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Micromorphological study of some Sabah
soils, with special reference to the
identification of oxic B and argillic B
horizons

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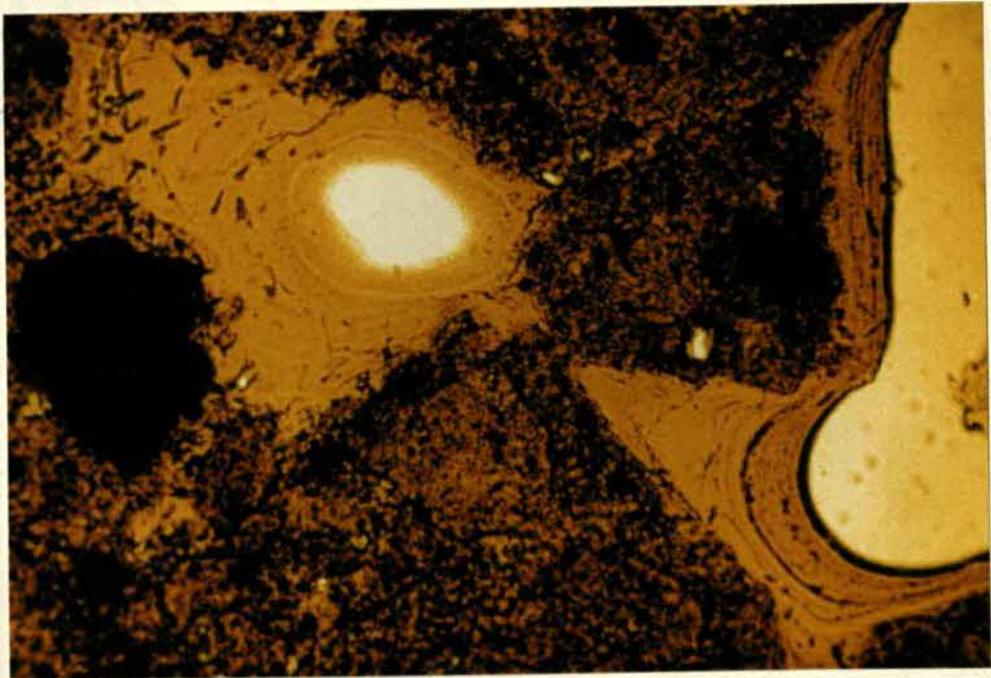
MICROMORPHOLOGICAL STUDY OF SOME SABAH SOILS,
WITH SPECIAL REFERENCE TO THE IDENTIFICATION OF
OXIC B AND ARGILLIC B HORIZONS

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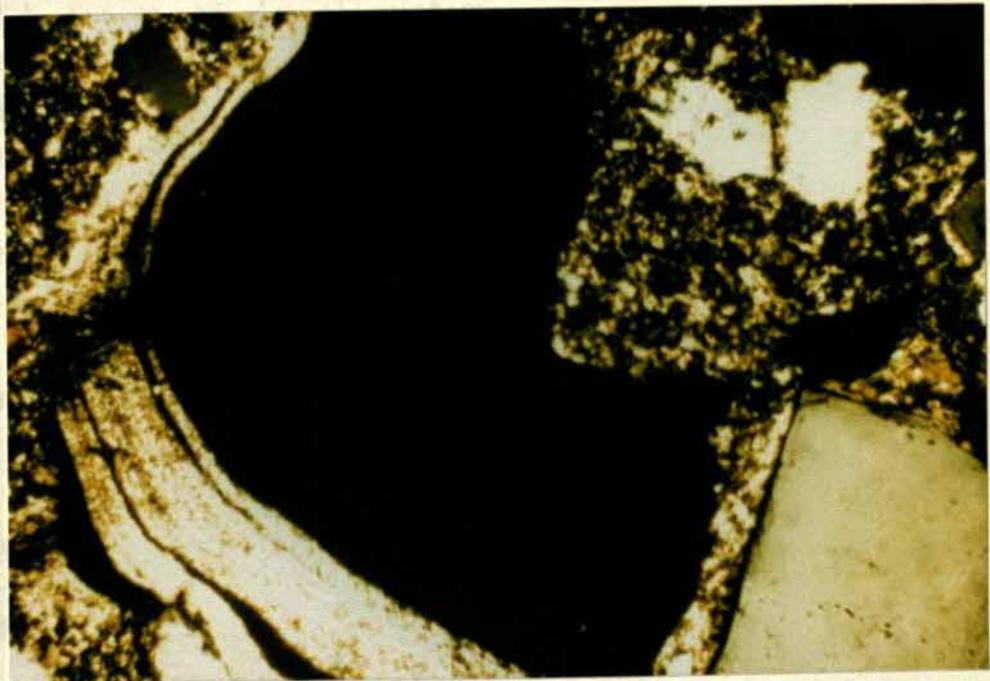
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Void goethans in an oxic horizon of the Ambum Family, Profile 6. Note chromium-rich nodule central left. Plane polarised light (x400)



Void argillan in an argillic horizon of the Tanjong Lipat Family, Profile 16. Crossed polarised light (x400)

Frontispiece Micrographs of cutans.

CONTENTS

	page
SUMMARY AND KEYWORDS	vii
ACKNOWLEDGEMENTS	viii
PART 1 INTRODUCTION	1
PART 2 MATERIALS AND METHODS	3
PART 3 RESULTS	5
3.1 General soil data	5
3.2 Micromorphology	5
3.2.1 Semi-quantative analysis	5
3.2.2 Quantative analysis	5
3.2.2.1 Orthic Ferralsols	5
3.2.2.2 Gleyic Acrisol	17
3.2.2.3 Ferric Acrisol	17
3.2.2.4 Orthic Acrisol	22
PART 4 DISCUSSION AND CONCLUSIONS	29
4.1 Identification	29
4.2 Relationships of soil properties used in the differentiation of the B horizon	29
4.2.1 Cutans and clay illuviation	31
4.2.2 Cation exchange capacity (CEC)	31
4.2.3 Structure and porosity	31
4.2.4 Fabric characteristics	32
4.2.5 Clay mineralogy	32
4.2.6 Biological activity	32
4.3 Implications for soil classification	33
PART 5 REFERENCES AND RELEVANT WORKS	35
APPENDIXES	
1. Soil profile descriptions and analyses	39
2. Profile description: horizon nomenclature and definitions of diagnostic horizons	49
FIGURE	
1. The relationship between porosity (as optically measured voids) and clay content in some oxic B and argillic B horizons	after p. 32
PLATES	
Frontispiece Micrographs of cutans (colour)	
Top. Void goethans in an oxic horizon of the Ambun Family.	

Frontispiece cont'd

- Profile 6. Note chromium-rich nodule central left. Plane polarised light (x400)
- Bottom. Void argillan in an argillic horizon of the Tanjong Lipat Family. Profile 16. Crossed polarised light (x400)
1. Benuou Family. Profile 5. B2ox horizon. Micrograph showing void argillan lining quartz grains. Crossed polarised (x200) 11
 2. Benuou Family. Profile 5. B3ox horizon. Micrograph showing iron-indurated sandstone fragments. Plane polarised light (x100) 11
 3. Benuou Family. Profile 5. A1 horizon. Micrograph showing the high proportion of faecal pellets. Plane polarised light (x200) 11
 4. Ambun Family. Profile 6. B1 horizon. Micrograph showing characteristic voids. Plane polarised light (x80) 11
 5. Ambun Family. Profile 6. A1 horizon. Micrograph showing the high degree of porosity characteristic of the soil. Plane polarised light (x35) 11
 6. Ambun Family. Profile 6. B2ox horizon. Micrograph showing faecal pellets forming channel infillings. Plane polarised light (x35) 11
 7. Scanning electron microscope micrograph of part of the B2ox horizon of Profile 6, Ambun Family, showing nodule development. Note the porosity of the matrix (x40) 11
 8. Same field as Plates 25 and 26, micrograph showing X-ray image of Fe as displayed on oscilloscope screen. There is no marked concentration of Fe. 11
 9. Scanning electron microscope micrograph of part of the B2ox horizon of Profile 6, Ambun Family, showing cutan (ferran) development (x31) 13

	page
10. Same field as Plate 28, micrograph showing X-ray image of Fe as displayed on oscilloscope screen. Density of white dots is approximately proportional to the concentration of Fe.	13
11. Same field as Plates 28 and 29, micrograph showing X-ray image of A1 as displayed on oscilloscope screen. There is no marked concentration of A1.	13
12. Ambun Family. Profile 6. B3ox horizon. Micrograph showing void terrans. Crossed polarised light (x200)	15
13. Ambun Family. Profile 6. B3ox horizon. Micrograph showing void terrans. Note chromium rich nodule central left. Plane polarised light (x200)	15
14. Masaum Family. Profile 12. A1 horizon. Micrograph showing vughs. Plane polarised light (x35)	15
15. Masaum Family. Profile 12. A1 horizon. Micrograph showing chamber. Plane polarised light (x35)	21
16. Masaum Family. Profile 12. BCg horizon. Micrograph showing chamber. Crossed polarised light (x200)	21
17. Masaum Family. Profile 12. B2t, fe horizon. Micrograph showing void argillan. Crossed polarised light (x35)	21
18. Masaum Family. Profile 12. A1 horizon. Micrograph showing faecal pellets in chamber. Plane polarised light (x100)	21
19. Lumisir Family. Profile 13. B2t, fe horizon. Micrograph showing void argillan. Crossed polarised light (x200)	21
20. Tanjong Lipat Family. Profile 15. B1 horizon. Micrograph showing void argillans. Crossed polarised light (x200)	21
21. Tanjong Lipat Family. Profile 15. B1 horizon. Micrograph showing void argillans. Crossed polarised light (x200), same view as Plate 15.	21

	page
22. Tanjong Lipat Family. Profile 15. B1 horizon. Micrograph showing void argillan. Plane polarised light (x200)	21
23. Tanjong Lipat Family. Profile 15. B1 horizon. Micrograph showing root and faecal material in vugh. Plane polarised light (x250)	27
24. Tanjong Lipat Family. Profile 16. A1 horizon. Micrograph showing root development. Plane polarised light (x200)	27
25. Tanjong Lipat Family. Profile 16. AE horizon. Micrograph showing spongy structure. Plane polarised light (x200)	27
26. Tanjong Lipat Family. Profile 16. B2t, fe horizon. Micrograph showing void argillan. Crossed polarised light (x200)	27
27. Tanjong Lipat Family. Profile 16. B2t, fe horizon. Micrograph showing void argillan. Plane polarised light (x200). Same view as Plate 21.	27
28. Tanjong Lipat Family. Profile 18. CR horizon. Micrograph showing vughs. Plane polarised light (x35)	27
29. Tanjong Lipat Family. Profile 18. B2t horizon. Micrograph showing channel. Crossed polarised light (x200)	27

SUMMARY AND KEYWORDS

SUMMARY

An initial study of cutan development was undertaken of 21 profiles, representative of a wide range of soils in Sabah, Malaysia. On comparing the data with their site, morphological, chemical, particle size distribution and clay mineralogy characteristics, seven profiles representative of major soil families were selected for further micromorphological analysis. This involved full micromorphological description, together with point counting, in order to provide reliable quantified assessments of selected features, particularly of cutans. The seven profiles comprised two Ferralsols and five Acrisols. Electronic microprobe X-ray analysis confirmed the presence of ferrans in one Ferralsol profile.

The results show that although significant amounts of cutans may be developed in the B horizons of both Ferralsols and Acrisols, in the former they are either composed of iron oxides and are ferrans, or the horizon in which they occur is overlain by an oxic horizon. Cutans are not, therefore, considered to be a useful diagnostic criterion for separating the two groups of soils. On the other hand, good correlation was found between the percentage of cutans observed in thin sections and porosity, clay mineralogy and cation exchange capacity.

KEYWORDS

Acrisol, ferralsol, kaolinite, oxide clay, pedology, soil classification, soil micromorphology, soil structure, Malaysia.

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PART 1 INTRODUCTION

During a study by LRDC of the soils of Sabah in 1970-74 (Acres et al., 1975) it was often difficult to distinguish the limits between the Ferralsols and Acrisols as defined in the legend of the FAO Soil Map of the World (Food and Agriculture Organisation, 1974), which closely follows the concepts of Oxisols and Ultisols in Soil Taxonomy (US Department of Agriculture Soil Conservation Service, revised 1975). Basic to this problem was the identification of argillic horizons. Horizons were described, because of the presence of shining ped surfaces, as having cutans (e.g. Table 1, Profile 5, Benuou Family), while others (e.g. Table 1, Profile 6, Ambun Family) met the particle size distribution requirements of an argillic B horizon. Not having thin-sections to verify the presence or absence of cutans at the time when the soils were being classified, a fairly flexible approach towards horizon identification was adopted. The basic approach was that positive identification of horizons should be based on several features, none being necessarily common, diagnostic or particularly required to be absent. The predominance of oxic characteristics, however, necessitated the classification of such soils as Ferralsols. Argillic B and oxic B horizons are defined in Volume 5 of The Soils of Sabah (Acres et al., 1975) (appended here as Appendix 2).

This problem frequently could not be resolved with assurance by conventional field and laboratory techniques; hence a study of the micromorphology of a range of soils has been made. During this study special effort has been made to verify to what extent micromorphological data corresponded to that related to the field distribution of argillic B and oxic B horizons, and also to relate generally the micromorphological characteristics with other measurable properties of the soil.

PART 2 MATERIALS AND METHODS

The selection of soil material was made both with the view of obtaining representatives of a wide range of soil units (see Table 1) and also concentrating on the soil units Acrisols and Ferralsols in which the problem of identifying argillic horizons commonly occurred. Twenty-one soil profiles were described and sampled in the field and a laboratory analysis made of the chemistry, particle size distribution and clay mineralogy of each. The methods employed are described in Appendixes 3 and 5 of Volume 5 of 'The Soils of Sabah' (Acres et al., 1975), except for clay mineralogy, which was determined by X-ray analysis.

