AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture

B. SECONDARY: Soils

2. TITLE AND SUBTITLE

Investigations in an oxisol-ultisol toposequence in S. Paulo State, Brazil

3. AUTHOR(S)

Lepsch, I.F.; Buol, S.W.

4. DOCUMENT DATE: 1974

5. NUMBER OF PAGES: 7p.

6. ARC NUMBER: ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Soil Science Department, North Carolina State University,
Box 5907, Raleigh, North Carolina 27607

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)

Published in Soil Science Soc. of Am. proc., v. 38, no. 3, p. 491-496

9. ABSTRACT

For this study, four soil profiles in Sao Paulo State, Brazil were sampled and analyzed physically, chemically, numeralogically, and micromorphologically. They were classified and, based on soil differences, hypotheses on the profiles' origin were developed. It was concluded form this study that the origins of these soils appear to be controlled mostly by the age of the geomorphic surfaces and by the nature of the parent material.

10. CONTROL NUMBER: PN-AAB-479

11. PRICE OF DOCUMENT

12. DESCRIPTORS

Brazil
Sao Paulo
Tropics

13. PROJECT NUMBER

14. CONTRACT NUMBER: CSD-2835 211(d)

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

Reprinted from the *Soil Science Society of America Proceedings*
Volume 38, no. 3, May-June 1974
677 South Segoe Rd., Madison, Wis. 53711 USA

Investigations in an Oxisol-Ultisol Toposequence in S.Paulo State, Brazil

I. F. LEPSCH AND S. W. BUOL

Investigations in an Oxisol-Ultisol Toposequence in S.Paulo State, Brazil[1]

I. F. LEPSCH AND S. W. BUOL[2]

ABSTRACT

Four soil profiles were sampled along a 550-m toposequence traverse in São Paulo State, Brazil and were characterized with physical, chemical, mineralogical, and micromorphological analyses. The soils were classified and hypotheses were developed concerning their genesis based on soil differences observed.

The soil on the upper part of the traverse has an ochric epipedon over an oxic horizon and is classified as clayey, oxidic, isothermic Typic Haplorthox. Slightly downslope organic matter content increases to form a Typic Umbriorthox of the same family. The soil below these two has an argillic horizon over an oxic horizon and is classified as clayey, oxidic, isothermic Orthoxic Palehumult. The soil in the lowest part has an argillic horizon over decomposed shale and is classified as clayey, Kaolinitic, isothermic Typic Paleudult. The main characteristics distinguishing the soils in the lower part of the toposequence from those in the upper part were the increase in depth and eventual loss of the oxic horizon, decrease in gibbsite content, decrease in chlorite/vermiculite intergradient clay minerals, increase in 2:1 clay minerals, decrease in fine clay to coarse clay ratio, increase in fine silt to clay ratios, increase in illuviated clay, and increase in bulk density.

The genesis of these soils appears to be controlled mostly by the age of the geomorphic surfaces and by the nature of the parent material.

Additional Index Words: tropical soils, pedogenesis, weathering, oxic horizon, argillic horizon, Latosol, Red Yellow Podzolic soils.

OXISOLS and Ultisols are often found in close association in the well drained uplands of the humid tropics. Characteristics of both oxic and argillic horizons frequently occur in the same profile. Four soil profiles representing a 550-m toposequence from Oxisols to Ultisols in São Paulo State, Brazil were sampled for this study. From field observations the soil on the upper end of the transect was identified by the Brazilian taxonomic name as a modal Oxisol (Ortho Dark Red Latosol)[3] and the soil on the lower end appeared as a modal Ultisol (Red-Yellow Podzolic Piracicaba Variation)[3]. The intervening two profiles were noted to have characteristics intermediate of both soil orders. Chemical, physical, mineralogical, and micromorphological analyses were carried out in order to describe, compare, and develop hypotheses about the genetic relationship of oxic and argillic horizon formation and to evaluate taxonomic criteria in an Oxisol-Ultisol transition.

DESCRIPTION OF STUDY AREA AND SOILS

The study area is located in the southern part of Rio Claro County, São Paulo State, Brazil. The approximate geographic coordinates are 17°32′ longitude Greenwich and 22°32′ latitude south. The area has an elevation of 615–645 m above sea level and slopes vary from 2% to 8% (Fig. 1). Climate is characterized as "subtropical of altitude" (Cwa) according to Köppen (Critchfield, 1960). The average annual temperature is 20.1C and annual rainfall is 1,375 mm.

