of the wetter profiles
approaches the level of the CEC.

The soils developed on these parent materials can be
classified as follows :

On coarse textured parent materials, under well drained
conditions, soil formation leads to a Spodosol-Orthod. Such profile
development is confined to flat landscapes on the summit of hills.
On more undulating landscapes and on parent materials with similar
or higher clay contents, Tropudults belonging to typic or oxic
subgroups are present.

On heavier parent materials under well drained condi-
tions, the typical profile is a Typic Tropudult. When drainage con-
ditions are interfered by a heavier substratum or because of the
physiographic position, Tropudalfs results. The subgroups are
Typic, Aquic or Fluventic. When imperfect drainage conditions pre-
vail, the normal profile is a Tropaquept frequantly belonging to
Fluventic subgroups.

2. METHODS

The routine physico-chemical analysis has been done according to conventional methods. For the clay separation, 50 g. of soil is first treated with 30% H_2O_2 to remove the organic matter. This is not the ideal method for soils with illite as detrimental effects on the clay minerals as a result of hydrogen peroxide treatment has been indicated in literature. For example, a peak shift to 12.5 Å from the 10 Å of illite has been shown when pure illite was treated with H_2O_2. This is a significant change and consequently misinterpretation of the original clay composition results. In the absence of a better method to remove organic matter, this limitation has to be accepted.

After organic matter removal, the clay is dispersed with a 2% solution of sodium carbonate (pH 9,5) in a litre beaker. Eight centimeters of the suspension is siphoned off after 8,5 hours into another beaker and the suspension in the latter is flocculated with a 2% solution of HCl (pH 4,5). This process is repeated until all the clay is removed. When platy minerals (muscovite) are present in the soil, a large source of error exists. These minerals do not obey Stoke's law and consequently silt size micas are indvertantly siphoned off as the clay (<2µ) fraction. Clear evidences for this will be provided later with electron microsopic studies.

After clay separation, a X-ray diffractogram is run on the untreated clay. This is mainly to establish the presence of iron minerals. The hydrogen peroxide treatment has solubilized all manganese minerals and so the presence of these are seldom reported. Nevertheless, if present they are expected to be only in traces.

The clay is then subject to a citrate - dithionite - bicarbonate treatment (MEHRA and JACKSON, 1964) to remove the free iron. It has to be noted that as dithionite is a strong reducer, minerals which contain iron in the lattice are attacked by the treatment with a concomitant change in crystalographic properties. The treatment however is necessary to remove the iron minerals (especially amorphous) which cause poor orientation of the silicate clays and due to their coating on these silicate clays reduce the diffraction intensity. After the removal of the iron, the clays are saturated with K and Mg in order to identify the 14 Å minerals. The criteria employed are :

	K saturated		Magnesium saturated	
	Normal	Heated 550°	Normal	Glycerol solvated
Montmoril-lionite	14	10	14	18
Vermiculite	10	10	14	14
Chlorite	14	14	14	14

Both the untreated and iron-free clays are studied with the electron microscope, the former to observe the iron minerals and the latter for the alumino-silicate minerals.

Differential-thermal analysis and thermogravimetric analysis are also performed on the untreated clays. Total analysis has been performed on the untreated clays.

Cation-exchange capacity of some of the clays were performed in two ways. First by saturating with Ca and determining the absorbed calcium by exchanging it with ammonium. This gives an estimate of the actual CEC. A separate sample is saturated with K and after washing off the excess K, the clay is dried at 110°C overnight. If vermiculite is present, this fixes the K.

The following day, K saturated sample is leached with ammonium
and the K that is replaced is determined. The difference in
CEC_{ca} and CEC_k gives an estimate of the vermiculite content which
is calculated assuming vermiculute has a CEC of 150 m.eq. per
100 g.

Based on the above analysis, a normative calculation
can be made of the clays.

(a) Vermiculite is determined as explained above.

(b) Illite is determined by allocating all the K_2O to
illite assuming illite has 10% K_2O.

(c) Kaolinite is determined by allocating the water loss
from 350 to 550°C assuming kaolinite loses 14% water.

(d) The amounts of SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O and H_2O
used up by these minerals is determined by the
compositions given below and this is substracted
from the total analysis.

	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	H_2O	CEC
Vermiculite	36.7	14.2	4.4	24.6	-	11.0	150
Illite	51.2	25.9	6.5	0.2	10.0	7.5	30
Kaolinite	46.5	39.5	-	-	-	14	6
Montmoril-lonite	64.0	22.7	-	-	-	7.0	90
Al chlorite	25.1	56.7	-	-	-	14.0	70
Lepidocrocite	-	-	90.0	-	-	10	-
Goethite	-	-	90.0	-	-	10	-
Quartz	100	-	-	-	-	-	-

(e) The remaining alumina is allocated to montmorillonite
assuming it has 22.7% alumina. The silica for this
amount of montmorillionite is calculated and sub-
tracted.

(f) The remaining silica is allocated as quartz.

(g) If chlorite is present, the water loss from 550°-1,000°C is employed and chlorite is calculated based on 14% H_2O. This is done prior to the montmorillionite determination.

(h) Lepidocrocite or goethite is calculated based on 90% Fe_2O_3 employing the iron left over after the silicate clays have been calculated.

These normative calculations are only estimates and because of the number of assumptions made, their closeness to the mode is questionable. The accuracy of the calculations is determined in the following way.

(a) The total composition should approach 100.

(b) The CEC of the minerals calculated can be added up to give the CEC of the clay and this should resemble the measured CEC. Complete agreement is an accident as normative CEC's are employed to calculate the total CEC e.g. the CEC of montmorillomite is based on 90 m.eq. though the species that is present may have a CEC which is much higher or lower.

Both the calculated CEC and the measured CEC are given later in the text. A simple linear regression was performed on the two sets of data comprising fifteen samples. The coefficient of correlation obtained is 0.9165[***] and is highly significant indicating that the results of the estimates approximate the modal composition.

For the micromorphological study, thin-sections were made from undisturbed samples taken in kubiena's boxes. The sections have been described using the terminology of BREWER (1964).

3. THE PROFILES STUDIED

The profile descriptions and the routine physico-
chemical analysis are given in Appendix I. Only five profiles
are included in this report. Profiles SAN 13, 10 and 11 are
believed to be derieved from a parent material where mudstone is
the dominant component whilst in profiles SAN 14 and 16, sandstone
forms the dominant component. Profile SAN 13 is a Fluventic
Tropaquept whilst SAN 10 and 11 are Typic Tropudult. Profile
SAN 14 is a Typic Tropudult whilst SAN 16 is a Troporthod.

The total analysis of the clay fraction together with
free iron content of the clay and CEC determination is also given
in the appendix. For convenience the data of the semi-quantitative
estimates of the clays are given together in table 2.

31. Profile SAN 13

311. Physico-chemical properties

The soil has about 30% clay, 60% silt and 10% sand. The
fluventic nature of the profile is indicated by the irregular
distribution of organic matter. CEC of the soil is high and when
calculated to 100 g. clay, the value decreases from 57 m.eq. in
the surface horizon to 44 m.eq. in the cambic horizon. The base
saturation is very high; in the cambic horizon it is 77% when
based on the NH_4OAc CEC and 59% when based on the sum of cations.
Both Ca and Mg are the dominant cations.

312. Clay mineralogy

Fig. 1, gives the X-ray diffractogram of the untreated
clays of profile SAN 13. The clays were also studied by X-ray
analysis after deferrification and K and Mg saturation. The most
interesting feature in fig. 1, is the peak for lepidocrocite at
6.24 Å. There seems to be a relative increase with depth as

Fig. 1 - X-ray diffractogram
of untreated clay
of profile SAN 13.