The soil units defined for the FAO-UNESCO Soil Map of the World (FAO, 1974) were used to classify the soils, together with locally recognised soil families. The classification is given in Table 1, and fully described in Volume 1 of Acres et al., (1975).

In situ sampling for micromorphological analysis was then undertaken following the method of Fitzpatrick (1970), together with the preparation of 10 x 5 cm sized thin sections. These were cut and mounted at Aberdeen University. Some profiles were sampled continuously to depth, while in others sampling was discontinuous, restricted to the median part of each horizon. A total of 187 thin sections was prepared for study.

A semi-quantative analysis was first made of the thin sections, primarily to identify profiles in which cutan development probably exceeded 1% of the total soil volume. Fourteen of the 21 profiles studied were so identified and seven selected, with the view to obtaining representatives from major soil families, for further study. This study used both plane and crossed polarised light and the soils were described systematically as recommended by Bullock (1974), basically using the terms of Brewer (1964). Soil structure was described according to the system of Bullock and Murphy (1976). The thin sections containing cutans were subject to optical measurement and, in addition to cutans, the proportions of voids, glaeboles, quartz grains and rock were determined. An automatic point counter consisting of an electric counter unit attached to a mechanical stage was used. The analysis was based on 1 500 point-counts for each thin section as recommended by Brewer (1964).

The distribution of certain elements in one thin section of an oxic B horizon was mapped by electronic microprobe X-ray analysis.

3.1 GENERAL SOIL DATA

The soil profile and site descriptions, together with the analytical data on chemistry, particle size distribution and clay mineralogy, are given in the Appendix 1.

3.2 MICROMORPHOLOGY

3.2.1 Semi-quantative analysis

A semi-quantative estimate of cutans in a range of soils is summarised in Table 1. It can be seen in the table that the microscopically determined cutans relate well with the horizon designations assigned as the result of the earlier field and laboratory work. There is, however, an outstanding exception, with cutans occurring in the oxic horizons of Ferralsols.

3.2.2 Quantative analysis

The following account gives the general characteristics of the seven profiles examined in more detail, comprising two representatives of the Orthic Ferralsols, one Gleyic Acrisol, one Ferric Acrisol and three Orthic Acrisol profiles.

3.2.2.1 Orthic Ferralsols

Benuou Family - Profile 5 Quartz grains of sand and silt, with the sand fraction varying from 26 to 64% of the total soil volume, predominate. Iron oxide appears to be replacing silica throughout the soil as evidenced by iron honeycombing some quartz grains and forming dark reddish brown haloes around others. Small, sub-rounded, black, undifferentiated and isotopic nodules also occur, having two maxima, in the BE horizon, (1.0% of total soil volume) and in the B_{3ox} horizon (3%). The predominance of the

TABLE 1 Semi-quantative estimate of cutans in a range of soils

Soil unit	Family	Profile no.	Horizons with cutans >1% total soil volume
Gleyic Podzol	Baiayo	1	Nil
		2	Nil
	Pa Sia	3	Bg and BCg
Orthic Podzol Orthic Ferralsol	Sibuga	4	Nil
	Benuou	5*	B1ox B2ox and
	Ambun	6*	B1. B2ox. B3ox
Gleyic Acrisol	Inanam	7	B2g
		8	B1g and B2t,g
		9	B1t
	Gunong Alab	10	Nil
	Masaum	11	BC1g, cn
		12*	B2t, fe
		13*	B2t, fe
	Ferric Acrisol	Lumisir	14
15*			B1 and B2t
Orthic Acrisol	Tanjong Lipat	16*	E. B1t. B2t, fe and R
		17	BC
		18*	AE. B1t and B2t
		19	Bt, cn
Orthic Luvisol	Lumpangon	19	Bt, cn
Dystric Cambisol	Laab	20	Nil
Albic Arenosol	Serai	21	Nil

* Profile selected for detailed micromorphological study

quartz grains gives rise to an agglomeroplastic soil fabric with an aseptic plasma incorporating normal void argillans in the B horizon. The argillans reach their maximum expression (3% of the total soil volume) in the B_{2ox} horizon where they are common, thick and compound, in parts lining plasma and coating quartz grains (see Plate 1). A weakly developed soil structure is dominant, but is vughy in parts. The voids occupy a maximum of 47% of the total soil volume but decrease at depth. A well defined stone-line consisting of angular iron-indurated sandstone fragments (see Plate 2) with their long axes parallel to the soil surface is conspicuous in the B_{3ox} horizon. Litter is restricted to the surface where it is intimately mixed with faecal pellets and roots. The extent of the faecal pellets is such that they probably comprise much of the s-matrix of the A horizon (see Plate 3), below which they are restricted to void infillings extending down into the B_{1ox} horizon, which also marks the observed limit of roots. The main micromorphological data are given in Table 2.

Ambun Family - Profile 6 The soil fabric is porphyroskelic and composed of dark reddish brown to brownish yellow, predominantly argillasepic plasma, scattered in which are very few, very fine, subangular to subrounded quartz grains, together with angular to subrounded black isotopic nodules which reach their maximum expression in the B_{3ox} horizon where they occupy some 3.7% of the total soil volume. Electronic probe analysis has shown that these are composed largely of chromium (see Plates 9, 10 and 11). There is a combination of subangular blocky and crumb structures, the former being dominant in the top 40 cm of the soil. Compound packing voids predominate except in the upper part of the B horizon where vughs, chambers and vesicles assume local importance (see Plate 4). The soil is highly porous (see Plate 9) with the voids occupying between 26 and 37% of total soil volume to a depth of 90 cm (see Plate 5). Litter is restricted to the A₁ horizon and upper part of the B₁ horizon whilst living roots extend into the B₁ horizon. Evidence of faecal pellets occurs throughout the soil and, below the B₁ horizon, appears as chamber and channel infillings (see Plate 6), sometimes incorporated in the s-matrix. Compound void terrans occur throughout, and the predominance of Fe in the cutans is confirmed by the X-ray diffraction pattern shown by electron probe analysis (see Plates 12, 13 and 14). The ferrans are best developed in the B_{2ox} horizon occupying some 8.5% of the total soil volume (see Plates 7 and 8). The data are summarised in Table 3.

TABLE 2 Main micromorphological data for Profile 5. Benuou Family Orthic Ferralsol

Horizon	Structure	Soil fabric	Skeletal grains		Voids		Plasma		Glaebules		Organic matter
				%*		%*	Fabric	Cutans		%*	
A1	vughy to coprogenic	agglomeroplasmic	quartz	nd	orthovughs	nd	undulic	absent	rounded nodules	nd	roots and faecal pellets
BE	subangular blocky	agglomeroplasmic	quartz	54	simple packing voids	29	asepic	normal void argillans	rounded nodules	1.0	roots and faecal pellets
B1ox	vughy to subangular blocky	agglomeroplasmic	quartz	50	orthovughs	47	asepic	normal void argillans	rounded nodules	0.2	roots and faecal pellets
B2ox	vughy to subangular blocky	agglomeroplasmic	quartz	51	orthovughs	31	asepic	normal void argillans	rounded nodules	0.4	absent
B3ox	subangular blocky to vughy	agglomeroplasmic	quartz	58	orthovughs	31	asepic	normal void argillans	rounded nodules	3.0	absent
B4ox	vughy to subangular blocky	agglomeroplasmic	iron indurated sandstone and quartz	nd	orthovughs	nd	asepic	normal void argillans	rounded nodules	nd	absent

* Expressed in terms of total soil volume
nd - not determined

TABLE 3 Main micromorphological data for Profile 6*. Ambun Family Orthic Ferralsol

Horizon	Structure	Soil fabric	Voids	Plasma		Glaebules		Organic matter
				Fabric	Cutans	%**	%**	
A1	subangular blocky to crumb	porphyroskelic	channels and compound packing voids	undulic	simple void ferrans	nd	botryoidal nodules	roots and faecal pellets
B1	subangular blocky to crumb	porphyroskelic	compound packing voids	argillasepic	compound void ferrans	1.6	botryoidal nodules	roots and faecal pellets
B2ox	subangular blocky to crumb	porphyroskelic	chambers	argillasepic	compound void ferrans	8.5	subangular to rounded nodules	faecal pellets
B3ox	crumb to subangular blocky	porphyroskelic	compound packing voids	argillasepic	compound void ferrans	1.5	irregular shaped nodules	faecal pellets

* Micromorphology of B4ox horizon not analysed
 ** Expressed in terms of total soil volume
 nd = not determined

- Plate 1 Benuou Family. Profile 5. B2ox horizon. Micrograph showing void argillan lining quartz grains. Crossed polarised light (x200)
- Plate 2 Benuou Family. Profile 5. B3ox horizon. Micrograph showing iron-indurated sandstone fragments. Plane polarised light (x100)
- Plate 3 Benuou Family. Profile 5. A horizon. Micrograph showing the high proportion of faecal pellets. Plane polarised light (x200)
- Plate 4 Ambun Family. Profile 6. B1 horizon. Micrograph showing characteristic voids. Plane polarised light (x80)
- Plate 5 Ambun Family. Profile 6. A horizon. Micrograph showing the high degree of porosity characteristic of the soil. Plane polarised light (x35)
- Plate 6 Ambun Family. Profile 6. B2ox horizon. Micrograph showing faecal pellets forming channel infillings. Plane polarised light (x35)
- Plate 7 Ambun Family. Profile 6. B2ox horizon. Micrograph showing void ferrans. Crossed polarised light (x200)
- Plate 8 Ambun Family. Profile 6. B3ox horizon. Micrograph showing void ferrans. Note chromite nodule central left. Plane polarised light (x200)

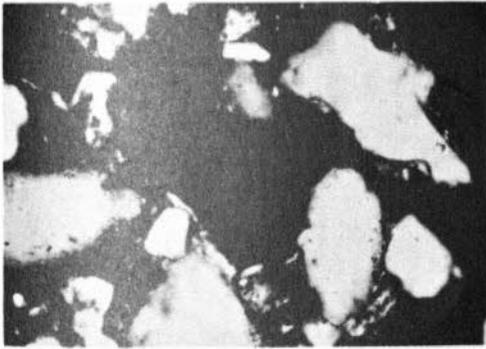


PLATE 1

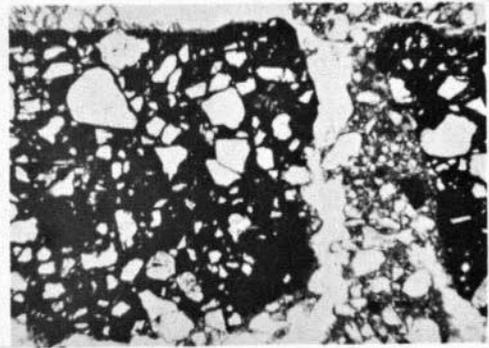


PLATE 2

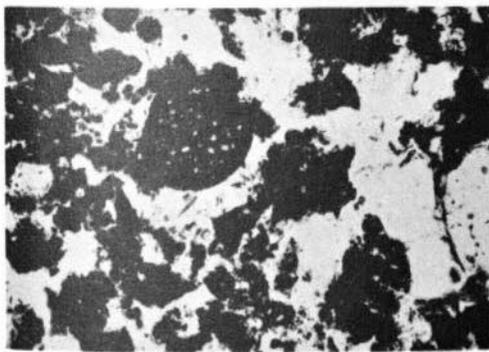


PLATE 3

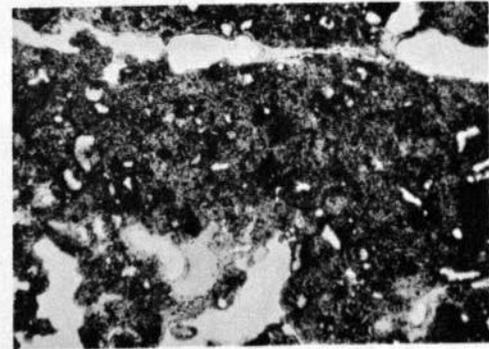


PLATE 4

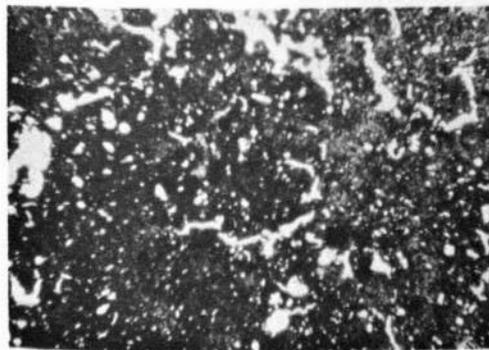


PLATE 5

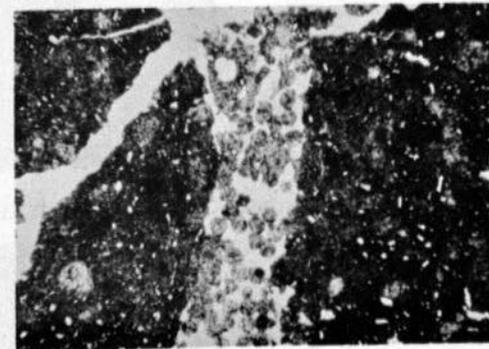


PLATE 6

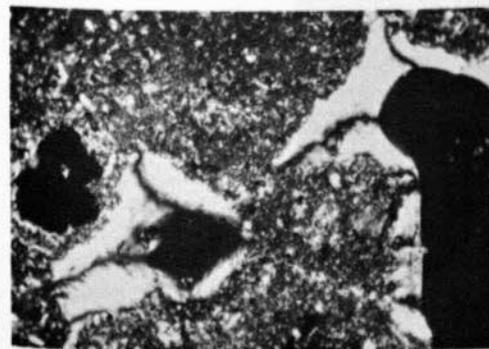


PLATE 7

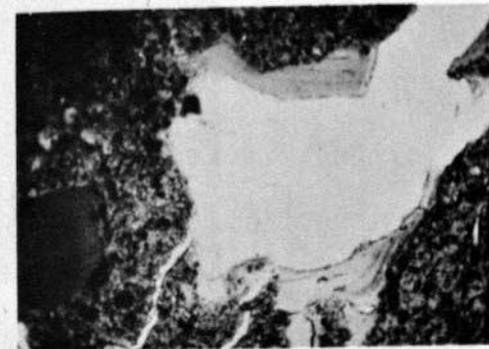


PLATE 8

Plate 9 Scanning electron microscope micrograph of part of the B2ox horizon of Profile 6, Ambun Family, showing nodule development. Note the porosity of the matrix (x40)

Plate 10 Same field as Plate 25, micrograph showing X-ray image of Cr as displayed on oscilloscope screen. Density of white dots is approximately proportional to the concentration of Cr.