Three geomorphic surfaces were identified in the sampling site (surfaces A, B, and C on Fig. 1). The geomorphic surface A where profile number 1 is located, corresponds to the Rio Claro surface of Middle Pleistocene age (Penteado, 1969). Profiles number 2 and 3 are located on a younger geomorphic surface (surface B, Fig. 1) being cut on the Rio Claro surface. Profile number 4 apparently is located on a transitional zone between surfaces B and C and is expected to be the youngest point on the landscape.

According to field observations and previous work done in the area (Penteado, 1969), the parent material is mainly surficial deposits originating from nearby sedimentary and basic extrusive rocks. Shale was found at different depths in sites 2, 3, and 4 (Fig. 1). A sharp contact between the red soil and the shale, some iron concretions, and quartz pebbles suggest a lithological discontinuity.

Native vegetation on the area seems to have been the tropical broadleaf semideciduous forest, as indicated by some small remnant areas such as the one in which profile number 1 was sampled. Sites number 2, 3, and 4 were cleared of primitive forest about 1900 A.D., according to farmers in the area. After clearing, coffee (*Coffea* sp.) was cultivated and in 1921 the area was transformed to pastures. It remained in pasture until around 1960 when sugarcane (*Saccharum officinarum* L.) was introduced. Ant and termite activity is prevalent in the entire area.

Soil pits, 2 m deep, were dug in each site and the pedons described according to the Soil Survey Manual (Soil Survey Staff, 1951). The soils were sampled by horizons in the pits and auger samples were taken each 50 cm below the pit.

[1] Published with the approval of the Director of the North Carolina Agr. Exp. Sta., Raleigh, N.C. as Paper no. 4188 of the Journal Series. This work supported in part by Fundação de Amparo a Pesquisa do Estado de São Paulo. Received 4 Oct. 1973. Approved 22 Feb. 1974.

[2] Soil scientist with Instituto Agronômico, Campinas, Brazil, and F.A.P.E.S.P. Scholar at N.C. State University, and Professor of Soil Science, respectively.

[3] Brazilian taxonomic name (Comissão de Solos do S.N.P.A., 1960).

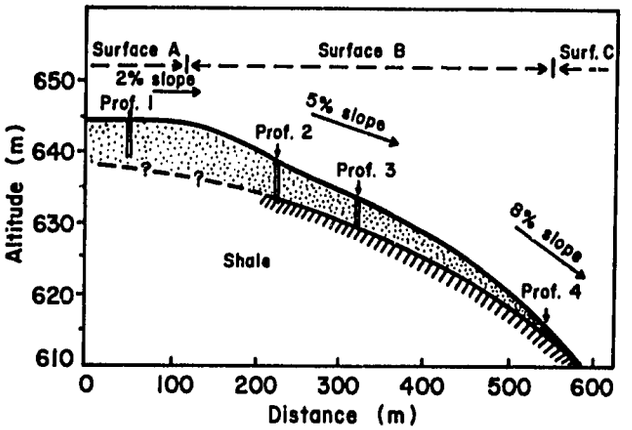

Fig. 1—Schematic cross-section diagram showing the position of the soil profiles in relation to the landscape, slope and substrata.

Soil samples were air-dried and processed to pass through a 2mm sieve. Particle size distribution was determined by the Calgon-pipette method (Kilmer and Alexander, 1949) and by the centrifugation method, with iron removal (Kittrick and Hope, 1963). Water dispersible clay was measured according to Vettori (1969). Soil water retention was measured on disturbed samples at a matric tension of 15 atm using a pressure plate apparatus as outlined by Richards (1951) and water content at 1 atm and ⅓ atm by centrifugation Paiva Neto et al. (1961). Bulk density was determined by the core method.

Soil pH was determined potentiometrically in water and *N* KCl in 1:1 soil/liquid ratios. Total organic carbon was determined by oxidation with acid dichromate using external heat (Allison, 1965). Cation exchange capacity (CEC) was determined by the neutral NH_4OAc procedure (Chapman, 1965), exchangeable K and Na contents determined by flame photometry and Ca and Mg contents determined by atomic absorption. Exchangeable acidity was determined by extraction with *N* KCl, and NaOH titration with bromothymol. Extractable hydrogen was determined by leaching the soil with 1*N* sodium acetate buffered at pH 7, titrating to phenolphthalein end point with 0.1*N* NaOH (Paiva Neto et al., 1961) and subtracting the exchangeable acidity.