Fig. 1 - X-ray diffractogram of untreated clay of profile SAN 13.
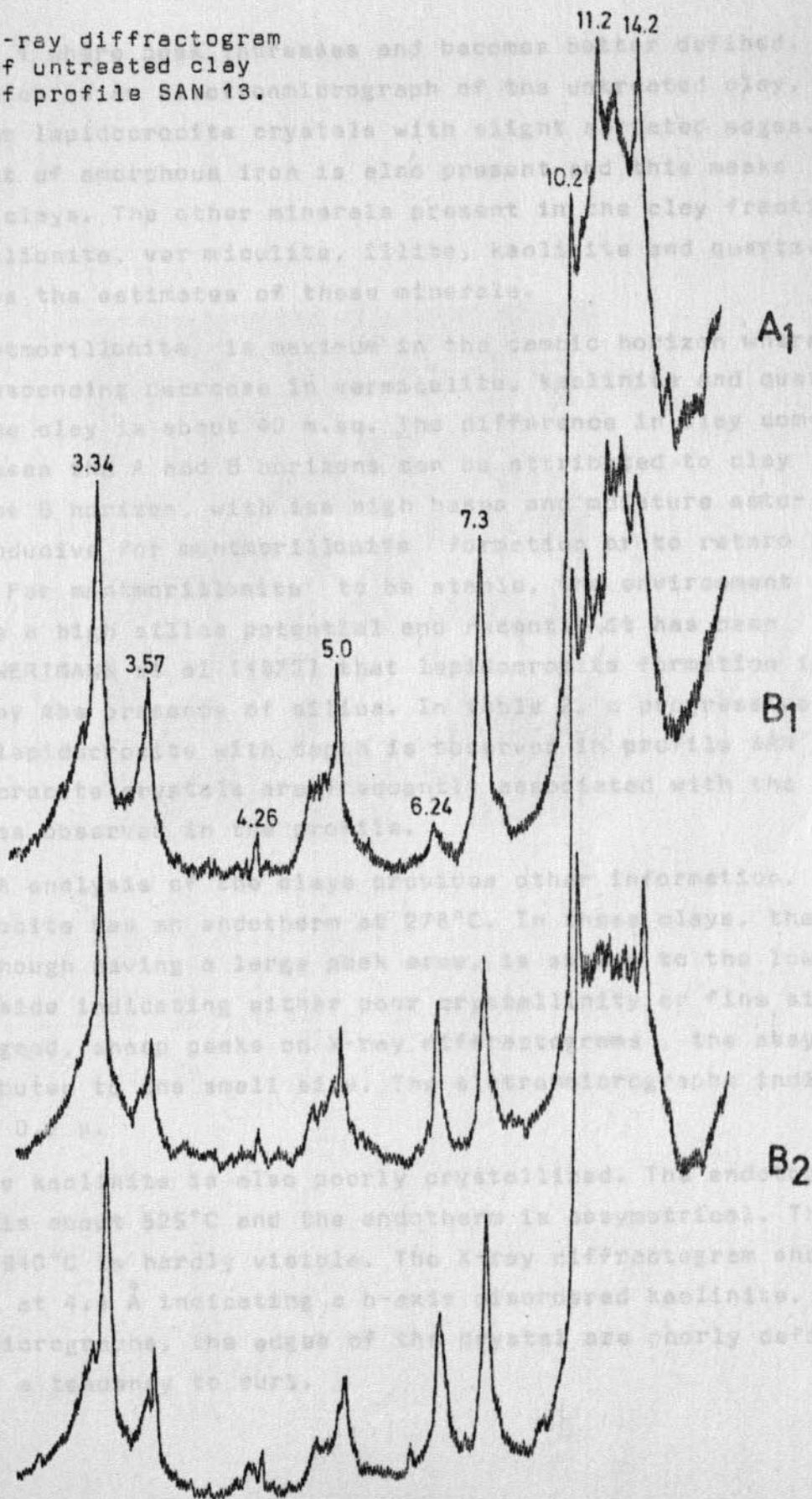
shown by fig. 1 where peak increases and becomes better defined.
In fig. 2, which is an electronmicrograph of the untreated clay,
the lenticular lepidocrocite crystals with slight serrated edges.
A large amount of amorphous iron is also present and this masks
the silicate clays. The other minerals present in the clay fraction
are montmorillionite, ver miculite, illite, kaolinite and quartz.
Table 2, gives the estimates of these minerals.

Montmorillonite is maximum in the cambic horizon where
there a corresponding decrease in vermiculite, kaolinite and quartz.
The CEC of the clay is about 40 m.eq. The difference in clay com-
position between the A and B horizons can be attributed to clay
formation. The B horizon, with its high bases and moisture satu-
ration is conducive for montmorillonite formation or to retard its
destruction. For montmorillonite to be stable, the environment
needs to have a high silica potential and recently it has been
shown by SCHWERTMANN et al (1972) that lepidocrocite formation is
accelerated by the presence of silica. In table 2, a progressive
increase of lepidocrocite with depth is observed in profile SAN 13.
These lepidocrocite crystals are frequently associated with the
orange mottles observed in the profile.

DTA analysis of the clays provides other information.
The lepidocrocite has an endotherm at 278°C. In these clays, the
endotherm, though having a large peak area, is skewed to the low
temperature side indicating either poor crystallinity or fine size.
As it gives good, sharp peaks on X-ray diffractograms , the assyme-
try is attributed to the small size. The elctronmicrographs indica-
te a size of 0.2 µ.

The kaolinite is also poorly crystallized. The endothermic
temperature is about 525°C and the endotherm is assymetrical. The
exotherm at 940°C is hardly visible. The X-ray diffractogram shows
a broad peak at 4.4 Å indicating a b-axis disordered kaolinite.
In electronmicrographs, the edges of the crystal are poorly defined
and there is a tendency to curl.

Fig. 2 - Electronmicrograph of untreated clay
of profile SAN 13. Note the lepidocrocite
crystals in the centre of the picture and
the high amount of amorphous iron which
masks the silicate clays.
× 35,000.

Profile Horizon	Mont-morillonite	Vermi-culite	Illite	Chlorite	Kaolinite	Quartz	Gibbsite	Lepido-crocite	Amorphous or Goethite	Calculated C.E.C.	Measured C.E.C.
Profile SAN 13											
A1	25.3	10.1	26.0		20.0	10.2		6.0	+	44.4	46.6
A12	14.4	10.1	27.5		27.0	12.3		9.0	+	36.7	40.6
B2g	31.2	6.2	26.5		21.4	2.4		13.6	+	44.0	38.4
Profile SAN 10											
A3	26.6	8.7	26.3		25.7	1.0		9.1	+	43.8	34.9
B2t	27.7	6.2	26.0		27.1	2.6		9.4	+	41.1	30.9
Profile SAN 11											
A1	17.1	10.2	26.5		27.1	10.7			7.4(A)	37.5	37.8
A3	16.7	8.4	25.7		27.1	8.4			9.4(A)	34.4	35.3
B1	18.2	7.6	27.3		25.7	7.7			9.2(A)	36.6	34.0
B2t	22.6	9.0	26.0		25.7	7.2			8.8(A)	42.8	43.4
B3g	12.1	10.4	28.6		27.1	7.2			8.6(A)	35.1	37.8
Profile SAN 14											
A3	–	3.9	3.5	11.3	62.1		18.3		7.2(A)	18.2	20.2
B2t1	–	+	+	+	+		+		+	+	
B2t2	–	3.9	5.1	10.9	54.3		12.0		10.9(A)	17.8	22.2
Profile SAN 16											
B2h	–	3.6	1.0	10.0	56.4		15.3		10.0(A)	16.0	17.6
B2ox1	–	+	+	+	+		+		+(G)	+	
B2ox2	–	3.2	2.8	10.8	60.8		10.7		7.6(G)	16.6	17.9

Table 2 - Composition of the clays. (+) indicates the presence of the mineral but no estimates have been made

The montmorillinonite, vermiculite and illite are well crystallised. The vermiculite shows little evidence of interlayering by aluminum. There is an immediate collapase to 10 Å upon K saturation.

The mineral association comprising the clay fraction gives it a high silica - alumina ratio - greater than 3.5.

313. Micromorphology

The one common feature present throughout the profile with a maximum in the Cambic horizon is the sesquioxide enrichment. The enrichement is in two forms : (a) as discrete nodules and (b) as diffusion features. Both these are genetically related features as will be discussed below. The diffusion features are mainly in the Cambic horizon.

Due to the moisture saturation of the profile, perhaps for extended periods of time, iron is mobilised. The mobilised iron diffuses into the matrix of the soil material and in the thin sections the diffusion is seen to proceed from the void wall into the S-matrix. Frequently the zone closest to the void wall is bright red and further away it is orange to yellow. Parts of the S-matrix are pale being iron deficient; this is further evidence that iron has been translocated.

The S-matrix, especially in A horizon is not homogenous, i.e., the grains are not uniformly spread out. Consequently there are pockets of areas where the matrix is composed only of plasma or plasma and silt. These pockets form the matrix for the development of nodules. When the soil material dries out, these plasma rich pockets retain the water enriched with iron for longer periods than the coarser parts of the S-matrix.

At a later stage, the iron in these pockets is oxidised
and precipitates as amorphous iron oxyhydrates. Due to this process,
the nodules do not have a well defined boundary or size. All sizes
are present and they are generally diffuse nodules. Growth of these
by accretion results in the coalition of adjoining nodules to
give large diffuse features. Void diffusion ferrans are also
created by plant roots. As the zone immediately around a living
root is an oxidising medium, precipitation of iron takes place.
These ferrans, subcutanic or quasicutanic to voids are also common
features.

All these sesquioxidic features decribed above are
characteristic for soils with periodic moisture saturation. If
such soils are drained, the sesquioxidic nodules are preserved
and will indicate the history of the soil.

The clay mineralogical study showed the presence of
lepidocrocite. It has been indicated in literature that this iron
mineral is confined to the orange mottles present in these profiles.

Drying and wetting of the profile induces stresses in the
soil. These show up as stress oriented features in thin-sections.
The structural elements observed in the field are partly a conse-
quence of the stress. The plasma separations are best expressed
in the Cambic horizon where the structural elements are also the
most developed. In the thin-sections, the iron defecient parts of
the S-matrix show up the stress features better than the enriched
parts as in the latter the iron tends to mask the oriented domains.