Plate 11 Same field as Plates 25 and 26, micrograph showing X-ray image of Fe as displayed on oscilloscope screen. There is no marked concentration of Fe.

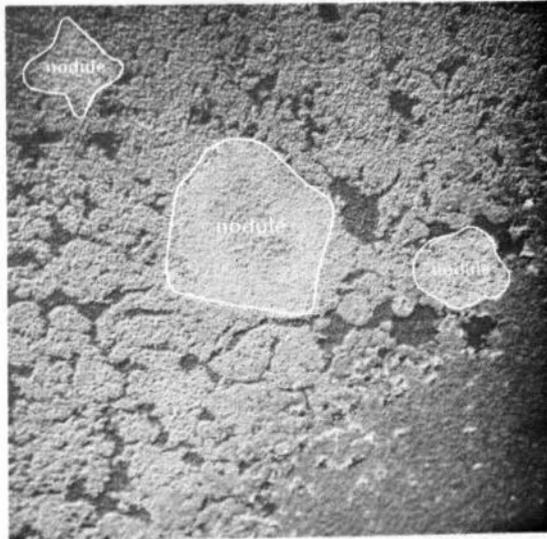


PLATE 9

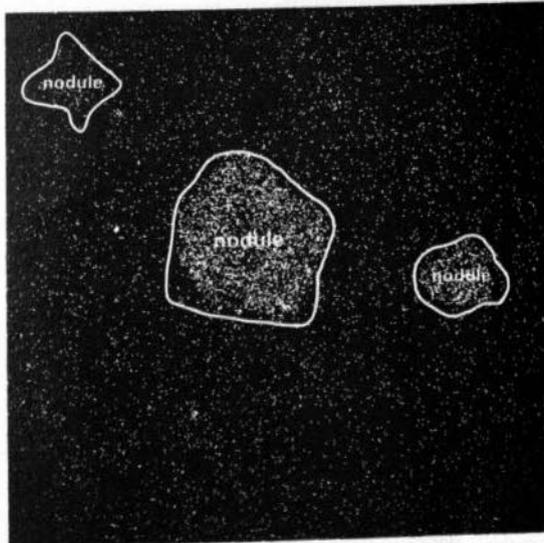


PLATE 10

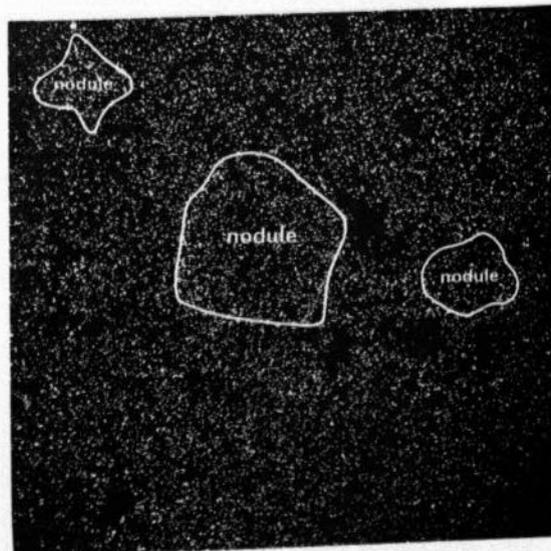


PLATE 11

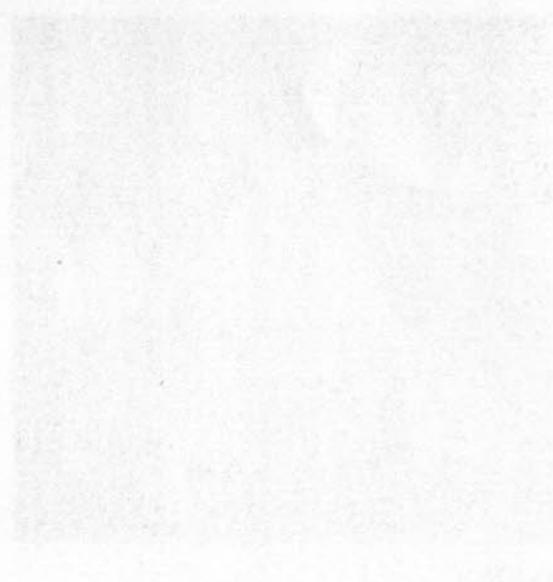


Plate 12 Scanning electron microscope micrograph of part of the B2ox horizon of Profile 6, Ambun Family showing cutan (ferran) development (x31)

Plate 13 Same field as Plate 28, micrograph showing X-ray image of Fe as displayed on oscilloscope screen. Density of white **dots** is approximately proportional to the concentration of Fe.

Plate 14 Same field as plates 28 and 29, micrograph showing X-ray image of A1 as displayed on oscilloscope screen. There is no marked concentration of A1.

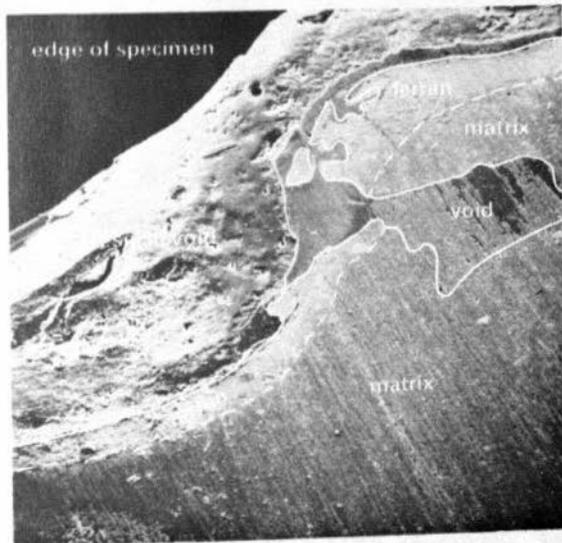


PLATE 12

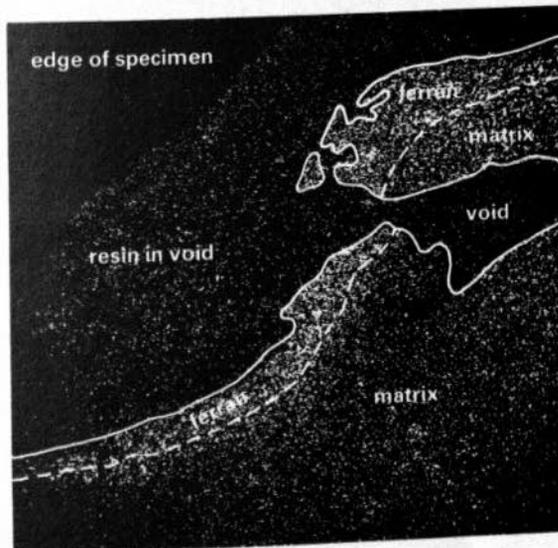


PLATE 13

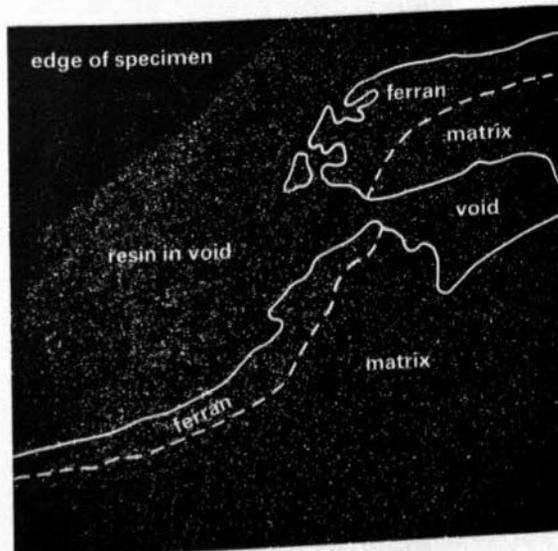


PLATE 14

3.2.2.2 Gleyic Acrisol

Masaum Family - Profile 12 Although the soil structure is generally vughy, it is subangular blocky in the A1 horizon and there is a tendency to a fissure structure in the BCg horizon. The voids are regular orthovughs (see Plate 15) with some chambers (see Plates 16 and 17). The soil fabric is porphyroskelic with the skeleton grains composed of gravel-sized iron stained fragments of siltstone and subangular to rounded quartz sand in a predominantly sepic plasma, except for the A1 and BCg horizons which are silasepic. Simple, normal void argillans appear throughout (see Plate 18) reaching a maximum of 1.0% of the total soil volume in the B2t, fe horizon. Weakly developed diffusion ferrans occur in the B2t, fe horizon. Small black, undifferentiated and isotopic nodules occur scattered throughout, bladed in the plasma, and rounded elsewhere. Evidence of root activity extends into the B2t, fe horizon, while faunal activity, as exemplified simple faecal pellets, are restricted to certain root channels in the A1 horizon (see Plate 19). The main micromorphological data are summarised in Table 4.

3.2.2.3 Ferric Acrisol

Lumisir Family - Profile 13 The soil fabric is agglomeroplasmic with skeletal grains composed of subangular to rounded quartz grains and scattered, rounded, fine, undifferentiated, black, isotopic nodules, in an asepic plasma. There are few, thin, compound, normal void argillans in the E and B horizons which reach their greatest development in the B2t, fe horizon (see Plate 20) occupying 1.2% of the total soil volume. Compound packing voids are found in the A and E horizons, and regular orthovughs in the B. The soil structure is more variable; predominantly vughy to subangular blocky in the A and E horizons, platy and vughy in the B1 horizon with the linearity probably marking a sub-horizontal depositional plane of the parent material (alluvium) and pronounced subangular blocky structure in the B2t, fe horizon. Evidence of litter is restricted to the surface of the soil where decomposing fragments of vegetation are admixed with simple and compound faecal pellets including rare earthworm casts. Faecal pellets also occur in the B2t, fe horizon in poorly-defined chambers. Observed root activity is restricted to the A, AE and E horizons. The micromorphological data are summarised in Table 5.

TABLE 4 Main micromorphological data for Profile 12. Masaum Family Gleyic Acrisol

Horizon	Structure	Soil fabric	Skeletal grains	Voids		Plasma		Glaebules	Organic matter	
					%*	Fabric	Cutans			%*
A1	subangular blocky to vugty	porphyroskelic	quartz	orthovugh	nd	silasepic	simple, normal void argillans	absent	0	roots and faecal pellets
EB	vugty to subangular blocky	porphyroskelic	quartz and siltstone	orthovugh	31	sepic	simple, normal void argillans	rounded and bladed nodules	0	roots and faecal pellets
B1t	vugty to subangular blocky	porphyroskelic	quartz and siltstone	orthovugh	22	sepic	simple, normal void argillans	rounded and bladed nodules	0	roots
B2t, fe	vugty to subangular blocky	porphyroskelic	quartz and iron-stained siltstone	orthovugh	35	sepic	compound, normal void argillans	rounded and bladed nodules	12.0	roots
BCg	Fissure to vugty	porphyroskelic	quartz and iron-stained siltstone	chamber	31	silasepic	simple, normal void argillans	rounded and bladed nodules	11.7	absent

* Expressed in terms of total soil volume
nd = not determined

TABLE 5 Main micromorphological data for profile 13* Lumisir Family Ferric Acrisol

Horizon	Structure	Soil fabric	Skeletal grains %**	Voids %**	Plasma		Glaebules %**	Organic matter
					Fabric	Cutans %**		
A1	vugly	agglomero-plasmic	quartz nd	compound packing voids nd	asepic	absent	rounded nodules nd	litter, roots and faecal pellets nd
AE	vugly to subangular blocky	agglomero-plasmic	quartz nd	compound packing voids nd	asepic	absent	rounded nodules nd	litter, roots and faecal pellets nd
E	subangular blocky to vugly	agglomero-plasmic	quartz nd	compound packing voids nd	asepic	absent	rounded nodules nd	roots nd
B1t	platy to vugly	agglomero-plasmic	quartz 80	orthovughs 12	asepic	compound, normal void argillans	rounded nodules 0.7	absent 0
B2t, fe	subangular blocky	agglomero-plasmic	quartz 62	orthovughs 11	asepic	compound, normal void argillans	rounded nodules 1.2	faecal pellets 3

* Micromorphology of BCG horizon not analysed
 ** Expressed in terms of total soil volume
 nd = not determined

- Plate 15 Masaum Family. Profile 12. A1 horizon. Micrograph showing vughs. Plane polarised light (x35)
- Plate 16 Masaum Family. Profile 12. A1 horizon. Micrograph showing chamber. Plane polarised light (x35)
- Plate 17 Masaum Family. Profile 12. BCg horizon. Micrograph showing chamber. Crossed polarised light (x200)
- Plate 18 Masaum Family. Profile 12. B2t, fe horizon. Micrograph showing void argillan. Crossed polarised light (x35)
- Plate 19 Masaum Family. Profile 12. A1 horizon. Micrograph showing faecal pellets in chamber. Plane polarised light (x100)
- Plate 20 Lumisir Family. Profile 13. B2t, fe horizon. Micrograph showing void argillan. Crossed polarised light (x200)
- Plate 21 Tanjong Lipat Family. Profile 15. B1 horizon. Micrograph showing void argillans. Crossed polarised light (x200)
- Plate 22 Tanjong Lipat Family. Profile 15. B1 horizon. Micrograph showing void argillans. Crossed polarised light (x200). Same view as Plate 15