Base saturation percentage was calculated based on CEC determined by sum of exchangeable bases plus exchangeable acidity and extractable hydrogen. Oliveira found that percent base saturation by this method *(Y)* is related to percent base saturation determined by sum of cations and $BaCl_2$ TEA pH 8.2 *(X)*, by the equation: $Y = 1.382X + 0.54$ ($r = .996$***) (Oliveira, J. B. de. 1972. Variação das caracteristicas morfológicas, físicas químicas e mineralógicas em duas areas de Oxissolo. Unpublished Thesis. Escola Superior de Agricultura Luiz de Queiroz. Piracicaba, S. Paulo, Brazil).

Free iron was extracted by the citrate-dithionite method as described by Kittrick and Hope (1963).

Mineralogical determinations were conducted on selected samples. The fine clay (< .2μm) and fine sand (100–250 μm) fractions were separated following the procedure of Kittrick and Hope (1963). Oriented clay specimens were prepared on glass slides for the following treatments: Mg-saturated, Mg-saturated and glycol-solvated, K-saturated, and K-saturated and heated to 350C and 500C following the procedure outlined by Jackson (1956). Identification of clay minerals in the coarse and fine clay fractions was made by means of an X-ray diffractometer. Clay mineral contents were estimated from characteristic basal plane peak intensities and DTA. Differential thermal characteristics of fine and coarse clays were determined in a DuPont 900 differential thermal analyser in a flowing N_2 atmosphere with a temperature range from 25C to 650C. The amorphous material was determined according to Hashimoto and Jackson (1960). Samples of coarse silt, very fine and fine sand were mounted on a glass slide under a coverslip with 1.54 index of refraction oil for petrographic examination.

Small undisturbed soil blocks, 2–3 cm in diameter, were impregnated with polyethylene glycol (Carbowax 6000) for thin section preparation (Mitchell, 1956). The thin sections were examined and described according to terminology developed by Brewer (1964).

Table 1—Field morphological descriptions

Horizon	Depth	Boundary*	Munsell color (moist)	Consistence (moist)†	Structure‡
	cm				
			Profile 1		
A1	0-15	CS	5YR3/3	F	str, med & co gr
A3	15-36	CW	3.5YR3/4	F	w, med, sbk
B1	36-65	GS	2.5YR3.5/6	VF	vw, med, sbk
B21	65-140	DS	2.5YR4/6	VF	vw, sbk to str, vf, gr
B22	140-180		2.5YR4/6	VF	str, vf, gr
(auger samples)	180-450		red		
			Profile 2		
Ap1	0-12	AW	3.5YR3/4	F	mod, med, f & co, gr
Ap2	12-33	CW	2.5YR3/6	Fir	massive
B11	33-64	GW	2.5YR3/6	F	mod, f & med, sbk
B12	64-90	GW	2.5YR3.5/6	F	vw, med, sbk
B21 & B22	90-200	DS	2.5YR3.5/6	VF	str, vf, gr
(auger samples)	200-500		2.5YR4/6		
(shale)	520-550		gray violet		
			Profile 3		
Ap1	0-10	AW	5YR3.5/4	Fir	mod, co & v co, gr
Ap2	10-25	CW	5YR3/4	Fir	massive
B1	25-40	CS	4YR3/4	F	mod, med, sbk
B21	40-57	CS	2.5YR4/4	F	mod, med, sbk
B22	57-82	CS	2.5YR3.5/6	F	w to mod, f & med, sbk
B23	82-100	DS	2.5YR4/6	VF	w, med, sbk
B3	100-200	DS	2.5YR4/6	VF	str, vf, gr
(auger samples)	200-400		2.5YR4/6		
(shale)	400-450		gray violet		
			Profile 4		
Ap1	0-10	AW	5YR4/5	F	mod, med & f, gr
Ap2	10-19	CW	5YR3/3	Fir	massive
A3	19-27	CW	5YR3/4	Fir	mod, med, sbk
B21t	27-64	GS	3.5YR4/6	Fir	str, f & med, sbk
B22t	64-95	GS	3.5YR4/6	Fir	str, med, sbk
B3	95-150	GS	5YR5/6	Fir	mod, med, sbk
C1	150-190	C	Red & yellowish red	Fir	mod, med, sbk
IIC2(shale)	190-260		gray violet		

* C = clear; S = smooth; W = wavy; G = gradual; D = diffuse; A = abrupt.
† F = friable; VF= very friable; Fir = firm.
‡ str = strong; mod = moderate; med = medium; co = coarse; gr = granular; sbk = subangular blocky; v = very; f = fine; w = weak.