The other pedological process that can be evaluated from
thin-sections is the translocation of clay. Fig. 3 is a micrograph
of the Cambic-horizon. The voids show a thin-lining of illuviation
argillans. The diffusion ferrans and nodules are opaque and so are
not evident in the figure.
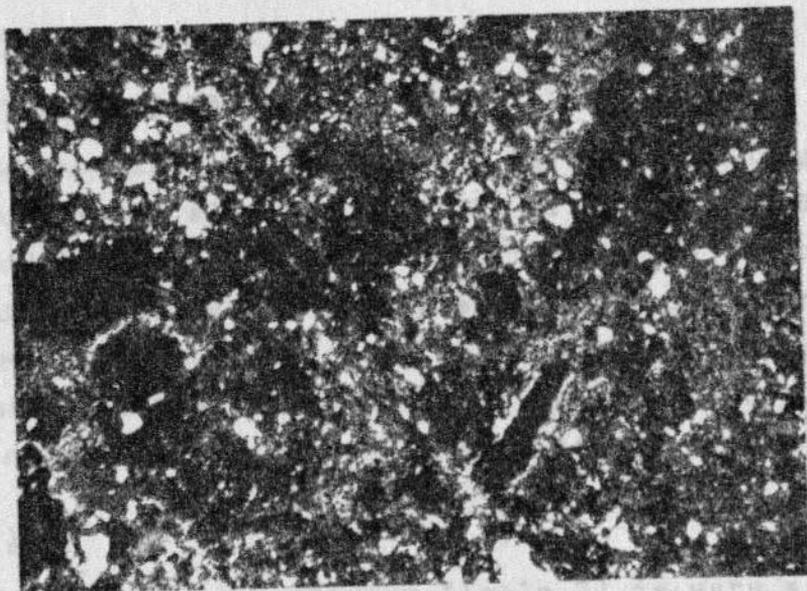
Fig. 3 - Profile SAN 13 (B) horizon. X 80 C.N.
Argillans are present in the ortho-vughs.
They are generally poorly developed and
occur as a thin lining to the voids.

In conclusion, the basic micromorphological features are (a) The various iron forms (b) a heterogenous S-matrix (c) minor amounts of translocated clay (d) strongly expressed stress features. All these features suggest a recent stage in the evolution of the soil. One of the most indicative feature is the plasmic fabric (ESWARAN, 1972). With progress in soil formation, the expression of the plasmic fabric is lost. The strongly expressed plasmic fabric is attributed to (a) stresses in the soil (b) dominance of 2:1 clays (c) low amounts of free iron.

32. Profile SAN 10

321. Physico-chemical analysis

Only two horizons were available for study. The granulometric composition varies slightly from the previous profile in having higher sand and less silt content. The profile is more acid, being better drained, and CEC and base saturation are significantly lesser. CEC by NH_4OAc is about 12 m.eq. and by sum of cations about 15. Calcium forms the dominant base. The B horizon just meets the clay increase required for an argillic horizon.

322. Clay mineralogy

The clay mineral composition (Table 2) is vary similar to profile SAN 13. The differences are mainly in details. All the iron not in the lattice of the silicate minerals has been employed to calculate the normative lepidocrocite content which gives a figure of 9%. However, the DTA indicates a poorly defined endotherm indicating only small amounts and a similar picture emerges from X-ray diffraction studies. A conservative estimate is 2% lepidocrocite and 7% amorphous iron. In normative calculations it is not possible to distinguish between the two.

The kaolinite is better crystallised in this profile
as is evidenced by the better developed endotherm and exotherm
in DTA analysis. It has to be stated, however, that the crystal-
linity is low. The measured CEC of the clays (table 2) is lower
than profile SAN 13. This profile shows the maximum discrepency
between the calculated CEC and measured CEC. As a standard proce-
dure has been adopted in this normative allocations, one source
of error will be the presence of amorphous alumino-silicates which
cannot be detected and which has not been allocated for in this
calculation. Comparing the calculated and measured CEC and after
studying the other analysis of these clays, it is evident that
the error lies in the allocated montmorillionite content which is
too high. Part of the silica and alumina allocated to montmoril-
lionite should go to amorphous alumino-silicates if they can be
shown to be present.

323. Micromorphology

Compared to the previous profile (SAN 13), this profile
has slightly more plasma and the grains are of similar shapes
and sizes. There is a more homogenous distribution of the grains
in the S-matrix. The plasma, in the surface horizons, is uniform
yellowish brown in colour and plasma separations are less well
expressed.

The most significant pedological feature is the abundant
amount of illoviation argillans. These are bright yellow, second
order interference colours, generally thick and well oriented.
They are present in vughs of all sizes. Fig. 4 shows such an argil-
lan filling up almost completely a void. These are evidences for
very strong clay translocation processes in this soil.

Collapse of voids with the argillans results in the
argillans becoming incorporated into the S-matrix of the soil.
This suggests a small internal dynamics in the profile. The small
amounts of swelling mineral present in the clay fraction could be
responsible for the stresses experienced by the soil mass.

In the lower part of the profile, a few diffuse, iron
nodules and diffusion patterns are present. These features resemble
those in profile SAN 13 but in a much smaller scale. This again
indicates that the soil material at some depth accompanies some
moisture saturation.
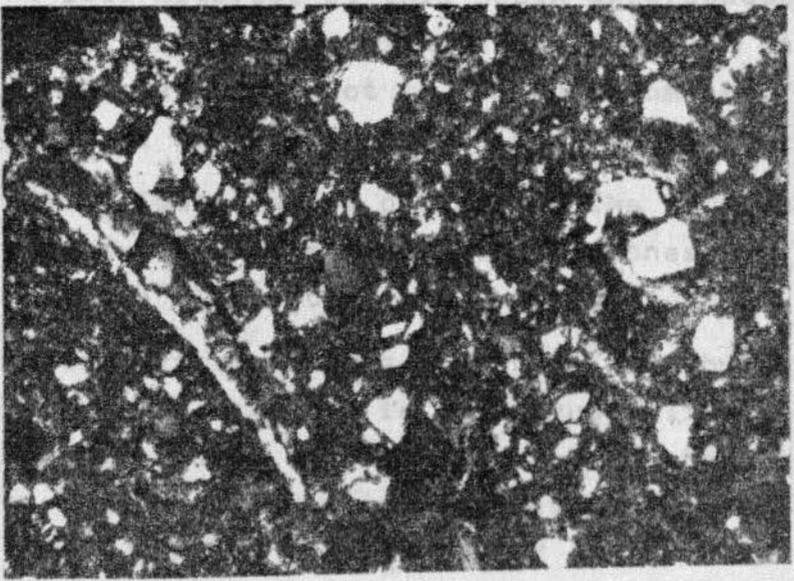
Fig. 4.- Profile SAN 10. B$_2$t horizon. X 80 C.N.
Photo shows a void (on the left) almost
completely infilled with translocated clay.

Collapse of voids with the argillans results in the argillans becoming incorporated into the S-matrix of the soil. This suggests a small internal dynamism in the profile. The small amounts of swelling mineral present in the clay fraction could be responsible for the stresses experienced by the soil mass.

In the lower part of the profile, a few diffuse, iron nodules and diffusion ferrans are present. These features resemble those in profile SAN 13 but in a much smaller scale. This again indicates that the soil material at this depth experiences some moisture saturation. Illuviation argillans in the lower part of the profile are particularly subject to iron enrichment. These are consequently reddish and in some cases the birefringence is masked.

A few relict features are present in the profile. These are mainly large, sandstone fragments. The sandstones, have small amounts of mica which is almost completely altered.

Another pedological feature, which is rare but present in nearly all the profiles studied, is amorphous silica gels. This feature will not be elaborated here as not much is known about it at present. It has been noticed in a number of soils especially volcanic ash soils (ESWARAN et al., 1973) and can be attributed to weathering and release of silica. At a later stage this crystallises as chert and this has also been noticed in these soils.

In conclusion, clay translocation is the dominant process in this profile. The lower part of the profile shows some evidence of moisture saturation. The profile has all micromorphological features for a Typic Tropudult.

33. Profile SAN 11

331. Physico-chemical analysis

As in the previous profile, the argillic horizon just meets the clay increase requirement stipulated by the 7th Approximation. The high silt content characterise this as well as the previous profiles. The solum is acid, base saturation is low. The CEC calculated to 100 g. clay is high and this is partly due to the contribution of organic matter which is high.

332. Clay mineralogy

Fig. 5 gives the X-ray diffractograms of the deferrified clays of profile SAN 11. No crystalline iron mineral could be identified in the diffractograms of the untreated clays and hence all the free iron is in the amorphous form. The clay mineral suite (table 2) is similar to the previous profiles, except the montmorillionite content is lesser.

Fig. 6 shows the morphology of montmorillionite in this profile. The calculated CEC and the measured CEC (table 2) agree extremely well in this profile indicating that the normative allocations are valid.

The kaolinite is relatively well crystallised as evidenced by the symmetrical endotherm and better developed exotherm in DTA.

The measured CEC of the clays range from 34 to 43 m.eq. per 100 g. The silica-alumina ratio is 3.5 or higher and the high ratio is partly due to the free quartz which is present to the extent of 7-10%.