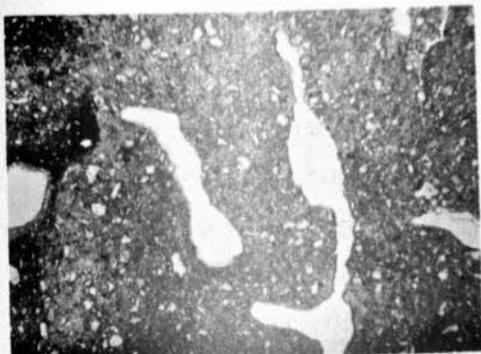


PLATE 15

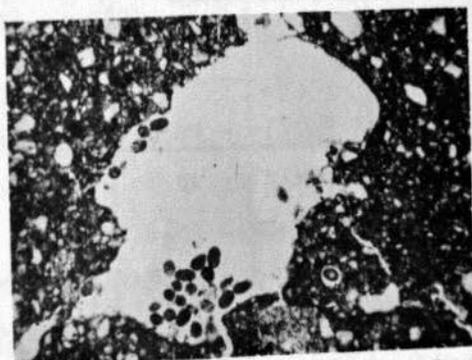


PLATE 16

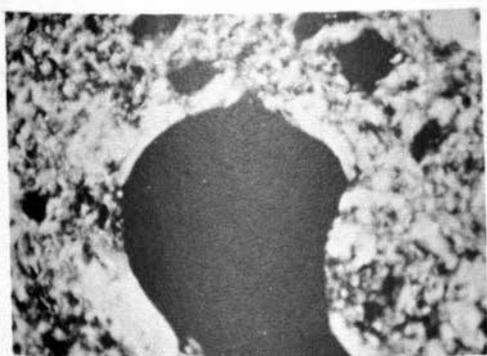


PLATE 17

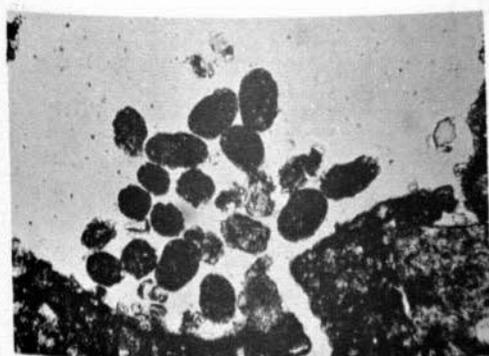
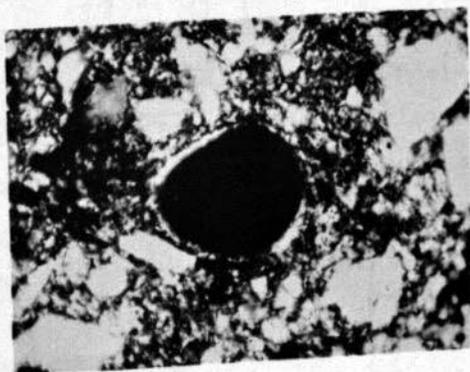


PLATE 19

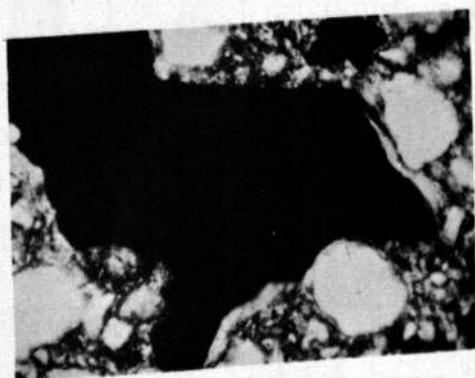


PLATE 20

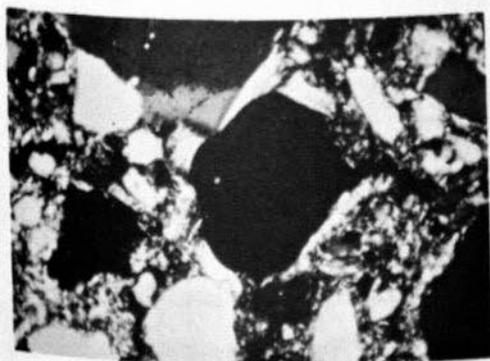


PLATE 21

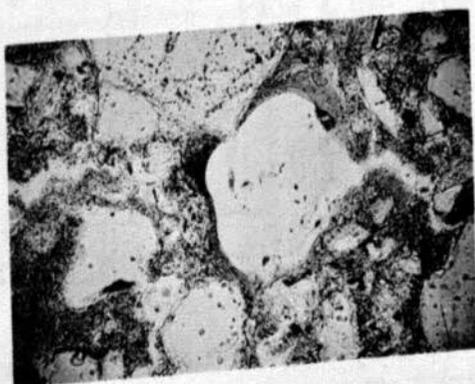


PLATE 22

3.2.2.4 Orthic Acrisols

Tanjong Lipat Family - Profile 15 Angular to subangular quartz grains predominate comprising up to 7% of the total soil volume, and giving rise to an agglomeroplastic soil fabric. The sand grains grade in size into the silt fraction, particularly in the A1 and B1t horizons, contributing to a pronounced silasepic fabric to the plasma. In the B2t horizon the plasma is more uniform and sepic. Void argillans occur throughout the B horizons and are best developed in the B1t occupying 5.0% of the total soil volume (see Plates 21, 22 and 23). Compound packing voids occur in all horizons. Vughs also occur in the B1t and B2t horizons (see Plates 21 and 22), and are probably related to faunal and root activity (see Plate 24). The overall soil structure is ill defined, but tends to be subangular blocky in the A horizons, vughy in the B1t and subangular blocky to crumb in the B2t horizons. Roots are particularly well developed in the A1 horizon (see Plate 25). Table 6 summarises the main data.

Tanjong Lipat Family - Profile 16 The soil fabric is agglomeroplastic with the skeleton grains composed of angular to subangular quartz sand which grade into silt-size particles in the plasma. In the B and R horizons much of the skeletal grains are composed of sandstone fragments containing the characteristic angular quartz grains of the fine-earth fraction. The plasma ranges from asepic in the weathering sandstone to sepic above. The AE and E horizons have much pore space and have a spongy structure (see Plate 26). This grades into a vughy structure below. The distribution of voids is related to these structural changes, with irregular packing voids in the AE and E horizons and regular orthovughs with some regular channels below. Compound void argillans occur reaching a maximum of 5.8% of the total soil volume in the B1t horizon and continuing at depth (see Plates 27 and 28). Small black, undifferentiated and isotopic nodules are loosely scattered throughout the soil. Decomposing root material extends into the E horizon. Table 7 gives the main micromorphological data.

Tanjong Lipat Family - Profile 18 The soil fabric is porphyroskelic with an asepic plasma and skeleton grains consisting of angular to rounded quartz which also comprise the silt fraction of the plasma. Compound, normal void argillans occur in the AE and B horizons, and are best developed in the

TABLE 6 Main micromorphological data for Profile 15* Tanjong Lipat Family Orthic Acrisol

Horizon	Structure	Soil fabric	Skeletal grains	Voids	Plasma		Glaebules	Organic matter			
					fabric	cutans			%**	%**	
A1	subangular blocky	agglomeroplasmic	quartz	compound packing voids	nd	silasepic	absent	nd	subrounded nodules	nd	roots and faecal pellets
AE	vughy	agglomeroplasmic	quartz	chambers and channels	29	silasepic	simple void argillans	0.1	subangular and irregular nodules	0.1	roots and faecal pellets
B1b	subangular blocky to crumb	agglomeroplasmic	quartz	orthovughs	24	silasepic	compound void argillans	5.0	subangular nodules	0.1	roots and faecal pellets
B2t	angular blocky to vughy	agglomeroplasmic	quartz	orthovughs	15	sepic	simple void argillans	1.4	absent	0	roots and faecal pellets

* Micromorphology of R not analysed
 ** Expressed in terms of total soil volume
 nd = not determined

TABLE 7 Main micromorphological data for Profile 16. Tanjung Lipat Family Orthic Acrisol

Horizon	Structure	Soil fabric	Skeletal grains	Voids		Plasma		Glaebules	Organic matter
					%*	fabric	cutans		
AE	spongy	agglomeroplastic	quartz	compound packing voids	nd	sepic	absent	nd	litter and roots
E	spongy	agglomeroplastic	quartz	compound packing voids and channels	54	sepic	compound void argillans	4.7	roots
B1t	vughy	agglomeroplastic	quartz and sandstone	orthovughs	37	sepic	compound void argillans	5.8	absent
B2t, fe	vughy	agglomeroplastic	quartz and sandstone	orthovughs and channels	38	sepic	compound void argillans	3.8	absent
R	vughy	agglomeroplastic	sandstone	orthovughs	84	asepic	compound void argillans	2.1	absent

* Expressed in terms of total soil volume
nd = not determined

B2t horizon comprising 4.4% of the total soil volume. Normal orthovughs occur throughout (see Plate 29) except for parts of the B2t horizon where normal channels predominate (see Plate 30). Sandstone fragments occupy as much as 16.3% of the total soil volume in part of the B1t horizon and increase in proportion with depth. Small, black, undifferentiated and isotopic nodules are common throughout both sandstone and soil. A sub-angular blocky structure predominates. Evidence of faunal activity extends from the surface of the soil into the AE horizon in the form of rare worm casts, and with small faecal pellets in the A1 horizon. Fine disseminated fragments of decomposing litter occur down into the B1t horizon and may be related to faunal activity. A summary is given in Table 8.

- Plate 23 Tanjong Lipat Family. Profile 15. B1 horizon. Micrograph showing void argillan. Plane polarised light (x200)
- Plate 24 Tanjong Lipat Family. Profile 15. B1 horizon. Micrograph showing root and faecal material in vugh. Plane polarised light (x250)
- Plate 25 Tanjong Lipat Family. Profile 15. A1 horizon. Micrograph showing root development. Plane polarised light (x200)
- Plate 26 Tanjong Lipat Family. Profile 16. AE horizon. Micrograph showing spongy structure. Plane polarised light (x200)
- Plate 27 Tanjong Lipat Family. Profile 16. B2t, fe horizon. Micrograph showing void argillan. Crossed polarised light (x200)
- Plate 28 Tanjong Lipat Family. Profile 16. B2t, fe horizon. Micrograph showing void argillan. Plane polarised light (x200).
Same view as Plate 21
- Plate 29 Tanjong Lipat Family. Profile 18. CR horizon. Micrograph showing vughs. Plane polarised light (x35)
- Plate 30 Tanjong Lipat Family. Profile 18. B2t horizon. Micrograph showing channel. Crossed polarised light (x200)

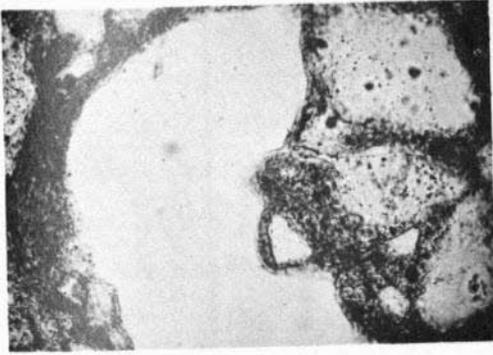


PLATE 23

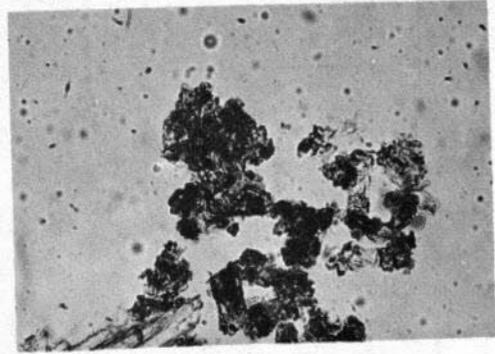


PLATE 24

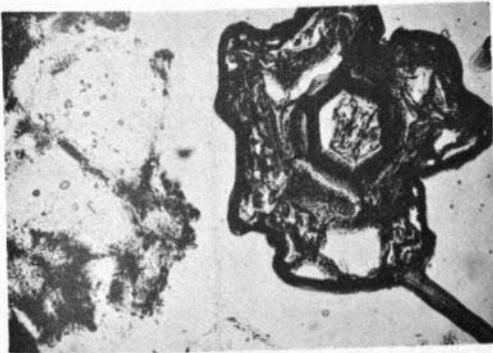


PLATE 25

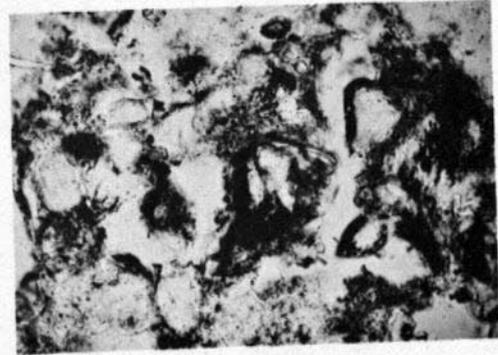


PLATE 26

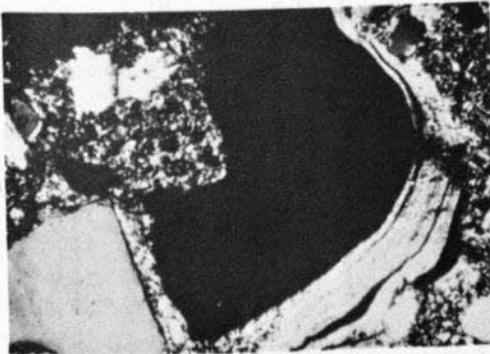


PLATE 27

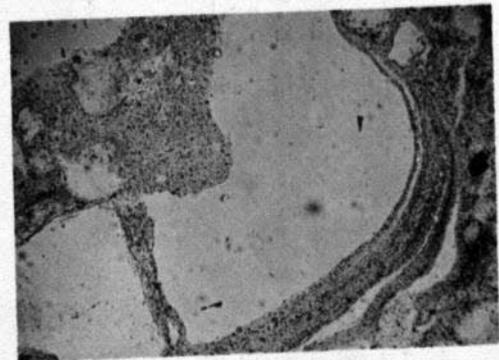


PLATE 28

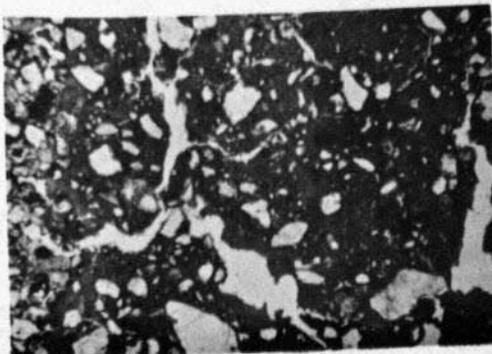


PLATE 29

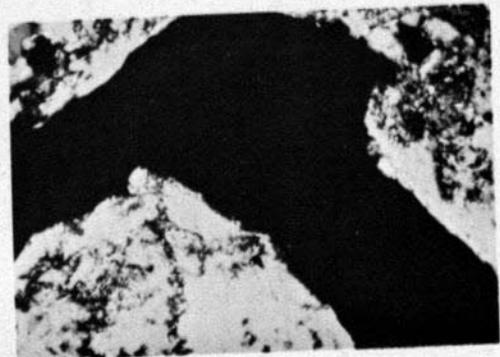


PLATE 30

TABLE 8 Main micromorphological data for Profile 18. Tanjong Lipat Family Orthic Acrisol