RESULTS AND DISCUSSION

Morphological Properties

Important morphological features are summarized in Table 1. Solum thickness decreased downslope. Profile 1 has weak, medium, and subangular blocky structure breaking to very fine granular structure in the upper B horizon, the granules making a very friable and porous soil mass, without any discernible ped surface coatings and with gradual and diffuse horizon boundaries. Downslope from profile 1 the upper part of the B horizon becomes progressively more subangular blocky in structure and some clay skins were observed. The horizon with subangular blocky structure increases in thickness from profile 2 to profile 4 whereas the underlying horizon with very fine granular structure eventually disappears some place between profiles 3 and 4.

Physical Properties

The particle size distribution (Table 2) showed clay content values over 50% throughout all profiles. Most of the clay, except for the decomposed shale layer, was found to be fine clay (< 0.2μm). Silt contents were generally low, specially for profiles 1, 2, and 3. The fine silt/clay ratio

Table 2—Selected physical properties

Horizon	Depth	Calgon pipette			Fine silt/clay	Centrifugation			Fine/ coarse clay ratio	H_2O dispers. clay	Bulk density	Water retention		15 atm 1/3 atm H_2O
		Sand	Silt	Clay		Coarse clay	Fine clay	Total clay				1/3 atm	15 atm	
	cm	%			ratio	%				%	g/cc	% wt	% wt	% vol
							Profile 1							
A1	0-15	20	10	70	0.10	7	53	60	7.6	11	0.90	29.5	26.4	2.8
A3	15-36	16	7	77	0.05	--	--	--	--	25	1.01	29.5	25.1	4.4
B1	36-65	14	7	79	0.05	8	61	69	7.6	3	0.90	31.8	25.3	5.9
B21	65-140	15	8	77	0.06	11	59	70	5.3	2	0.98	32.8	25.7	7.0
B22	140-180	14	10	76	0.08	--	--	--	--	2	0.89	32.5	26.2	5.6
--	400-450	16	19	65	0.20	12	60	72	5.1	3	---	---	---	---
							Profile 2							
Ap1	0-12	17	9	74	0.06	15	51	66	3.4	30	1.22	28.9	23.3	6.8
Ap2	12-33	16	9	75	0.05	-	-	-	-	20	0.48	29.7	24.3	8.0
B11	33-64	14	7	77	0.04	10	63	73	6.3	13	1.30	30.8	26.4	5.7
B12	64-90	14	7	79	0.05	13	58	71	4.5	1	1.03	32.0	27.2	4.9
B21	90-140	13	8	79	0.06	-	-	-	-	2	0.90	34.6	26.8	7.0
-	450-500	13	24	63	0.27	17	56	73	3.3	2	-	-	-	-
-	520-550	8	25	67	0.28	28	43	71	1.5	2	-	-	-	-
							Profile 3							
Ap1	0-10	18	14	68	0.10	12	50	62	4.2	20	1.32	27.8	19.7	10.7
Ap2	10-25	18	14	68	0.10	-	-	-	-	17	1.42	29.2	20.5	12.4
B1	25-40	19	15	67	0.11	-	-	-	-	25	1.34	28.1	20.5	10.2
B21	40-57	14	12	75	0.09	-	-	-	-	31	1.19	29.1	22.6	7.7
B22	57-82	13	11	76	0.09	16	53	69	3.3	18	1.07	30.8	24.3	7.0
B23	82-100	12	11	77	0.09	19	45	69	2.4	2	0.89	33.4	25.4	7.1
B32	130-165	13	12	75	0.08	23	39	62	0.7	tr	0.88	-	-	-
-	350-400	12	21	67	0.20	-	-	-	-	2	-	-	-	-
-	400-450	11	28	62	0.32	-	-	-	-	2	-	-	-	-
							Profile 4							
Ap1	0-10	20	21	59	0.24	16	38	54	2.4	31	1.23	26.5	18.1	10.3
Ap2	10-19	19	20	61	0.22	-	-	-	-	32	1.41	26.8	18.9	11.1
A3	19-27	18	21	60	0.21	14	40	54	2.9	31	1.34	26.8	19.0	10.5
B21t	27-64	9	13	78	0.12	19	51	70	2.7	6	1.31	34.8	26.5	10.9
B22t	64-95	8	12	81	0.10	-	-	-	-	5	1.32	35.1	27.7	9.8
B3	95-150	8	9	82	0.09	19	54	73	2.8	2	1.25	35.6	28.4	9.0
C1	150-190	8	14	79	0.13	-	-	-	-	2	1.24	-	-	-
IIC2	190-260	2	27	71	1.32	30	38	68	1.3	2	-	-	-	-