333. Micromorphology

The S-matrix of profile SAN 11 resembles those of profile SAN 13 and SAN 10 which indicates a similar origin for the three profiles. In profiles 10 and 11, there is a random
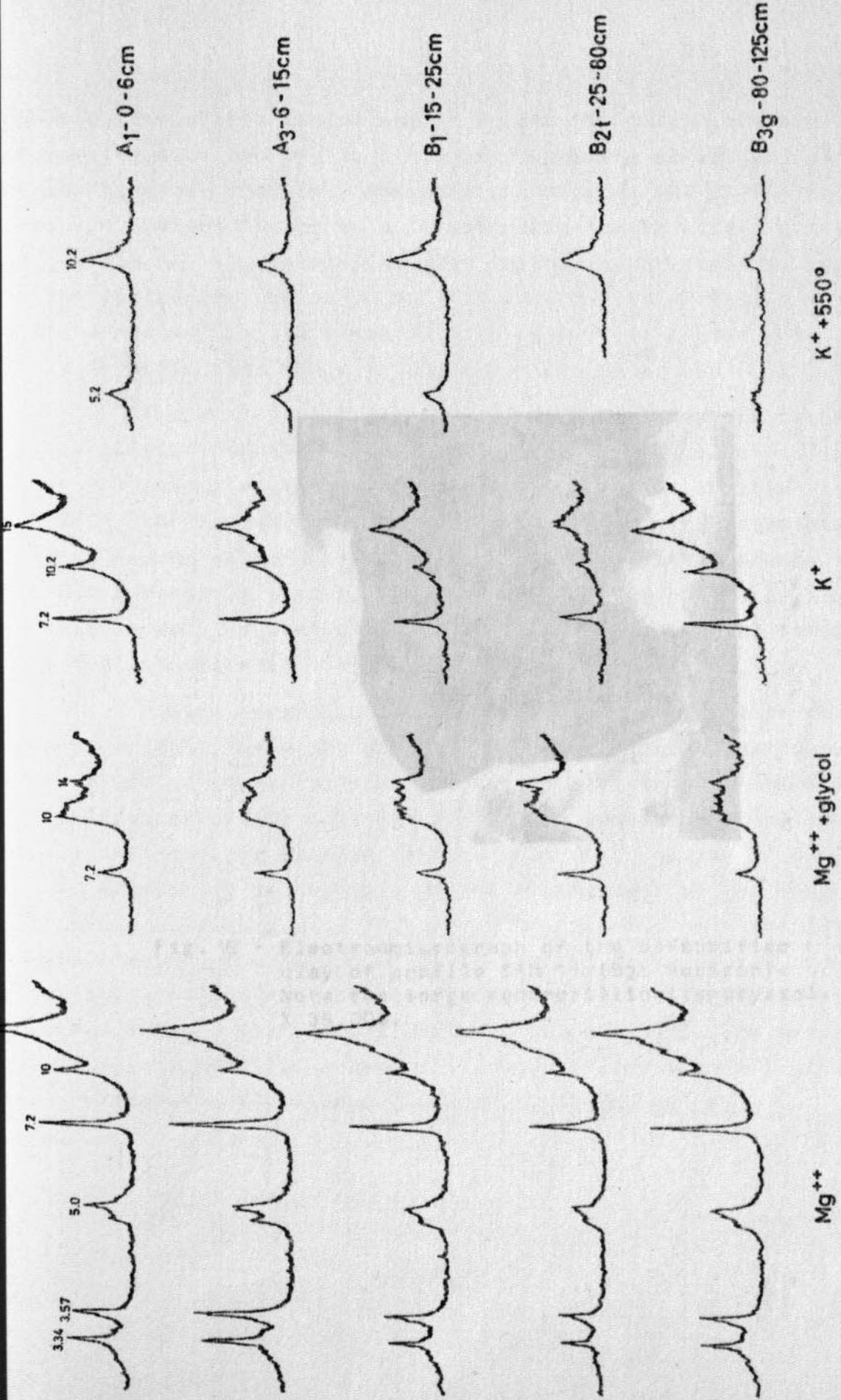
Fig. 5 — X-ray diffractograms of profile SAN 4.

...tribution of the grains whilst in SAN 13, though the grains are
...similar size and shape, a slight clustering effect was noticed.
...In the other profiles, sesquioxide nodules and diffusion fer-
...ns are present though to a considerably lesser extent and as
...profile SAN 10, increasing with depth. The s-matrix in general
...uniformly pale yellow colour. As observed in profile SAN 13,
...fferentiation in the s-matrix with respect to colour only takes
...ace in soils with ungle-moisture regimes.

...The most si...is of
...ree illuviation a...also
...wes the nature of t.......................................in the
...(Fig. 7b) is extr..inuation.
...le yellow in colour..colours
...d not invaded by ses......................................argillans
...this as well as the c.....................................formation
...a current process.

...Plasma separation...........................to the low
...sma content. These are................................chains. Unlike
...file SAN 13 where there w........................which indi-
...ted stresses in the soil mass...............isolated and
...ndom/skel-insepic plasmic fabric. This distribution of domains
...n be attributed to orginal spatial arrangement of the plasma
...th minor effects due to stresses. The presence of these identi-
...ble demain, the...................................minralo-
...al composition,..
...tures exclude the profile from an oxic subgroup. The micro-
...rphological features consequently support the classification of
...e profile as a lylic Tropualf.

Fig. 6 - Electronmicrograph of the deferrified
         clay of profile SAN 11 (B2t horizon).
         Note the large montmorillionite crystal.
         X 35,000.

distribution of the grains whilst in SAN 13, though the grains are
of similar size and shape, a slight clustering effect was noticed.
As in the other profiles, sesquioxidic nodules and diffusion fer-
rans are present though to a considerably lesser extent and as
in profile SAN 10, increasing with depth. The S-matrix in general
is uniformly pale yellow colour. As observed in profile SAN 13,
differentiation in the S-matrix with respect to colour only takes
place in soils with aquic moisture regimes.

The most significant micropedological feature is of
course illuviation argillan. Fig. 7 illustrates this and also
shows the nature of the S-matrix. The illuviation argillan in the
B_2t (Fig. 7b) is extremely well formed, thick, good orientation,
pale yellow in colour with second order yellow interference colours
and not invaded by sesquioxides. The morphology of the argillans
in this as well as the other profiles indicate that the formation
is a current process.

Plasma seperations are also well formed. Due to the low
plasma content, these are present as small, short, domains. Unlike
profile SAN 13 where there were long oriented domains which indi-
cated stresses in the soil mass, here the domains are isolated and
random (skel-insepic plasmic fabric). This distribution of domains
can be attributed to orginal spatial arrangement of the plasma
with minor effects due to stresses. The presence of these identi-
fiable domains, the nature of the plasma in terms of its mineralo-
gical composition, the absence of masking by free iron and other
features exclude the profile from an oxic subgroup. The micro-
morphological features consequently support the classification of
the profile as a Typic Tropudult.
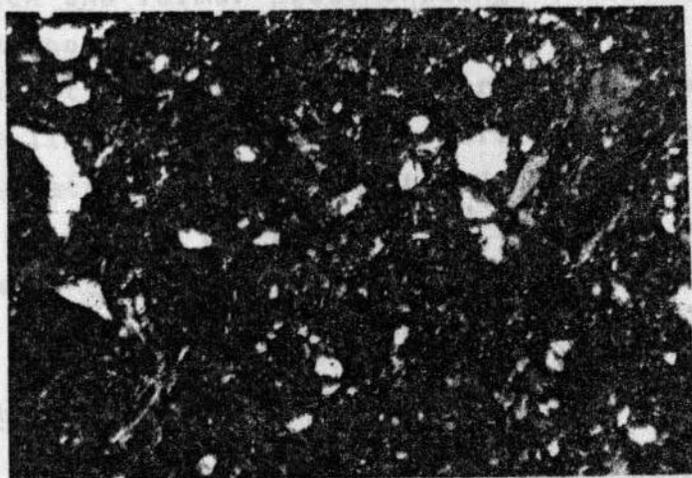
(a)
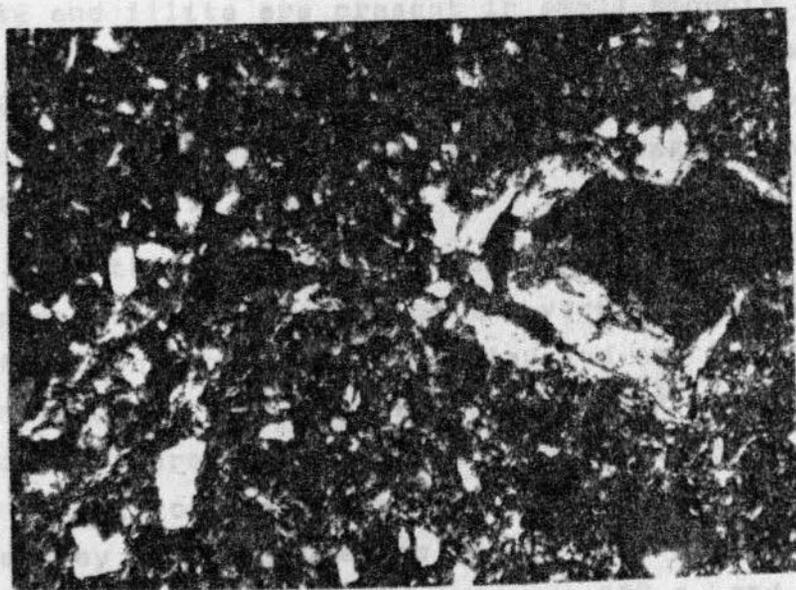
(b)

Fig. 7 - Profile SAN 11. X 80 C.N.
The two photographs illustrate the well
developed illuviation argillan present in
this horizon.
(a) B_1 horizon and (b) B_2t horizon.