Horizon	Structure	Soil fabric	Skeletal grains	Voids		Plasma			Glaebules	Organic matter
					%*	fabric	cutans	%*		
A1	crumb to subangular blocky	porphyroskelic	quartz	orthovughs	nd	asepic	absent	nd	subrounded nodules	litter, roots and faecal pellets
AE	subangular blocky to crumb	porphyroskelic	quartz and sandstone	orthovughs	34	asepic	compound void argillans	2.4	subrounded nodules	litter, roots and faecal pellets
B1t	subangular blocky to crumb	porphyroskelic	quartz and sandstone	orthovughs	49	asepic	normal void argillans	3.2	subrounded nodules	litter, roots and faecal pellets
B2t	subangular blocky to vughy	porphyroskelic	quartz and sandstone	orthovughs and channels	52	asepic	compound void argillans	4.4	subrounded nodules	absent
CR	subangular blocky to vughy	porphyroskelic	quartz and sandstone	orthovughs	nd	asepic	compound void argillans	nd	subrounded nodules	absent

* Expressed in terms of total soil volume
nd = not determined

PART 4 DISCUSSIONS AND CONCLUSIONS

From the results given in the preceding section answers to a number of questions can be at least partly resolved. The questions mainly relate to the extent which the results of the micromorphological examination correspond to the conventional use of field and laboratory data to determine the distribution of the oxic B and argillic B horizons, and the implications for soil classification.

4.1 IDENTIFICATION

The main problem of identification lies with the argillic B horizon. Clay translocation can be difficult to detect in both the field and the laboratory, even when data on particle size distribution is available. When thin-sections are available, the identification of an argillic B horizon can be uncertain, because of the difficulties involved in determining the amount and mineralogy of the cutans. Study of the thin-sections has revealed that the problem mainly concerns the Ferralsols (Profiles 5 and 6). Why the problem of identifying argillic B horizons particularly relates to soils with predominant oxic characteristics is not understood. The taxonomic significance of the argillic B horizon, together with that of the less problematical oxic B horizon is discussed later, under Implications for soil classification.

4.2 RELATIONSHIPS OF SOIL PROPERTIES USED IN THE DIFFERENTIATION OF THE B HORIZON

Although the main question concerns evidence of clay illuviation, it is important to investigate other characteristics which might help to differentiate the two B horizons. Table 9 gives selected field, laboratory and micromorphological data with this in view. The main relationships are discussed below.

TABLE 9 Selected field, laboratory and micromorphological data of the soil profiles used to assist in differentiating the oxic B and argillic B horizons

Profile	Soil classification		Field data			Laboratory data			Micromorphological data				
	Unit	Family	Horizon*	Horizon*	Dominant structures	CEC me /100g clay	Clay %	Dominant mineral in PWT sized fraction	Cutans %	Voids %	Dominant soil fabric	Dominant structures	Organic matter
5	Orthic Ferralsol	Benuou	A1	Absent	SAB	39.4	17	Kaolinite	n.d.	n.d.	Agglomeroplastic	Vughy	Roots, faecal pellets
			BE	Absent	"	14.3	21	"	0.1	29	"	SAB	"
			B1ox	"	"	18.4	25	"	1.9	47	"	Vughy	"
			B2ox	Present	"	13.2	25	"	3.0	31	"	"	Absent
			B3t, fe	"	"	19.1	23	"	2.4	31	"	"	"
B4fe	Absent	"	20.8	26	"	"	"	n.d.	"	"	"		
6	Orthic Ferralsol	Ambun	A1	Absent	"	80.4	46	Goethite and Haematite	n.d.	n.d.	Porphyro-skelic	SAB	Roots, faecal pellets
			B1	"	AB	26.6	32	"	1.6	28	"	SAB	"
			B2ox	"	"	11.1	44	"	8.5	37	"	SAB	Faecal pellets
			B3ox	"	"	12.1	23	"	1.5	28	"	Crumb	"
			B4ox	"	"	27.0	37	"	"	"	n.d.	n.d.	n.d.
12	Gleyic Acrisol	Masaum	A1	Absent	SAB	51.9	27	Vermiculite and Illite	n.d.	n.d.	Porphyro-skelic	SAB	Roots, faecal pellets
			EB	"	"	41.3	31	Vermiculite	0.9	31	"	Vughy	"
			B1t	"	"	41.1	35	"	0.2	22	"	"	Roots
			B2t, fe	Present	Prismatic	45.9	29	Vermiculite and Illite	1.0	35	"	"	"
			BCg	Absent	SAB	33.3	45	Illite	0.7	31	"	Fissure	Absent
13	Ferric Acrisol	Lumisir	A1	Absent	Crumb SAB	69.2	12	Vermiculite	n.d.	n.d.	Agglomeroplastic	Vughy	Litter, roots, faecal pellets
			AE	"	"	44.0	15	"	n.d.	n.d.	"	"	"
			E	"	"	29.3	14	"	n.d.	n.d.	"	"	"
			B1t	Present	"	18.9	19	"	0.7	12	"	SAB	Roots
			B2t, fe	"	"	24.0	25	Vermiculite and Kaolinite	1.2	11	"	Platy SAB	Absent
15	Orthic Acrisol	Tanjong Lipat	AE	Absent	"	23.4	35	Vermiculite	n.d.	n.d.	n.d.	n.d.	Faecal pellets
			A1	Absent	SAB	102.1	14	"	n.d.	n.d.	Agglomeroplastic	SAB	Roots, faecal pellets
			AE	"	"	67.9	14	"	0.1	29	"	Vughy	"
			B1t	Present	"	43.7	19	"	5.0	24	"	SAB	"
			B2t	"	"	40.5	19	"	1.4	15	"	AB	"
16	Orthic Acrisol	Tanjong Lipat	AE	Absent	"	82.0	10	Kaolinite	n.d.	n.d.	Agglomeroplastic	Spongy	Litter, roots
			E	"	"	52.9	14	"	4.7	21	"	"	Roots
			B1t	Present	"	50.0	31	"	5.8	11	"	"	Absent
			B2t	Absent	"	31.2	25	"	3.8	23	"	"	"
			CR	Absent	"	"	"	"	"	"	"	"	"
18	Orthic Acrisol	Tanjong Lipat	A1	Absent	Crumb SAB	61.0	21	Vermiculite	n.d.	n.d.	Porphyro-skelic	Crumb SAB	Litter, roots, faecal pellets
			AE	"	"	41.7	24	"	2.4	29	"	"	"
			B1t	Present	"	35.9	29	"	3.2	29	"	"	"
			B2t	"	"	39.0	28	"	4.4	9	"	"	"
			CR	Absent	"	51.3	16	"	"	"	n.d.	"	Absent

* Designated prior to the micromorphological study, and based on the field and laboratory data
 / SAB - Subangular blocky AB - angular blocky

4.2.1 Cutans and clay illuviation

The presence of cutans is generally accepted as evidence of clay translocation, and the micromorphological data show that they occur in all the B horizons of each of the soil profiles studied, and in sufficient amounts (1% or more of the soil) to satisfy the volumetric requirements of an argillic B horizon. Thus, in the case of the Acrisols, the occurrence of argillic B horizons is fully substantiated by the micromorphological data. With the Ferralsols, however, considerable problems occur in identifying the B horizons. Much of the field and laboratory evidence indicates the B horizons to be oxic, but the micromorphology shows them to contain significant amounts of cutans. It should be noted, however, that the cutans occurring in Profile 6 are composed of iron oxide and not layer-lattice silicate clays which is one of the criteria specified in Soil Taxonomy (US Department of Agriculture, 1975) for defining an argillic B horizon. Even so, clay-sized particles are being precipitated, in this case from a soil solution supersaturated with iron.

4.2.2 Cation exchange capacity (CEC)

Oxic B horizons are characteristically at an advanced stage of weathering. One of the criteria used in their identification is CEC, which should be 16 meq or less per 100 grams of clay. The data shown in Table 9 indicates that the clays of the oxic B horizons are, in general, of low activity, and there is a reasonable correlation with the other oxic features. This correlation is endorsed by the fact that the CECs of all the Acrisol profiles are well above the specified limit.

4.2.3 Structure and porosity

The combination of different types of peds and voids gives rise to a wide range of structure but, as can be seen from Table 9, there is very little relation between the ped shapes described in the field and those determined microscopically. Similarly, there are no diagnostic structural differences discernable for oxic B horizons or argillic B horizons. There is, however, a clear difference in porosity between the two horizons. When the porosity, as determined by the proportion of the soil occupied by voids, is considered, the oxic B horizons are found to be significantly more porous. This difference in

porosity between the oxic B and argillic B horizons is well illustrated by Figure 1. The figure also establishes that there is a poor relationship between porosity and clay content.

4.2.4. Fabric characteristics

The micromorphological data concerning the soil fabric are summarised in Table 9, and those of the plasma in Tables 2 to 8. The tables show that there is little correlation between the distribution of oxic B horizons or argillic B horizons: the soil fabric may be agglomeroplasmic or porphyroskelic in either; and the plasma, although aseptic in the oxic B horizons, can be aseptic or septic in the argillic B horizons.

4.2.5 Clay mineralogy

The clays of oxic B horizons, because of their highly weathered nature, should primarily be a mixture of 1:1 type crystal lattice clays and sesquioxides. This is well supported by the mineralogical data given in Table 9, which shows that the dominant clay sized minerals in the oxic B horizons are composed of iron oxides and kaolinite. The clays of the argillic B horizons are predominantly vermiculite, although kaolinite and other 2:1 type crystal lattice clays also occur.

4.2.6 Biological activity

The micromorphological data on organic matter in Table 9 indicates that biological activity is intense in the A horizons. Evidence of litter - decomposing plant material - is sparse, reflecting rapid conversion of plant residues to nutrients in the nutrient cycling zone of these soils. That roots and fauna are the integral agents in the cycling of nutrients is seen by the concentration of root development and associated faecal pellets. Evidence of biological activity extends into the B horizons, where voids containing pellets are particularly common in the oxic horizons (Profiles 5 and 6) and even incorporated into the s-matrix (Profile 6). Similar activity also occurs in argillic B horizons (Profiles 12, 13, 15 and 18). This is contrary to what can be expected. The evidence points to a high rate of biological activity and soil mixing while the presence of cutans depends on the amount of clay translocation which is basic to the concept of the argillic B horizon in Soil Taxonomy (US Department of

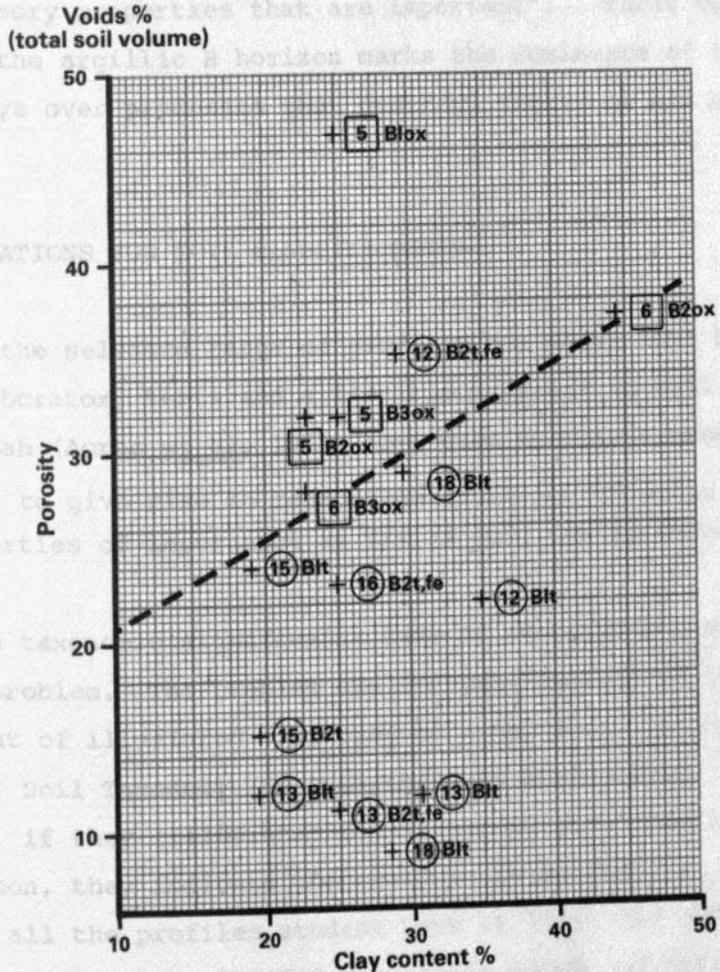
Agriculture, (1974). Thus judging from the amount of organic matter and the evidence of biological activity, the amount of clay has increased over the soil mixing process, is clear. This is in accordance with the tenets of Soil Taxonomy (US Department of Agriculture, 1975) that an argillic horizon by itself has little importance to soil classification and that it is the associated horizons that are important. Thus to make the point that the argillic horizon itself is not the cause of the increase in silicate clays over the soil mixing process.