34. Profile SAN 14

341. Physico-chemical analysis

This profile is developed on a mixture of sandstones and mudstones with the former predominating. The sand fraction is more than 50% and the sand is dominantly 100-500 µ in diameter. Clay content is about 20% and the clay increase in the B horizon is again on the limit for an argillic horizon. The profile is acid and the base saturation is less than 5%. The CEC of the soil is less than 8 m.eq. and the CEC calculated to 100 g. clay is very high, approaching 40%. The exchange complex is saturated with hydrogen, the bases being present only in traces.

342. Clay mineralogy

The clay mineralogical composition (table 2) is distinctly different from the previous profiles. Montmorillionite is absent, vermiculite and illite are present in small amounts and kaolinite dominates the clay composition. In addition, small amounts of chlorite and gibbsite are present. The chlorite is considered to be Al-chlorite as only small amounts of magnesium is present in the total analysis.

Even this magnesium can be attributed to the vermiculite which is present. The presence of the vermiculite is indicated by the K fixation property of the clay and not by X-ray diffraction which cannot detect such low levels. The 14 Å peak, which does not collapse on K saturation and heating and does not expand on Mg saturation and glycolation, is attributed to Al-chlorite. The high CEC of the clay is attributed to the Al-chlorite. The Al-chlorite is assumed to have a CEC of 70 m.eq. per 100 g. and the agreement between the measured and calculated CEC indicates the assumption to be true.

Gibbsite is also present and has been calculated from the water loss from 110°C to 350°C after subtracting the water due to the amorphous iron. The kaolinite is relatively well crystallised and due to the large amounts present, a well defined endotherm and exotherm is evidenced in DTA.

The absence of quartz in the clay fraction is striking and this is in accordance with our observations on tropical clays where when quartz is present, gibbsite is absent and vice versa.

No iron mineral has been detected by X-ray diffraction. All the free iron is thus amorphous (fig. 8).

343. Micromorphology

Profile SAN 14 and the following profile SAN 16, are derieved from coarse textured material. This distinguished them from the previous three profiles. The S-matrix in profile SAN 14 differs from the previous profiles in several respects. The grains in this profile belong to two size groups -less than and greater than 500 microns- which are in almost equal proportions. The smaller size group appeared to characterise the previous profiles. These difference are more accurately shown in the textural analysis.

The colour of the plasma is pale brownish yellow. Under crossed nicolls, the plasma is distinctly different. The birefringent domains which characterised the previous profiles are scarce. The plasmic fabric is essentially argillasepic with a tendency to isotic or the plasma is almost isotropic. Illuviation argillans are poorly developed, often occuring as thin lining to voids. Only, very locally, are well defined argillans present and this is illustrated in fig. 9. On the whole, the argillans show poor orientation.

A few sandstone and chert fragments are present. These are small, irregular and generally have a fragmented appearance.

Fig. 8 - Electronmicrograph of untreated clay of
profile SAN 14. No crystalline iron forms
are discernable.
X 70,000.

Sesquioxidic nodules and diffusion features are rare,
this indicates a well drained environment.

The soil thus has the characteristics for an oxisol.
However, the nature of the plasma indicates that it is at an
advanced stage of weathering - many of the oxic characteristics
are portrayed by the profile. Nevertheless the soil has been
classified as a Typic Tropudult because of the high activity of
the clay as determined by the CEC of the soil. The reasons for
this high activity will be discussed later.

6. Profile SAN 14

61. Physico-chemical

This is a [...] [...] [...]
It is developed on a [...]
A well developed elpic [...] [...] horizon,
the latter being a B[...] [...] [...] [...] iron.
The horizon beneath [...] [...]
[...] that the textu[...] [...]
[...] in the field be[...]
B[...]g, and thus mode[...]

From both the morphological appearance and the physico-
chemical analysis, it appears that the profile is drained as
many well drained Oxisols are but in this case the [...] drainer
of an Oxisol. This [...] [...] [...] such a
profile development [...] [...]

62. Clay mineralogy

Unfortunately, there was insufficient material to separate
the clay in the A[...] horizon. In table 5, the clay composition
of the remaining horizons is given. The marked similarity to profile
SAN 14 is evident. The only exception is that crystalline goethite
is detected in the axic horizons whereas the iron is all in the
amorphous form in profile SAN 14.

Fig. 9 - Profile SAN 14. B$_2$t horizon. X 80 C.N.
Sand sized quartz grains dominate the
S-matrix. Illuviation argillans are
present in the smaller voids.

Sesquioxidic nodules and diffusion features are rare. This indicates a well drained environment.

The soil thus has the characteristics for an Ultisol. However, the nature of the plasma indicates that it is at an advanced stage of weathering - many of the oxic characteristics are portrayed by the profile. Nevertheless the soil has been classified as a Typic Tropudult because of the high activity of the clay as determined by the CEC of the soil. The reasons for this high activity will be discussed later.

35. Profile SAN 16

351. Physico-chemical analysis

This is a profile with some interesting characteristics. It is developed on a sandy material and field morphology indicates a well developed albic horizon with an underlying Spodic horizon, the latter being a horizon of accumulation of humus and not iron. The horizon beneath has all the properties of an oxic horizon except that the texture may be on the limit. The horizon termed B_{2ox2} in the field has 16% clay and a CEC per 100 g. clay of 15 m.eq. and thus meeting the requirements of an oxic horizon.

From both the morphological appearance and the physico-chemical analysis, it appears that the profile is bisequal as many well drained Spodosols are but in this case the lower sequum is an Oxisol. This is perhaps the first instance where such a profile development has been reported.

352. Clay mineralogy

Unfortunately, there was insufficient material to separate the clay in the A_2 horizon . In table 2, the clay composition of the remaining horizons is given. The marked similarily to profile SAN 14 is evident. The only exception is that crystallised goethite is detected in the oxic horizons whereas the iron is all in the amorphous form in profile SAN 14.

Fig. 10 shows an interesting electron-micrograph. A few such large illite grains are present but the interesting feature is the formation of hexaganol kaolinite crystals in the inter- layers. This can be distinctly seen in fig. 6.

353. Micromorphology

As mentionned before, the bisequal nature of the profile - Spodosol-Oxisol- is evident both in the field and the physico- chemical analysis.

The Albic horizon consists of almost completely of sand grains with little or no plasma. The grains are firmly packed with the edges touching each other. The only void type are the inter- granular voids. The Spodic horizon -B_2h- has a similar micromorpho- logy to such horizons in temperate Podzols. The humus is present in three forms. The most dominant is as clusters in the intergranu- lar voids. The humus is also present locally as coatings on the grains and forming bridges connecting the grains. The humus is characteristically opaque. The S-matrix of the B_2h horizon is loose as compared to the Albic horizon. The grains are relatively for apart and there is a relatively higher amount of intergranular voids. Consequently this horizon is more porous. Comparing the B_2h of this profile with temperate Podzols, it can be said that podzo- lisation is weakly expressed.

Locally in the B_2h horizons, are spots where slight cementation with iron can be observed. This is a subsidiary feature.

The lower horizons, have a different micromorphology. There is considerably more mineral plasma and the S-matrix is again compact. There are no intergranular voids and the only void types are small amounts of ortho-vughs. The plasma is almost isotropic, plasmic fabric is isotic. There is absolutely no evidence of clay translocation.

These are all the micromorphological characteristics of an Oxic horizon.

4. GENERAL DISCUSSION

4.1. Physico-chemical and micromorphological properties

With the exception of the Spodosol, the most striking feature is the high cation exchange property of the soils. This is not a normal feature for soils developed on similar parent materials in other tropical regions. Having studied similar soils in tropical Africa (SYS, 1970) assumed that the soils may fall into Oxic subgroups. The large number of soils on similar parent material studied by FOLLAND and ACRES (1972) show similar magnitudes in CEC. The reason for the high CEC resides in the clay mineral composition. The clay mineral suite consists of illite, vermiculite, chlorite, montmorillonite and kaolinite. Compared to tropical soils in other areas it is evident that the .... of ..... genesis is different here. This will be discussed ....

The climate is hot and humid .... environment. However, as is evident from the .... of FOLLAND and ACRES (1972) and .... is essentially a function of the .... In well drained environments .... at 1.2 m from the surface is below 10% and .... textural B horizons are visible. The soils with less internal drainage tend to have a higher base saturation and .... described as Aquic Tropudalfs or Tropaquepts. In these soils the base saturation is high. The high base saturation is due not to a high level of exchangeable calcium but rather due to magnesium (data of FOLLAND and ACRES, 1972). The source of the magnesium .... the rocks in the area has not been studied. However, it appears that the high magnesium content favours the formation of vermiculite and montmorillonite. In the soils employed in this study, both calcium and magnesium are high in the wetter profiles.

Fig. 10 - Electron micrograph of clay of profile SAN 16, B_2O_{x1} horizon. X 35,000.

4. GENERAL DISCUSSION

41. Physico-chemical and micromorphological properties

      With the exception of the Spodosol, the most striking feature is the high cation exchange property of the soils. This is not a normal feature for soils developed on similar parent materials in other tropical regions. Having studied similar soils in tropical Africa (SYS, 1970) assumed that the soils may fall into Oxic subgroups. The large number of soils on similar parent material studied by FOLLAND and ACRES (1972) show similar magnitudes in CEC. The reason for the high CEC resides in the clay mineral composition. The clay mineral suite comprises illite, vermiculite, chlorite, montmorillionite and kaolinite. Comparing tropical soils in other areas it is evident that the trend in clay genesis is different here. This will be discussed later.

      The climate is Udic and this is a leaching environment. However, as is evident from the review of the report of FOLLAND and ACRES (1972) and in this study, the base status is essentially a function of the ground-water table in these soils. In well drained environments, the base saturation at 1,5 m. from the sur-face is below 10% and the soils with textural B horizons are Ultisols. The soils with lesser internal drainage tend to have a higher base saturation and are classified as Aquic Tropudalfs or Tropaquepts. In these soils the base saturation is high. The high base-saturation is due not to a high level of exchangeable calcium but rather due to magnesium (data of FOLLAND and ACRES, 1972). The source of the magnesium is not evident as the rocks in the area has not been studied. However, it appears that the high magnesium content favours the formation of vermiculite and montmorillionite. In the soils employed in this study, both calcium and magnesium are high in the wetter profiles.

Clay translocation is a significant process in these soils as has been confirmed by the micromorphological study. For good textural B horizons to be formed, the soil has to experience a moisture defecit in the upper part of the profile for some periods during the year in some years. Ad hoc studies on soils from different climatic regimes by us seems to indicate that illuviation argillans are better developed as the dry period increases upto a certain maximum. The exact climatic conditions have not been evaluated but periodic drying provides the physical conditions for clay translocation. Considering only the climatic data for the Sandakan area, would suggest that the soil may never dry out due to the high total annual and monthly rainfall. The evaporation data, however, shows that in the summer months evaporation may balance or be more than precipitation. In the latter case the soil tends to dry out. On moistening the soil then, clay can be dispersed and be translocated down the profile in suspension. Absorbtion of water by the soil in the lower parts of the solum plasters the suspended clay onto void walls giving rise to clay skins.

The fact that the moisture content of the soil determines the degree of development of the argillans is illustrated by the three profiles SAN 13, 10 and 11. The amount of sesquioxidic nodules and diffusion features decreases from profile SAN 13 to SAN 11. If this can be used as an indicator of the moisture status of the profile - despite the fact that both SAN 10 and 11 belong to Typic subgroups - then profile SAN 13 is the wettest and SAN 11 the driest of the three. In this sequence, SAN 13 has the least argillans (consequently it is an aquept) and the argillans are best expressed in SAN 11.

The moisture regime alone does not determine clay translocation as the clay has to be in a position to move. Cementation by free oxides to form pseudosands can retard this process. This is perhaps the situation in profile SAN 14 where argillans are poorly expressed. Other physico-chemical factors may also be operating.

The basic conclusion is that clay has been translocated in these soils. The question on weather this is a current process can only be answerd indirectly. The first evidence is that the climatic conditions are favourable for such a process. Secondly, there is no micromorphological evidence to suggest that it is a "Pale"feature.

The coarser textured soils appear to have a slightly different pedogenesis. This applies to profiles SAN 14 and SAN 16. In the five soils studied, these two profiles are situated in a geomorphologically higher position which may indicate slightly older soils. The clay mineral suite is different from the other three profiles and the micromorphology is different. The end stage in pedogenesis on this parent material is a spodosol as shown by profile SAN 16. The curious feature however is that the lower sequum in SAN 16 is an Oxisol and not an Ultisol as would be expected.

In temperate well drained Spodosols, the lower sequum in many cases shows the presence of a textural B horizon. In the well drained Spodosols, when the parent material contained slightly high clay, clay translocation is a necessary prelude to podsolization. In profile SAN 16, no micromorphological evidences for clay translocation can be shown in the two horizon beneath the Spodic that were studied. The translocated clay may be present deeper down. Nevertheless, the horizons below the Spodic has all physico-chemical and micro- and macromorphological characteristics of an Oxic horizon.

This implies that the profile has gone through an Oxic stage of weathering. The reason for podzolisation in this profile can be attributed to the change in vegetation. The original forest in the area has been cleared and planted with pines and there is also a secondary growth of shrubs which perhaps produces an acid litter.

The micromorphological study suggests that the podzolisation is recent due to the poorly formed spodic features. The soils in this area defenitely deserve greater study and detailed mapping should throw much light on this problem.

42. Clay mineralogy

The clay mineralogical study provides some interesting information. In profiles SAN 13, 10 and 11, montmorillionite, vermiculite and illite dominate the silicate clays. Kaolinite is only of minor importance. In profiles SAN 14 and 16, kaolinite is the most important clay with minor amounts of chlorite and gibbsite. The soils thus belong to two stages of weathering.

The source material for these secondary clay minerals is believed to be muscovite. Apart from muscovite, no other primary mineral has been observed in any significant amount. If the two groups of soils are considered to be two environments of weathering, the possible transformations are :

Muscovite (illite)

montmorillionite ⟶ Vermiculite ⟶ Kaolinite

Al-chlorite   Gibbsite
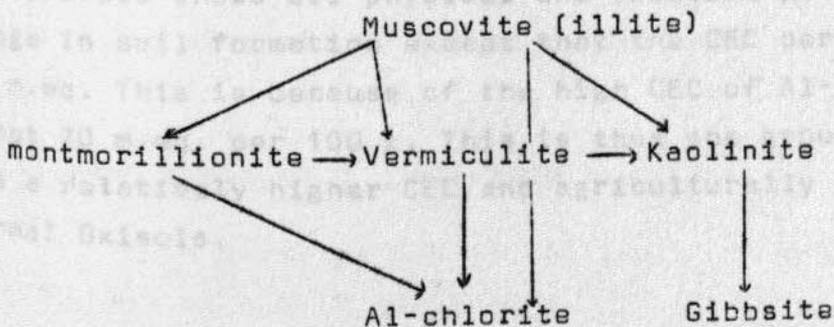
The conditions and factors governing these transformations have not been evaluated in detail and consequently only certain generalisations can be made. The formation of montmorillionite and vermiculite needs an ample supply of magnesium. Profiles SAN 13, 10 and 11 have these minerals and the exchangeable cation composition shows a relatively high magnesium content. For kaolinite and gibbsite formation, especially the latter, an acid free draining environment is required. It appears as though that a similar environment is necessary for Al-chlorite.

KAWASAKI and AOMINE (1966) have reported the presence of Al-chlorite in free draining volcanic ash soils in Japan. They suggest that it could be derieved from either muscovite or pyroxenes and the transformation proceeds through several intergrades of which montmorillionite and vermiculite may be members. JACKSON (1963) considers the formation of Al-chlorite as an "anti-gibbsite" effect whereby aluminum instead of precipitating as gibbsite forms hydroxy inter-layer between the sheets of illite. The situations when the anti-gibbsite effect or gibbsite formation prevails is not elaborated. In profiles SAN 14 and 16, both Al-chlorite and gibbsite are present.

The formation of Al-chlorite in soils is of great pedological and agronomical significance. Al-chlorite is a very resistent mineral and can be present even in Oxisols. When present in Oxisols, the profile shows all physical and chemical properties of such a stage in soil formation except that the CEC per 100 g. clay exceeds 16 m.eq. This is because of the high CEC of Al-chlorite which is about 70 m.eq. per 100 g. This is thus one group of Oxisols which has a relatively higher CEC and agriculturally better than the normal Oxisols.

The iron minerals in this set of profiles are also interesting. Lepodocrocite is confined to the wetter soils. Not much is known about this mineral and only recently SCHWERTMANN et al. (1972) by experimental work has shown that free silica is necessary for its formation. The role of the silica has not yet been evaluated. In the two profiles (SAN 13 and 10) where lepido-crocite is found , thin-sections also showed the presence of amorphous silica gels. Further, these two profiles have montmoril-lionite and for it to be stable, the soil must have a high silica potential. Indirectly, it can be said that conditions in these two soils are favourable for the presence of lepidocrocite. In profile SAN 11 and 14 no lepidocrocite or other crystalline iron forms are present. The free iron is all in the amorphous form. In the Oxic horizon of profile SAN 16, goethite is the crystalline iron mineral.