4.1 IMPLICATIONS

The work on the soil field and laboratory soils of Sabah levels: so as to common properties

However, the a proposed problem of the amount of horizon. Soil states "... if any horizon, the

been shown, all the which the amount of this area



Note oxic B horizon \square , argillic B horizon \circ , profile numbers enclosed e.g. 15

FIGURE 1 The relationship between porosity (as optically measured voids) and clay content in some oxic B and argillic B horizons

resulting in an immobile clay...
 that we have with the...
 conditions can be recognized...
 very specialised and relatively...
 ventrally clay phenomena. It...
 at by applying the criteria...

Agriculture, (1975). Thus judging from the amount of cutans in relationship to the evidence of biological activity, the dominance of clay translocation over the soil mixing processes is clear. This is in accordance with the tenets of Soil Taxonomy (US Department of Agriculture, 1975) that the argillic horizon by itself has little importance to soil classification but that 'it is the accessory properties that are important'. Tacit to this is the recognition that the argillic B horizon marks the dominance of the translocation of silicate clays over processes that destroy, remove or mix horizons.

4.3 IMPLICATIONS FOR SOIL CLASSIFICATION

The work on the selected range of profiles has shown that by applying routine field and laboratory tests and a flexible approach to soil classification, the soils of Sabah (Acres et al, 1975) have been differentiated at the highest levels so as to give rise to reasonable groupings of soils with many common properties of importance as far as soil use is concerned.

However, the taxonomic significance made of the argillic B horizon still poses a profound problem. The problem applies particularly to the quantification of the amount of illuviated clay used as a criterion to identify an argillic B horizon. Soil Taxonomy (US Department of Agriculture, 1975), page 38, states '.... if they (illuviated clays) occupy more than 1% of the volume of any subhorizon, they indicate the presence of an argillic horizon'. As has been shown, all the profiles studied have at least one subhorizon of the B in which the amount of translocated clay is in excess of this figure. Clearly, this substantiates the Acrisols grouping but not that of the Ferralsols. Indeed, the amount of clay movement implied contradicts the common concept of oxic conditions - a high order of stability affording extreme weathering resulting in an immobile clay fraction.

Thus we have with the Ferralsols a classification problem whereby oxic conditions can be recognised by routine tests without much difficulty, but where specialised and relatively difficult micromorphological tests show contrary clay phenomena. It is true that the correct answers are arrived at by applying the criteria of Soil Taxonomy (US Department of Agriculture, 1975)

in their strictest sense i.e. the classificatory predominance of an oxic horizon if it overlies an argillic horizon (Profile 5), and the need for illuviated silicate clays and not iron oxides or ferrans (Profile 6) in an argillic horizon. These seem to be narrow technical criteria unworthy of use for groupings at such a high level of classification.

In conclusion, the use of the argillic B horizon as defined at present by FAO and USDA is not considered to be warranted to distinguish between Ferralsols and Acrisols in Sabah. Rather, oxic properties should be considered as being diagnostic for the categorisation of Ferralsols, whether or not features of an argillic B horizon are detected.

PART 5 REFERENCES AND RELEVANT WORKS

- ACRES B D, BOWER R F, BURROUGH P A, FOLLAND C J, KALSI M S, THOMAS P & WRIGHT P S (1975) The soils of Sabah. Vol. 1: Classification and description Vol.5: References and appendixes. Land Resource Study, Land Resources Division, UK Ministry of Overseas Development, no.20..
- BENNEMA J, JONGERIUS A & LEMOS R C (1970) Micromorphology of some oxic and argillic horizons in south Brazil in relation to weathering sequences. Geoderma Vol. 4, no.3.
- BRAMAO D L, SMYTH A J, ECTEEVS S, BAREN F A van & DUDAL R (1967) Proposals for a uniform system of soil horizon designation. Bulletin of the International Society of Soil Science, no.31, 4-7.
- BREWER R (1964) Fabric and mineral analysis of soils. Wiley, New York.
- BREWER R (1972) The basis of interpretation of soil micromorphological data. Geoderma Vol. 8, no.2/3, 81-94.
- BROOK R H & van SCHULEMBORGH (1975) Weathering chemistry of a Paleudult in tropical Surinam. Geoderma Vol.14, no. 1, 3-14.
- BULLOCK P (1974) Micromorphology. In: Soil survey laboratory methods. Avery B W and Bascomb C L ed. Technical Monograph. Agricultural Research Council, Soil Survey, Harpenden, England no.2, 70-81.
- BULLOCK P & MURPHY C P (1976) The microscopic examination of the structure of subsurface horizons of soils. Outlook on Agriculture Vol. 8, no.6, 348-354.
- ESWARAN H (1970) Micromorphological indications of pedogenesis in some tropical soils derived from basalts from Nicaragua. Geoderma Vol. 7, no.1/2 15-31.
- ESWARAN H & SYS C (1971) The mineralogy and micromorphology of the soils of the Sook Plain, Sabah, Malaysia, Ghent, Belgium: Rijksuniversiteit.
- ESWARAN H & SYS C (1972a) The mineralogy and micromorphology of the soils of Sandakan, Sabah, Malaysia. Ghent, Belgium: Rijksuniversiteit.

- ESWARAN H (1972b) A micromorphological study of some B horizons from Sahah, Malaysia. Geological Institute, University of Ghent, Belgium.
- FITZPATRICK E A (1970) A technique for the preparation of large thin sections of soils and unconsolidated materials. In: Micromorphological techniques and applications. Osmond D A and Bullock P ed. Technical Monograph. Agricultural Research Council. Soil Survey, Harpenden, England no.2, 3-23.
- FITZPATRICK E A (1974) The preparation and description of thin sections of soils. Unpublished report. Department of Soil Science, Aberdeen University.
- FAO (1965) Guidelines for soil profile description. Rome: FAO.
- FAO (1974) Soil map of the world, Vol. 1. Legend. Rome: FAO.
- GAULD J H (1969) A study of four characteristic Malaysian soils. Thesis presented for the degree of Doctor of Philosophy in the University of Aberdeen, May 1969.
- HILL I D (1970) Quantitative micromorphological evidence of clay movement. In: Micromorphological techniques and applications. Osmond D A and Bullock P ed. Technical Monograph. Agricultural Research Council, Soil Survey, Harpenden, England, no.2, 33-38.
- HOOKE R L YANG H Y & WEIBLEN P.W (1969) Desert varnish: an electron probe study. The Journal of Geology, vol. 77, no.3, 275-288.
- HILL I D (1977) The micromorphology of some West African soils in relation to their classification. Ph.D thesis. Soil Science Department, University of Reading.
- RUTHERFORD G K (1964) Observations on the origin of a cutan in the yellow-brown soils of the highlands of New Guinea. Soil micromorphology. Edited by A Jongorius. Elsevier Publishing Company.
- RUTHERFORD G K (1967) A micropedological study of the genesis of a grey-brown podzolic soil in south-eastern Ontario, Canada. Geoderma, vol. 1, no.3/4, 277-287.

REYNDERS J J (1972) A study of argillaceous horizons in some soils in Morocco. *Geoderma*, vol. 8. no.4, 267-279.

SMITH GUY D, SYS C & VAN WAMBEKE (1975) Application of Soil Taxonomy to the soils of Zaire (Central Africa), *Pedologie*. 1975-1, 5-25.

UNITED STATES DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE (1975) Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. Washington: Soil Conservation Service, United States Department of Agriculture.

WALL J R D, HANSELL J R F, CATT J A, ORMEROD E C, VARLEY J A & WEBB I S (1979) The soils of the Solomon Islands. Technical Bulletin 4, Vol. 1. Land Resources Development Centre, Overseas Development Administration, Tolworth Tower, Surbiton, Surrey, England.

APPENDIXES

Appendix 1

Soil profile descriptions and analyses

Profile 5 Orthic Ferralsols

Benuou family
 Location Telipok area
 Road cutting about $\frac{1}{2}$ mile along Lapanas jeeptrack from the Karambunai road
 Surroundings Steep-sided narrow ridges
 Site Flat ridge top
 Slope Nil
 Elevation 30 m (100 ft)
 Site drainage Shedding
 Parent material Terrace alluvium
 Vegetation Savanna. Site almost bare except for scattered bushes and tufts of grass
 Soil drainage Well drained

Horizon	Depth cm (in)	Description
A1	0-10 (0-4)	Dark greyish brown (10YR 3/2), moist; sandy loam; weak fine subangular blocky structure; friable, moist; few fine pores; few fine roots; few small clear inclusions of underlying horizon; abrupt smooth boundary
BE	10-28 (4-11)	Strong brown (7.5YR 5/6), moist; sandy clay loam; weak fine subangular blocky structure; friable, moist; few fine pores; few fine roots; clear smooth boundary
B1 _{ox}	28-53 (11-21)	Reddish yellow (7.5YR 5.5/8), moist; sandy clay loam; weak fine subangular blocky structure; firm, moist; few fine pores; few fine roots; gradual smooth boundary
B2 _{ox}	53-84 (21-33)	Reddish yellow to strong brown (7.5YR 5.5/8), moist, sandy clay loam; weak fine subangular blocky structure; firm, moist; patchy thin cutans; no roots; gradual smooth boundary
B3 _{ox}	84-112 (33-44)	Reddish yellow (5YR 6/8), moist, sandy clay loam; moderate fine subangular blocky structure; firm, moist; patchy thin cutans; few fragments of indurated sandstone and shale; gradual smooth boundary
B4 _{ox}	112-150 (44-60)	Reddish yellow (5YR 6/8), moist, with many (40%) coarse distinct clear strong brown (7.5YR 5/8) mottles; sandy clay loam; moderate fine subangular blocky; firm, moist

Depth cm	Particle size distribution %				Org C%	Total N%	Easily sol. P ppm	pH H ₂ O	Exch. cations meq %				CEC meq %	Base satn %	H ₂ O disper sable clay	Loss on ignition %
	Coarse sand	Fine sand	Silt	Clay					Ca	Mg	K	Na				
0-10	15	58	10	17	2.1	0.12	2	3.9	0.1	0.1	0.0	0.0	6.7	3	18	8
10-28	12	57	11	21	0.4	0.03	0	4.4	0.1	0.1	0.0	0.0	3.0	4	24	5
28-53	14	53	10	25	0.1	0.02	0	4.4	0.1	0.1	0.0	0.0	4.6	3	4	7
53-84	13	53	10	25	0.2	0.01	0	4.4	0.1	0.2	0.0	0.0	3.3	9	3	11
84-112	17	50	11	23	0.1	0.01	<0.5	4.7	0.1	0.4	0.0	0.0	4.4	11	0	10
112-152	12	49	15	26	0.1	0.01	<0.5	4.6	0.0	tr	0.0	0.0	5.4	1	1	8

Depth cm	Minerals of the clay fraction	
	Kaolinite	Vermiculite
0-10	dominant	moderate
10-28	dominant	moderate
28-53	dominant	present
53-84	dominant	present
84-112	dominant	trace
112-150	dominant	trace

Profile 6 Orthic Ferralsols

Ambun family
 Location Ranau area, 4 miles on Lohan road
 Surroundings Steepland
 Site Lower slope, even
 Slope 17°
 Elevation 540 m (1 800 ft)
 Site drainage Shedding
 Parent material Colluvium derived from ultrabasic rocks
 Vegetation Primary forest
 Soil drainage Well drained

Horizon	Depth cm(in)	Description
A ₁	0-2 (0-1)	Dark greyish brown (10YR4/2), moist; silty clay; strong very fine subangular blocky structure; very friable, moist; thick mat of roots; abrupt smooth boundary
B ₁	2-28 (1-15)	Dark reddish brown (5YR3/4), moist; clay; strong fine angular blocky structure; very friable, moist; few coarse fine roots; abrupt smooth boundary
B _{2ox}	28-73 (15-29)	Dark reddish brown (5YR3/4), moist; clay; weak very fine angular blocky structure; friable, moist; few fine roots; abrupt smooth boundary
B _{3ox}	73-122 (29-48)	Dark reddish brown (5YR3/4), moist; clay; structure and consistency as above; few fine roots; clear smooth boundary
B _{4ox}	122-152 (48-60)	Dark reddish grey (5YR4/2), moist; clay; structure and consistency as above; very few fine pores.