Quartz is present in the clay fraction of profile SAN 13, 10 and 11 whilst in profiles SAN 14 and 16, gibbsite is present. The general observation, though there are exceptions, is that when quartz is present gibbsite is absent and vice versa.

If type of clay minerals can be used to indicate a weathering stage, then the following stages can be evaluated for such parent materials :

Stage 1   Stage 2   Stage 3

Quartz + 2:1 minerals →   Quartz + kaolinite →   kaolinite →

Stage 4   Stage 5

Kaolinite + gibbsite →   Gibbsite

Then profiles SAN 13, 10 and 11 belong to stage 1 and profiles SAN 14 and 16 to stage 4.

43. <u>Suitability of the soils</u>

Both the mineralogical and micromorphological study
has shown that the soils of Ulu Dusun are recent. They have
excellant physico-chemical properties; their nutrient retention
capacity is high and they have a good structure. The major limi-
ting factor in some of the soils will be the ground water table.

Based on soil properties (SYS, 1971) has a worked out
a scheme to evaluate the soil. A soil capability index is calcu-
lated and employing this the land can be classified into several
classes. The system enables a first approach to evaluate land. The
five profiles studies here have the following indices :

Profile SAN 13	75
Profile SAN 10	80
Profile SAN 11	80
Profile SAN 14	50
Profile SAN 16	10

These indices have to be correlated with the crops that
are intended to be grown. Using the data of SYS (1971) for cocoa
under African conditions, the first three profiles should give an
yield ranging from 1350 to 1800 kg/ha.; profile SAN 14, an yield
of 540 to 990 kg/ha. and profile SAN 16 an yield less than 500 kg/ha.
These are perhaps conservative estimates as with good husbandry
and agronomic practises much higher yields can be anticipated.

5. <u>CONCLUSION</u>

The basic objective of the study has been to show that
clay translocation has taken place. Ample micromorphological
evidences has been given to show that it is a current process in
some of these soils.

The clay mineralogical study has shown that significant amount of 2:1 minerals are present. These contribute to the high cation exchange capacity of these soils. Mineralogically these soils are young.

From a physico-chemical point of view, the soils of Ulu Dusun will form one of the better soils of Malaysia. Their physico-chemical properties and mineralogical composition are ideal for large scale agricultural exploitation.

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APPENDIX

PROFILE DESCRIPTIONS

PROFILE SAN 13

Location : Oil-palm station of Ulu Dusun.
Vegetation : Newly planted oil-palm.
Parent material : Soil derieved from sandstones and shales.
Topography : Small depression in alluvial valley.
Drainage : Poor.

A_{11} 0-7 cm   Sandy clay loam; very dark grayish brown (10 YR
                      3/2); moderately well developed, weak, subangular
                      blocky structure; friable; numerous roots; distinct
                      smooth boundary; to,

A_{12} 7-30 cm   Sandy clay loam; light gray (2.5 YR 6/0); massive;
                      few roots; distinct boundary; to.

(B)g 30-100 cm   Clay; loam yellowish brown (7.5 YR 5/6) with
                      light gray (2.5 Y 7/2) and red (2.5 YR 5/6)
                      mottles; well developed, coarse subangular blocky;
                      few clay skins in pores and few discontinous on
                      peds; few roots.

CLASSIFICATION : FLUVENTIC TROPAQUEPT.

Profile SAN 13
Fluventic Tropaquept

Granulometric data

Depth in cm.	Horizon	Sample No.	Total μ			Silt μ			Sand μ				
			Clay 0-2	Silt 2-50	Sand 50-2000	2-10	10-20	20-50	50-100	100-250	250-500	500-1000	1000-2000
0-7	A1	32/50	34.2	60.9	4.9	29.3	18.3	13.3	-	2.2	-	-	-
7-30	A12	/51	32.5	56.2	11.3	20.0	12.8	23.4	8.0	2.9	0.3	0.1	-
30-100	B2g	/52	32.9	52.5	14.6	18.8	12.3	21.4	9.2	4.8	0.5	0.1	-

C.E.C. and exchangeable bases

Sample No.	O.C. %	pH KCl	pH H₂O	meq/100g. of clay						Tt NH4OAc	B.S.Sum %	C.E.C. 100g. clay	B.S. % (V)
				Ca++	Mg++	K+	Na+	H+	Total				
32/50	0.83	4.10	5.25	8.66	3.52	0.41	0.09	9.1	21.78	19.52	58.2	57.1	65.0
/51	0.45	4.50	5.35	8.21	3.73	0.39	0.10	7.1	19.53	14.72	63.6	45.3	84.4
/52	0.64	4.00	5.00	7.27	3.47	0.41	0.09	7.8	19.04	14.56	59.0	44.3	77.2

TOTAL ANALYSIS OF CLAY OF PROFILE SAN 13

Profile no.: SAN 13 clay   Locality

Sample no.	32/50	32/51	32/52
Horizon			
SiO_2	52.68	51.95	48.21
Al_2O_3	21.80	22.54	23.29
Fe_2O_3	7.50	10.04	14.22
FeO	1.30	1.24	0.98
MgO	2.09	2.00	1.82
CaO	0.13	0.13	0.03
Na_2O	0.33	0.28	0.24
K_2O	2.60	2.75	2.65
TiO_2	0.86	0.76	0.69
MnO	0.09	0.14	0.06
H_2O^+	8.05	8.81	7.09
H_2O^-	1.96	1.06	1.79
Total	99.39	100.46	100.09

PROFILE SAN 10

Location : Oil-palm station, Ulu Dusun.

Vegetation : Secondary forest transformed to an oil-palm planta-
tion.

Parent material : Soil derived from sandstones and shales.

Topography : undulating, upper part of slope.

Drainage : well drained.

Ap   0-10 cm   Sandy clay loam; very dark grayish brown
                     (10 YR 3/2); fine and medium subangular blocky
                     with crumb around the roots; friable; numerous
                     roots; distinct boundary; to,

A_3 10-25 cm   Sandy clay loam; yellowish brown (10 YR 5/6);
                     weak, medium subangular blocky; friable; numerous
                     roots; gradual boundary; to,

B_2t 25-100 cm   Clay; strong brown (7.5 YR 5/6); well developed,
                     coarse subangular blocky with continuous clay
                     skins on the peds; friable; numerous roots.

CLASSIFICATION : TYPIC TROPUDULT.

Profile SAN 10
Typic Tropudult

Granulometric data

Depth in cm.	Horizon	Sample No.	Total μ			Silt μ			Sand μ				
			Clay 0-2	Silt 2-50	Sand 50-2000	2-10	10-20	20-50	50-100	100-250	250-500	500-1000	1000-2000
10-25	A3	32/41	28.9	41.8	29.3	13.9	9.1	18.8	13.6	11.0	3.6	0.8	0.3
25-100	B2t	32/42	33.4	41.2	25.4	17.8	8.8	14.6	10.0	12.0	1.5	1.0	0.9

C.E.C. and exchangeable bases

Sample No.	O.C %	pH		Ca++	Mg++	K+	Na+	H+	Total	Tt NH4OAc	B.S.-Sum %	C.E.C. 100g. clay	B.S. % (V)
		KCl	H2O	meq/100g. of clay									
32/41	0.67	3.95	4.60	2.68	1.20	0.18	0.02	11.2	15.28	11.52	26.7	39.9	35.4
32/42	0.51	4.00	5.00	1.99	0.56	0.18	0.02	12.1	14.85	12.00	18.5	35.9	22.9

TOTAL ANALYSIS OF CLAY OF PROFILE SAN 10

Profile no.: SAN 10 clay   locality

Sample no.	32/41	32/42
Horizon		
SiO_2	45.97	48.54
Al_2O_3	24.23	24.62
Fe_2O_3	10.25	10.53
FeO	0.97	1.27
MgO	1.63	1.56
CaO	0.21	0.14
Na_2O	0.45	0.48
K_2O	2.63	2.60
TiO_2	0.86	0.66
MnO	0.06	0.03
$H_2O^{\pm}$	10.88	8.37
H_2O^{-}	2.10	2.86
Total	99.27	100.39

PROFILE SAN 11

Location : Oil-palm station, Ulu Dusun.
Vegetation : Secondary forest.
Parent material : Soil derived from sandstone and shales.
Topography : Flat alluvial valley.
Drainage : moderately well drained.

A_1　　0-6 cm　　Sandy clay loam; very dark grayish brown
　　　　　　　　　　(10 YR 3/2); well developed medium crumb;
　　　　　　　　　　friable; numerous roots; gradual boundary; to,

A_3　　6-15 cm　　Sandy clay loam; dark brown (10 YR 4/3); well
　　　　　　　　　　developed medium and fine subangular blocky;
　　　　　　　　　　friable; numerous roots; gradual boundary.

B_1　　15-25 cm　　Transition horizon.