Depth cm	Particle size distribution %				Org. C%	Total N%	Easily sol. P ppm	pH H ₂ O	Exch. cations meq%				CEC meq%	Base satn %	Loss on ignition %
	Coarse sand	Fine sand	Silt	Clay					Ca	Mg	K	Na			
0-2	5	9	26	46	10.0	0.61	1	5.4	1.1	0.7	0.4	0.2	27.9	37	27
2-28	3	15	46	32	2.7	0.26	1	5.6	0.7	2.0	0.1	tr	8.5	33	nd
28-73	8	31	16	44	0.8	0.08	0	5.7	0.2	0.2	0.0	0.0	4.9	8	nd
73-122	20	43	16	23	0.9	0.05	3	5.7	tr	0.7	0.0	0.0	2.8	29	nd
122-152	8	38	18	37	0.2	0.02	0	6.0	0.3	tr	0.0	0.0	10.0	4	nd

Depth cm	Al O 2 3	Al	Fe O 2 3	Fe	Minerals of the clay fraction	
					Goethite	Haematite
0-2	8.10	4.30	42.5	29.1	dominant	dominant
2-28	10.3	5.50	52.2	36.5	dominant	dominant
28-73	11.1	5.90	56.8	39.7	dominant	dominant
73-122	11.5	6.10	56.6	39.5	dominant	dominant
122-152	10.9	5.80	56.7	39.6	dominant	dominant

nd... .. not determined

Profile 12 Gleyic Acrisol

Masaum family

Location

Labuan. $\frac{1}{2}$ mile from agricultural station on Bukit Kuda road; about 20 yds to the south

Surroundings

Hilly

Site

Flat summit of hill

Slope

Nil

Elevation

6m (20 ft)

Site drainage

Normal

Parent material

Mudstone

Vegetation

Rubber, medium to good quality, about 10 years old

Soil drainage

Imperfect

Horizon	Depth cm(in)	Description
A 1	0-5 (0-2)	Brown (10YR 5/3), moist; clay loam; moderate medium subangular blocky structure; friable, moist; few pores; frequent fine roots; gradual smooth boundary
E B	5-20 (2-8)	Yellowish brown (10YR 5/4), moist; fine sandy clay; strong medium subangular blocky structure; friable, moist; discontinuous thick cutans; frequent fine roots; gradual smooth boundary
B1t	20-41 (8-16)	Brownish yellow (10YR 6/6), moist, uncommon medium distinct clear grey (10YR 6/1) mottles; sandy clay; moderate medium subangular structure; firm, moist; few roots; gradual smooth boundary
B2t, fe	41-81 (16-32)	Brownish yellow (10YR 6/6), moist, common medium distinct clear light grey (10YR 7/1) mottles; sandy clay loam; weak prismatic structure; firm, moist; continuous thick cutans; few decomposing fragments of mudstone with iron staining; few roots; gradual smooth boundary
BCg	81-150 (32-60)	Grey (5Y5/1), moist, many medium prominent clear brownish yellow (10YR 6/8) mottles; clay; weak medium subangular blocky structure; firm, moist; very few roots

Depth cm	Particle size distribution %				Org. C %	Total N %	Easily sol. P ppm	pH H ₂ O	Exchangeable cations meq%				CEC meq %	Base satn %
	Coarse Sand	Fine Sand	Silt	Clay					Ca	Mg	K	Na		
0-5	4	41	26	27	2.4	0.23	1	4.5	1.2	2.0	0.2	0.3	14.0	33
5-20	3	38	26	31	1.0	0.14	0	4.4	0.7	1.1	0.2	0.2	12.8	17
20-41	2	34	28	35	0.6	0.11	0	4.8	0.9	1.6	0.2	0.3	14.4	21
41-81	9	42	19	29	0.4	0.09	0	5.2	1.3	2.5	0.2	0.3	13.3	32
81-150	1	20	33	45	0.2	0.09	0	5.2	1.5	5.4	0.2	0.3	15.0	50

Depth cm	Minerals of the clay fraction		
	Vermiculite	Illite	Quartz
0-5	moderate	moderate	trace
5-20	dominant	moderate	trace
20-41	dominant	moderate	trace
41-81	moderate	moderate	trace
81-150	trace	moderate	trace

Profile 13 Ferric Acrisol

Lumisir family
 Location Papar to Beaufort Road, 100 m past mile 9 and 6 m to the west
 Surroundings Undulating terrace
 Site Summit
 Slope 6°
 Elevation 30 m (100 ft)
 Site drainage Normal
 Parent material Terrace alluvium
 Vegetation Rubber
 Soil drainage Well drained

Horizon	Depth cm (in)	Description
Al	0-18 (0-7)	Dark grey brown (10YR4/2), moist; silt loam; strong medium crumb structure; very friable, moist; frequent fine roots; clear wavy boundary
AE	18-30 (7-12)	Brown to dark brown (10YR4/3), moist; loam; weak fine subangular blocky structure; friable, moist; few roots; clear wavy boundary
E	30-46 (12-18)	Light grey (10YR7/2), moist; loam; weak fine subangular blocky structure, friable, moist; very few roots; gradual smooth boundary
Blt	46-81 (18-32)	Very pale brown (10YR7/3), moist; clay loam; weak medium subangular blocky structure; firm, moist; patchy thin cutans; very few roots; gradual smooth boundary
B2t,fe	81-145 (32-57)	Reddish yellow (7.5YR7/6), moist, many coarse distinct clear reddish yellow (5YR6/6) and few fine faint clear very pale brown (10YR7/3) mottles; clay loam; moderate medium subangular blocky structure; firm, moist; patchy thin cutans; no roots; gradual smooth boundary
BCg	145-178 (57-70)	Light grey (5Y7/1), moist, common medium prominent dark brown (10YR4/3) mottles; silty clay; weak fine subangular blocky structure; sticky, slightly plastic wet;

Depth cm	Particle size distribution %				Org. C%	Total N%	Easily sol.P ppm	pH H ₂ O	Exchangeable cations meq/l				CEC meq/l	Base satn %
	Coarse sand	Fine sand	Silt	Clay					Ca	Mg	K	Na		
0-18	9	59	16	12	2.2	0.14	4	4.7	0.2	0.1	tr	tr	8.3	4
18-30	8	58	18	15	1.2	0.08	1	4.6	0.1	tr	tr	tr	6.6	3
30-46	9	58	18	14	0.7	0.05	tr	4.6	0.2	tr	tr	tr	4.1	5
46-81	7	57	17	19	0.1	0.02	tr	4.5	0.1	tr	tr	tr	3.6	6
81-145	6	52	17	25	0.9	0.02	tr	4.5	0.2	tr	tr	tr	6.0	6
145-178	5	39	21	35	0.1	0.02	tr	4.4	0.2	tr	tr	tr	8.2	4

tr..... trace

Depth cm	Minerals of the clay fraction		
	Vermiculite	Kaolinite	Illite
0-18	dominant	moderate	trace
18-30	dominant	moderate	trace
30-46	dominant	moderate	trace
46-81	dominant	moderate	trace
81-145	dominant	dominant	trace
145-178	moderate	moderate	trace

Profile 15 Orthic Acrisol

Tanjong Lipat family

Location

Telipok to Kiulu road about $\frac{1}{2}$ mile after TV station road junction

Surroundings

Steepland, ridge country

Site

Middle slope

Slope

18°

Elevation

660 m (2 000 ft)

Site drainage

Shedding

Parent material

Sandstone

Vegetation

Rubber

Soil drainage

Well drained

Horizon	Depth cm (in)		Description
A1	0-13	(0-5)	Very dark greyish brown (10YR3/2), moist; Loamy sand; weak fine subangular blocky structure; Loose, moist; very frequent roots; clear smooth boundary
AE	13-28	(5-11)	Brownish yellow (10YR6/6), moist; many fine faint greyish brown (10YR5/2) mottles; sandy loam; moderate fine subangular blocky structure; friable moist; frequent roots; clear smooth boundary
Bl _t	28-61	(11-24)	Brownish yellow (10YR6/8), moist; loam; weak fine subangular blocky structure; friable, moist; patchy thin cutans; few roots; clear smooth boundary
B2 _t	61-102	(24-40)	Brownish yellow (10YR6/6), moist, common fine faint yellow (10YR8/6) mottles; sandy clay loam, moderate medium subangular blocky structure; firm, moist; broken thin cutans; few fragments of decomposing sandstone; abrupt smooth boundary
R	102 +	(40 +)	Fine grained weathering sandstone

Depth cm	Particle size distribution %				Org. C%	Total N%	Easily sol. P ppm	pH H ₂ O	Exchangeable cations meq%				CEC meq%	Base satn %
	Coarse sand	Fine sand	Silt	Clay					Ca	Mg	K	Na		
0-13	14	56	12	14	2.5	0.21	3	3.7	0.3	0.2	0.1	0.1	14.3	5
13-28	15	57	12	14	1.0	0.09	2	4.0	0.4	0.1	0.1	0.1	9.5	6
28-61	13	54	13	19	0.3	0.15	tr	4.0	0.3	0.0	0.1	0.1	8.3	6
61-102	13	55	13	19	0.2	0.03	tr	4.2	0.4	tr	0.1	0.1	7.7	8
102 +	10	58	17	17	0.2	0.03	tr	4.3	0.4	tr	0.1	0.1	7.2	9

tr.... trace

Depth cm	Minerals of the clay fraction			
	Vermiculite	Kaolinite	Illite	Quartz
0-13	dominant	trace	trace	absent
13-28	dominant	trace	trace	absent
28-61	dominant	trace	trace	trace
61-102	dominant	moderate	trace	trace
102 +	dominant	moderate	trace	trace

PROFILE 16 Orthic Acrisol

Tanjong Lipat family

Location Pulau Gaya, sample strip, base line chain 30
 Surroundings Steepland, ridge country
 Site Termination of spur, upper slope
 Slope 32°
 Elevation 366 m (1 100 ft)
 Site drainage Shedding
 Parent material Sandstone
 Vegetation Primary forest
 Soil drainage Well drained

Horizon	Depth cm (in)	Description
O	2-0 (1-0)	Decomposing leaves and litter; abrupt smooth boundary
AE	0-13 (0-5)	Greyish brown (10YR5/2), moist; sandy loam to loam; weak medium subangular blocky structure; friable, moist; frequent roots; gradual smooth boundary
E	13-30 (5-12)	Brownish yellow (10YR5/8), moist; loam; weak fine subangular blocky structure; friable, moist; frequent roots; gradual smooth boundary
Blt	30-76 (12-30)	Reddish yellow (7.5YR6/6), moist; sandy clay; moderate fine subangular blocky structure; firm, moist; patchy thin cutans; few roots; gradual smooth boundary
B2t, fe	76-112 (30-44)	Reddish yellow (7.5YR6/6), moist; sandy clay; weak fine subangular blocky structure; firm, moist; common fragments of sandstone; clear smooth boundary
R	112 (44)	Decomposing sandstone

Depth cm	Particle size distribution %				Org C %	Total N %	Easily sol. P ppm	pH H ₂ O	Exch. cations meq%				CEC meq%	Base satn %	Total S %	Loss on ignition %
	Coarse sand	Fine sand	Silt	Clay					Ca	Mg	K	Na				
2-0	36	39	10	9	1.3	0.14	5	4.3	0.4	1.0	0.1	tr	10.7	14	nd	nd
0-13	35	42	11	10	0.8	0.12	2	4.4	0.1	0.7	0.1	0.0	8.2	11	nd	nd
13-30	36	39	10	14	0.6	0.05	1	4.4	0	0.5	0.1	0.0	7.4	8	nd	nd
30-76	23	33	13	31	0.3	0.04	0.5	4.1	0	0.3	0.2	0.0	12.7	4	nd	nd
76-112	34	32	9	25	0.1	0.03	0.5	4.5	0.1	0.1	0.1	0.0	7.8	4	0.01	1
112 +	66	25	6	5	0.1	0.01	0	5.0	0.1	0.1	0.1	0.0	5.5	6	0.01	1

nd... . not determined
 tr..... trace

Depth cm	Minerals of the clay fraction		
	Kaolinite	Vermiculite	Illite
2-0	dominant	dominant	present
0-13	dominant	moderate	trace
13-30	dominant	moderate	trace
30-76	dominant	present	trace
76-112	dominant	present	trace
112 +	dominant	present	trace

PROFILE 18 Orthic Acrisol

Tanjong Lipat family

Location Telipok to Kiulu road, approximately mile 3
 Surroundings Steepland, ridge country
 Site Middle slope
 Slope 32°
 Elevation 460 m (1 400 ft)
 Site drainage Shedding
 Parent material Ferruginous sandstone
 Vegetation Rubber
 Soil drainage Well drained

Horizon	Depth	cm (in)	Description
O	3-0	(1½-0)	Very dark greyish brown (10YR3/2), moist; partly decomposed litter; very frequent roots; abrupt smooth boundary
Al	0-13	(0-5)	Dark brown to brown (10YR4/3), moist; sandy loam; very weak fine crumb structure; very friable, moist; few roots; gradual smooth boundary
AE	13-25	(5-10)	Brown (10YR5/3), moist; loam; moderate medium subangular blocky structure; friable, moist; few fragments of red and yellow weathering sandstone; few roots; gradual smooth boundary
Bl _t	25-71	(10-28)	Reddish yellow (7.5YR6/6), moist; sandy clay loam; moderate medium subangular blocky structure; friable, moist; broken thin cutans; few fragments of red and yellow weathering sandstone; few roots; gradual smooth boundary
B2 _t	71-107	(28-42)	Reddish yellow to strong brown (7.5YR5/6), moist; moderate medium subangular blocky structure; friable, moist; broken thin cutans; few to frequent fragments of weathering sandstone; few roots; gradual wavy boundary
CR	107 +	(42 +)	Dominant weathering sandstone

Depth cm	Particle size distribution (%)				Org. C %	Total N %	Easily sol.P ppm	pH H ₂ O	Exch. cations meq%				C.E.C. meq%	Base satn %	Loss on ignition %
	Coarse sand	Fine sand	Silt	Clay					Ca	Mg	K	Na			
3-0	10	46	11	20	4.9	0.36	23	4.7	5.5	4.8	0.9	0.2	22.0	52	18
0-13	11	56	11	21	2.4	0.26	10	4.3	0.5	0.9	0.2	0.1	12.8	14	0
13-25	11	53	10	24	0.9	0.09	2	4.1	0.3	0.2	0.1	0.1	10.0	7	0
25-71	12	47	11	29	0.4	0.06	0	4.2	0.3	0.1	0.1	0.1	10.4	6	0
71-107	12	49	10	28	0.2	0.04	tr	4.2	0.3	0.1	0.1	0.1	10.9	5	0
107 +	20	53	11	16	0.2	0.03	0	4.4	0.6	0.1	0.1	0.2	8.2	9	0

Depth cm	Minerals of the clay fraction			
	Vermiculite	Kaolinite	Illite	Quartz
3-0	dominant	trace	trace	trace
0-13	dominant	moderate	trace	trace
13-25	dominant	moderate	trace	absent
25-71	dominant	moderate	trace	absent
71-107	dominant	moderate	trace	absent
107 +	dominant	moderate	trace	absent

Appendix 2

Profile description: Horizon nomenclature and definitions of diagnostic horizons

HORIZON NOMENCLATURE

Terms used in the description of individual soil horizons follow Section 4 of the FAO Guidelines (Food and Agriculture Organization, 1965). Horizon nomenclature, however, is based on that proposed by the International Soil Science Society (Bramao *et al*, 1967) with one major departure. The G horizon has been omitted and the suffix 'g' refers only to strong gleying.

Master horizons

- O An horizon forming the upper part of the soil, consisting of fresh and/or partly decomposed organic matter accumulated under predominantly aerobic conditions, and having a minimum organic matter content of 30% if the mineral fraction contains more than 50% of clay, or 20% organic matter if the mineral fraction has no clay. For intermediate clay contents, proportional organic matter contents are required
- A An horizon formed or forming at or adjacent to the surface, consisting of an accumulation of humified organic matter intimately associated with the mineral fraction, and having an organic matter content of less than 30% if the mineral fraction contains more than 50% of clay, or less than 20% organic matter if the mineral fraction has no clay. For intermediate clay contents, proportional organic matter contents are required
- E An horizon underlying the O or A horizon (if present), having a lower content of organic matter and/or sesquioxides and/or clay than the immediately underlying horizon, and usually indicated by a pale colour and a relative accumulation of quartz and/or other resistant minerals of sand or silt sizes
- B An horizon lying between the A or E horizons (if present) and the C or R horizons (if present), in which rock structure is obliterated or is faintly evident, and characterised by a concentration of silicate clay (by illuviation or alteration), sesquioxides (by illuviation or residual accumulation), or organic matter (by illuviation), alone or in combination. (The B horizon may show accumulations of calcium or magnesium carbonate, gypsum or other more soluble salts)
- C An horizon consisting of unconsolidated material which does not show properties diagnostic of the other master horizons. (The C horizon may show accumulations of calcium or magnesium carbonate, gypsum or other more soluble salts)
- R Consolidated bedrock

Transitional horizons

Horizons which are transitional between two master horizons are indicated by both capital letters of the master horizons concerned (for instance AE, EB, BE, BC), the first letter marking the master horizon to which the transitional horizon is more alike i.e. the order of the letters indicates the dominant properties of the transitional horizon (for instance AB or BA). Mixed horizons are indicated by both capital letters of the master horizons concerned but separated by a diagonal stroke (for instance E/B, B/C). It is to be noted that transitional horizons are no longer marked by figures as has been done in the past.

Subhorizons

This subdivision of master and transitional horizons is indicated by numerals in continuous sequence. These numerals merely indicate differences which can be observed and recorded in a profile description (for instance A1, A2, A3, EB1, EB2, B1, B2, BC1, BC2).

In addition to the numerical subdivision, an interpretative suffix letter, having a genetic implication, may be added to the horizon designation. The suffix letters should be used only if there is sufficient evidence for the implied interpretation. The suffix follows the numerical notation (for instance, A1a, A2a, B1t, B2t, B3t, C1, C2ca); if the horizon is not subdivided by numerals, the suffix letter may be used immediately following the capital letter (for instance, Aa, Bt, Cca).

Lithological discontinuities

When it is necessary to number layers of contrasting materials, Roman numerals are pre-fixed to the horizon designations concerned (for instance, when the C horizon is different from the material in which the soil is presumed to have formed, the following soil sequence could be given: A, B, IIC). The same notation can be applied when different materials are recognised within the C horizon (for instance, IC, IIC, IIIC).

Proposed suffixes

- a Well decomposed organic matter accumulated under hydromorphic conditions; used with the A horizon (for instance Aa)
- b Buried horizon
- cn Accumulation of concretions or hard non-concretionary nodules enriched in sesquioxides (for instance, B2ox, cn)
- f Fermented, partly decomposed organic matter; applied to the O horizon (for instance Of)
- fe Illuvial accumulation of iron; applied to the B horizon of Podzols (for instance B2fe)
- g Strong gleying
- h Humified, well decomposed organic matter; applied to:
 1. The lower part of the O horizon (for instance, Oh)
 2. An undisturbed A horizon (for instance, Ah)
 3. The illuvial accumulation of organic matter in the B horizon of Podzols (for instance B1h) or in B horizons formed in peat

- l Litter; applied to the upper part of the O horizon (for instance Ol)
- o Poorly decomposed organic material accumulated under hydromorphic conditions; applied to peats (for instance, Co)
- ox Residual accumulation of sesquioxides; applied to the B horizon of Ferralsols (for instance, B1 ox)
- p Disturbed by ploughing or other tillage practices; applied to the A horizon (for instance, A1p)
- t Illuvial accumulation of clay; applied to B horizons (for instance Bt)

DEFINITIONS OF DIAGNOSTIC HORIZONS

The definitions of the diagnostic horizons used by the FAO have been drawn largely from those adopted in Soil Classification, a Comprehensive System (USDA, 1960) and subsequent supplements (USDA, 1967 and 1973).

Mollic A horizon

The mollic A horizon is a surface layer which, after the surface 18 cm (7 in) are mixed, as by ploughing, has the following properties:

1. Soil structure is sufficiently strong that the horizon is not both massive and hard, or very hard when dry
2. Both broken and rubbed soils have colours with a chroma of less than 3.5 when moist, a value darker than 3.5 when moist, and 5.5 when dry, and at least one unit darker than the C (both moist and dry). If only hard rock is present, comparison should be made with the next underlying horizon
3. The base saturation is more than 50% (by the ammonium acetate method)
4. The organic matter content is at least 1% (0.58% organic carbon) throughout. If the dark surface horizon is less than 18 cm (7 in) thick in a virgin soil with a solum of less than 45 cm (18 in.), the organic matter content must be sufficient to give an average of 1% to a plough layer that is 18 cm (7 in) thick. The upper limit of organic carbon content of the mollic A horizon is the lower limit of the peaty A horizon
5. The thickness is more than 10 cm (4 in) if resting directly on hard rock. If the soil contains an argillic, natric, spodic or cambic B horizon or a fragipan or duripan, the thickness of the A must be more than one-third of the thickness of the solum, where the solum is less than 75 cm (30 in) thick, and must be more than 25 cm where the solum is more than 75 cm (30 in)thick
6. The mollic A horizon has less than 250 parts per million of P_2O_5 soluble in citric acid, or has increasing amounts of P_2O_5 soluble in citric acid below the A horizon

Umbric A horizon

The umbric A horizon is comparable to the mollic A horizon in its colour, organic carbon and thickness requirements. It includes those thick dark surface horizons that have a base saturation less than 50% (by amonium acetate method) or that are both hard and massive when dry.

Histic A horizon

The histic A horizon is a horizon at or near the surface, saturated with water at some season (unless artificially drained) and containing 30% or more organic matter (17.4%

organic carbon) if the mineral fraction has more than 50% clay, or 20% or more organic matter (11.6% organic carbon) if the mineral fraction has no clay. For intermediate textures the required organic matter content is proportional to the clay content. If the A horizon is less than 20 cm (8 in) thick or has been ploughed, it is sufficient, after the upper 20 cm (8 in) have been mixed, that the organic matter content be 28% (16.2% organic carbon) and 14% (8.1% organic carbon) respectively. Where a histic horizon is buried it is diagnostic if its upper boundary occurs within 50 cm (20 in) of the surface.

Ochric A horizon

The ochric A horizon is too light in colour, too low in organic carbon, or too thin to be mollic umbric or histic.

Albic E horizon

The albic E horizon is an E horizon from which clay and free iron oxides have been removed, or in which the oxides have been segregated to the extent that the colour of the horizon is determined primarily by the colour of the primary sand and silt particles, rather than by coatings on these particles. The dominant colours in the matrix of at least a part of the E horizon have moist and dry chromas of two or less.

Argillic B horizon

The argillic B horizon is one that contains illuvial layer-lattice clays. This horizon forms below an eluvial horizon, but it may be at the surface if the soil has been partially truncated. It has the following properties that may be used for identification in the field:

1. If an E horizon remains, the argillic B horizon contains more total and more fine clay than does the eluvial horizon, exclusive of differences which may result from a lithological discontinuity, in accordance with the following specifications:
 - i. If any part of the E horizon has less than 15% total clay in the fine earth (less than 2 mm) fraction, the B horizon must contain at least 3% more clay
 - ii. If the E horizon has more than 15% and less than 40% total clay in the fine earth fraction, the ratio of the clay in the B horizon to that in the E horizon must be 1.2 or more
 - iii. If the E horizon has more than 40% total clay in the fine earth fraction, the B horizon must contain at least 8% more clay
2. An argillic B horizon should be at least one-tenth the thickness of the sum of all overlying horizons, or more than 15 cm (6 in) thick if the E and B horizons are thicker than 150 cm (60 in). The clay increases required under item 1 must be reached within a vertical distance of 30 cm (12 in) or less
3. In soils with massive or single grained structure, the argillic B horizon should have oriented clays bridging the sand grains and in some pores
4. If peds are present, an argillic B horizon has the following properties: (a) there are clay skins on some of the vertical and horizontal ped surfaces and in fine pores, or oriented clays in 1% or more of the cross section; (b) if the horizon is clayey with kaolinitic clay and the surface horizon has more than 40% clay, there are some clay skins on peds and in pores in the lower part of that horizon having blocky or prismatic structure; (c) if the B horizon is clayey with two to one lattice clay, clay skins may be lacking, provided there are evidences of pressure caused by swelling, the evidence of pressure may be occasional slickensides or wavy horizon boundaries in the illuvial horizon, accompanied by uncoated sand or silt grains in the overlying horizon

5. If a soil shows a lithologic discontinuity between the E horizon and the argillic B horizon, or if only a plough layer overlies the argillic B horizon, the horizon need show only clay skins in some part, either in some fine pores, or if pedis exist, on some vertical and horizontal ped surfaces. Thin sections should show that some part of the horizon has about 1% or more of oriented clay bodies

Cambric B horizon

The cambric B horizon is an altered horizon reaching to at least 25 cm (10 in) below the soil surface that lacks the dark colours and organic matter that are characteristic of mollic, umbric or histic A horizons and it has:

1. Textures of loamy very fine sand or finer in the fine earth (less than 2 mm) fraction
2. Soil structure rather than rock structure
3. Some weatherable minerals
4. Evidence of alteration reflected by stronger chromas or redder hues than the underlying horizons* and/or evidences of removal of carbonates
5. Too few evidences of illuviation to meet the requirements of an argillic or a spodic B horizon
6. No cementation or induration and lacks a brittle consistence when moist

Spodic B horizon

The spodic B horizon is characterised by the following properties:

1. If there is a strongly bleached eluvial horizon (continuous or intermittent) thicker than 18 cm (7 in.) underlying an A horizon, the spodic B horizon has:
 - i. so much amorphous material that

$$\frac{\% \text{ extractable C + Fe + Al}}{\% \text{ clay}} > 0.15^{**}$$
 - ii. A thickness of 1 cm or more, either as a continuous horizon or as a sum of lamellae within 100 cm (40 in)
 - iii. Extractable C + Fe + Al > 1.0% or moist colour hues which are 7.5YR or redder; and moist values of 3 or less in some continuous part of the horizon or in any other subhorizon that is at least 1 cm thick; and hues which are as red or redder than the underlying horizon
 - iv. No clay skins on ped faces or in pores
2. In an A horizon rests on the spodic B horizon the spodic B horizon meets the requirements listed under 1, and in addition has:
 - i. A 15-bar water content of less than 20% or, if it is higher, a pH (H₂O) which is less than 5.0 but at least 0.5 higher than pH (KCl)

* If soils are poorly drained (in the case of the gleyic soils) the hues should not be bluer than 10Y and should change on exposure to the air; if there is mottling, chromas are two or less; if there is no mottling chromas are less than one if values are less than four, otherwise chromas are one or less.

** Elemental weight % by pyrophosphate-dithionite extraction.

- ii. Enough depth that the horizon is not obliterated by ploughing (to 18 cm (7 in)) or enough degree of expression that the horizon after mixing to 18 cm (7 in) has:
- a. More than 3% organic matter (1.7% organic carbon)
 - b. $\frac{\% \text{ extractable C + Fe + Al}}{\% \text{ clay}} > 0.20^{**}$
 - c. Fragments of amorphous coatings or pellets can be clearly identified
 - d. A hue redder than 10YR with a moist value of less than three, or a chroma of three or more in hues of 10YR or redder

Oxic B horizon

The oxic B horizon is a horizon which lacks the characteristics mentioned for the argillic B horizon and:

1. Is at least 30 cm (12 in)thick
2. Has a fine earth fraction that retains 10 meq or less of ammonium ions per 100 g clay from a 1N NH₄ Cl solution:

$$\frac{\text{meq bases retained} \times 100}{\% \text{ clay}} \leq 10$$

or has less than 10 meq of bases extractable with NH₄ OAc and aluminium extractable with 1 N KCl per 100 g clay

3. Has an apparent cation exchange capacity of the fine earth of 16 meq or less per 100 g clay by the ammonium acetate method thus:

$$\frac{\text{meq CEC} \times 100}{\% \text{ clay}} \leq 16$$

4. Has no more than traces of primary aluminosilicates such as feldspars, micas, glass and ferro-magnesian minerals
5. Has no more than traces of water-dispersible clay in some subhorizons
6. Has texture of sandy loam or finer (in the fine earth fraction) and more than 15% clay
7. Has mostly gradual or diffuse boundaries between its subhorizons
8. Has less than 5% by volume that shows rock structure

Gleyic horizon

The gleyic horizon is indicative of pronounced wetness. In the absence of a precise definition of the gleyic horizon by FAO the definition of strong gleying (USDA 1960) has been adopted.

'In aggregated material, ped faces in horizons with strong gleying generally have chromas of two or less as a continuous phase, and commonly have few of faint mottles. Interiors

** See previous page.

of peds may have prominent and many mottles but commonly have a network of threads or bands of low chroma surrounding the mottles. In soils that are not aggregated, a base chroma of one or less, with or without mottles, is indicative of strong gleying'.

Horizons 'in which portions have mottles with chromas of 2 or less and moist values of four or more, whether or not that portion is dominant in volume or whether or not it is a continuous phase surrounding spots of higher chroma' (USDA 1973) are not considered to be gleyic horizons. However the phrase 'mottles with chromas of two or less' includes the meaning that the horizons that have such mottles are saturated with water at some time of the year or are artificially drained.

Thionic horizon

The thionic horizon contains an amount of sulphides and/or elemental sulphur which is sufficiently high to cause acidification of the soil upon oxidation to pH (KCl) of less than 3.5 within 100 cm (40 in) of the surface.