B_2t　25-80 cm　　Clay; dark yellowish brown (10 YR 4/4); well
　　　　　　　　　　developed, coarse subangular blocky, with thick
　　　　　　　　　　continous clay skins on the peds; moderate root
　　　　　　　　　　penetration; somewhat sticky; faint mottling in
　　　　　　　　　　lower part; gradual transition; to,

B_3g　80-120 cm　　Clay; moderately well developed subangular; few
　　　　　　　　　　roots; distinct mottling.

CLASSIFICATION : TYPIC TROPUDULT.

Profile SAN 11

Typic Tropudult

Granulometric data

Depth in cm.	Horizon	Sample No.	Total μ			Silt μ			Sand μ				
			Clay 0-2	Silt 2-50	Sand 50-2000	2-10	10-20	20-50	50-100	100-250	250-500	500-1000	1000-2000
0-6	A1	32/43	21.1	56.3	22.6	17.2	13.2	25.9	14.2	7.4	0.6	0.2	0.2
6-15	A3	/44	22.8	56.3	20.9	18.6	14.2	23.5	13.5	6.8	0.4	0.2	0.0
15-25	B1	/45	19.8	56.1	24.1	18.9	13.5	23.7	14.9	8.6	0.5	0.1	0.0
25-80	B2t	/46	24.7	50.2	25.1	19.7	11.3	19.2	13.5	11.0	0.5	0.1	0.0
80-120	B3g	/47	26.7	49.9	23.4	22.9	12.5	14.5	12.4	10.1	0.6	0.2	0.1

C.E.C. and exchangeable bases

Sample No.	O.C %	pH		meq/100g.						Tt	B.S.Sum	C.E.C. 100g.	B.S. % (V)
		KCl	H_2O	Ca^{++}	Mg^{++}	K^+	Na^+	H^+	Total	NH_4OAc	%	clay	
32/43	3.62	4.00	4.65	4.93	4.58	0.47	0.07	15.9	25.95	16.80	38.7	79.6	59.8
/44	0.93	3.80	4.70	0.38	0.85	0.13	0.05	12.2	13.61	11.68	10.4	51.2	12.1
/45	0.58	3.85	5.00	0.40	0.03	0.11	0.05	10.9	11.49	10.40	5.1	52.5	5.7
/46	0.35	3.85	5.00	0.62	0.02	0.15	0.06	11.5	12.35	11.04	6.9	44.7	7.7
/47	0.10	3.90	5.10	0.07	1.37	0.12	0.08	11.2	12.84	10.40	12.8	39.0	15.8

meq/100g. of clay

TOTAL ANALYSIS OF CLAY OF PROFILE SAN 11

Profile no. SAN 11 Clay   locality

Sample no.	32/43	32/44	32/45	32/46	32/47
Horizon					
SiO_2	51.61	47.89	48.05	50.22	45.97
Al_2O_3	22.91	22.35	22.45	23.28	22.35
Fe_2O_3	8.37	10.32	10.39	9.97	10.04
FeO	4.36	1.20	0.96	0.88	0.86
MgO	1.96	2.00	1.85	1.80	1.77
CaO	0.01	0.16	0.11	0.01	0.01
Na_2O	0.27	0.59	0.54	0.21	0.25
K_2O	0.65	2.57	2.73	2.60	2.86
TiO_2	0.79	1.00	0.69	0.83	0.69
MnO	0.07	0.12	0.12	0.08	0.04
H_2O^+	9.43	10.49	10.13	8.96	11.17
H_2O^-	1.93	1.03	1.83	1.86	2.95
Total	100.0	98.52	98.79	99.82	98.10

PROFILE SAN 14

Location : Profile in a terrace of 50-6P m. near Sandakan.
Vegetation : Ruderal grasses.
Parent material : Clay loam over terrace gravel.
Topography : undulating.
Drainage : Well drained.

A_1 0-5 cm   Sandy clay loam; very dark grayish brown
                         (10 YR 3/2); medium and fine subangular blocky;
                         friable; numerous roots; distinct boundary.

A_3 5-25 cm   Sandy clay loam; strong brown (7.5 YR 5/6); weak,
                         medium and coarse, subangular blocky; friable;
                         gradual boundary; to,

B_2t 25-100 cm   Clay loam; yellowish red (5 YR 5/6); coarse
                         moderately developed to weak subangular blocky,
                         with thin discontinous clay skins on the peds;
                         friable; distinct smooth boundary; to,

IIC   100 cm+   Terrace gravel.

CLASSIFICATION : TYPIC TROPUDULT.

Profile SAN 14

Typic Tropudult

Granulometric data

Depth in cm.	Horizon	Sample No.	Total μ			Silt μ			Sand μ				
			Clay 0-2	Silt 2-50	Sand 50-2000	2-10	10-20	20-50	50-100	100-250	250-500	500-1000	1000-2000
5-25	A3	32/53	19.0	27.4	54.6	7.9	5.2	14.3	11.5	24.0	13.6	4.0	1.5
25-50	B2t1	/54	19.4	27.8	52.8	7.9	6.5	13.4	12.1	23.2	13.4	3.1	1.0
50-100	B2t2	/55	21.8	26.9	51.3	7.4	5.9	13.6	11.0	21.7	12.1	3.9	2.6

C.E.C. and exchangeable bases

Sample No.	O.C %	pH		Ca++	Mg++	K+	Na+	H+	Total	Tt NH4OAc	B.S.Sum %	C.E.C. 100g. clay	B.S. % (V)
		KCl	H2O										
32/53	0.42	4.00	4.70	0.01	0.11	0.09	0.01	7.8	8.02	6.40	2.7	35.6	3.4
/54	0.22	4.10	4.75	0.01	0.03	0.06	0.01	6.1	6.21	6.24	1.8	32.2	1.8
/55	0.19	4.10	4.95	0.05	0.03	0.06	0.02	6.7	6.86	7.84	2.3	36.0	2.0

meq/100g. of clay

TOTAL ANALYSIS OF CLAY OF PROFILE SAN 14

Profile no. SAN 14 clay		Locality	
Sample no.	32/53	32/54	32/55
Horizon			
SiO_2	41.21	39.55	42.36
Al_2O_3	27.35	28.65	29.91
Fe_2O_3	9.97	10.04	9.77
FeO	1.27	1.24	0.98
MgO	0.71	0.72	0.79
CaO	0.01	0.01	0.01
Na_2O	0.15	0.18	0.15
K_2O	0.35	0.44	0.51
TiO_2	1.61	1.57	1.03
MnO	0.03	0.05	0.03
H_2O^+	13.73	13.69	13.34
H_2O^-	5.21	4.78	3.31
Total	100.33	100.92	101.21

PROFILE SAN 16

Location : Water catchment station, Sandakan.
Vegetation : Planted Conifers.
Parent material : Derieved from sandstones and shales.
Topography : Flat; slope less than 4 per cent.
Drainage : Excessively drained.

A_{oo} 8-0 cm   Undecomposed plant remains.

A_2 0-20 cm   Loamy sand; light gray (10 YR 7/1); single
                      grained; friable; few roots; distinct wavy
                      boundary; to,

B_2h 20-24 cm   Loamy sand; dark brown (7.5 YR 3/2); massive;
                      somewhat hard with thin discontinous iron-
                      humus pan at bottom of horizon; no roots; clear,
                      wavy, boundary; to,

$B_{2ox,1}$ 24-100 cm Sandy clay loam, strong brown (7.5 YR 5/8);
                      massive; no roots; pseudo-concretions, few;
                      diffuse boundary; to,

$B_{2ox,2}$ 100-150 cm Sandy clay; yellowish red to red (5-2.5 YR
                      5/6); massive with pseudoconcretions.

* The profile appears to be developed in the upper part of
  the Oxic horizon.

CLASSIFICATION : ORTHOXIC TROPORTHOD.

Profile SAN 16

Troporthod

C.E.C. and exchangeable bases

Sample No.	O.C %	pH		meq/100g. of clay							C.E.C. 100g. clay	B.S. % (V)
		KCl	H₂O	Ca++	Mg++	K+	Na+	H+ Total	Tt NH₄OAc	B.S.SUM %		
32/77	1.4	3.9	4.7	0.2	0.1	0	0.1		1.9		95.0	16.0
/78	3.1	3.7	4.1	0.2	0.1	0	0.1		13.4		33.5	4.0
/79	0.3	4.0	4.5	0.2	0.1	0.1	0.1		2.3		16.4	12.0
/80	0.1	4.0	5.1	0.2	0.1	0	0.1		2.2		15.0	15.0

TOTAL ANALYSIS OF CLAY OF PROFILE SAN 16

Profile no. SAN 16 clay   Locality

Sample no.	32/78	32/79	32/80
Horizon			
SiO_2	36.65	36.92	44.73
Al_2O_3	32.05	31.01	28.82
Fe_2O_3	9.17	7.90	6.85
FeO	1.24	0.01	0.14
MgO	0.31	0.32	0.37
CaO	0.01	0.01	0.07
Na_2O	0.21	0.16	0.16
K_2O	0.10	0.15	0.28
TiO_2	1.38	1.31	0.93
MnO	0.03	0.03	0.03
H_2O^+	15.05	14.96	13.84
H_2O^-	3.92	2.92	4.14
Total	100.12	95.69	100.22