increased and fine/coarse clay ratio decreased downslope. Distribution of clay indicates greater clay illuviation at sites 3 and 4. On sites 1 and 2, clay content increase is not sufficient to meet the argillic horizon criteria (Soil Survey Staff, 1974). Content of water dispersible clay was always found to decrease from the surface to the deepest layers.

Profile 1 has bulk density lower than 1.2 g/cc throughout the profile (Table 2). The other profiles have higher bulk densities in the upper part of the B horizon with profile 4 being the most dense. Bulk densities above 1.00 g/cc coincide in most cases with the angular blocky structure as described in field soil descriptions (Table 1), whereas bulk densities below 1.0 g/cc coincide with the horizons with friable, strong, very fine, and granular structure, characteristic of most oxic horizons (Soil Survey Staff, 1974).

Water retention values for ⅓ atm and 15 atm are given in Table 2. Only slight differences are observed when the moisture is presented on a weight basis. However, calculation of the amount of water contained between these two tensions, on a volume basis, reveals appreciably higher values in the angular blocky, higher bulk density horizons.

Chemical Properties

Results of pH determinations (Table 3) show no apparent significant differences in the pH values measured in water in sites 1, 2, and 3. Site 4 has slightly higher pH values. The pH values determined in KCl were always lower than those determined in water. Some differences among profiles are apparent when Δ pH values are compared [ΔpH = (pH in 1*N* KCl)-pH in H_2O)]. According to Mekaru and Uehara (1972), when the Δ pH value is negative the soil has a net negative charge. By this calculation the net negative charge seems to increase from profile 1 to profile 4.

Contents of more than 1% organic carbon were determined to depths of 65, 90, and 82 cm respectively for profiles 1, 2, and 3. In profile number 4 organic carbon decreases to values of less than 1% at a depth of 27 cm. The relative high organic matter content at depths of 1 m in profiles numbers 1, 2, and 3 suggest that faunal and floral pedoturbation (Hole, 1961) either is greater on these sites - that they have been exposed longer at these propedoisotropic processes.

Cation exchange capacity (Table 3) normally decreases with depth and this seems to be correlated with a decrease in organic matter content.

Mineralogy

Petrographic identification of silt and sand fractions showed that quartz was the dominant mineral in all samples, varying from 62 to 97%. Grains identified as "heavy and opaque" were the second most common and they were observed most frequently in the 20 to 50 μm fractions. It was noticed that the content of these minerals decreases from site 1 to site 4. Some elongated angular rock fragments were found in sites 2, 3, and 4. The relative amount of these rock fragments increased from profile 2 to profile 4 and the decomposed shale rock (450–550 cm depth in profile 2) contained greater amounts of these grains than the overlying soil. The decrease in content of "heavy plus opaques" downslope and the increase in rock fragment con-

Table 3—Selected chemical properties

Horizon	Depth	pH H_2O	pH KCl	ΔpH	Organic carbon	CEC (NH_4OAc)	Exchangeable ions Ca	Mg	K	Na	Exch. acidity	Ext. Al	Base sat.	Free Fe_2O_3
	cm				%	meq/100 g soil							%	
						Profile 1								
A1	0-15	5.0	4.2	-0.8	3.0	11.4	3.1	0.7	0.4	0.2	1.5	11.4	26	9.3
A3	15-36	4.8	4.0	-0.8	1.7	8.7	0.2	0.2	0.2	0.2	3.0	8.6	6	-
B1	36-65	5.0	4.2	-0.8	1.0	8.6	0.1	0.1	0.1	0.1	4.5	2.5	7	9.5
B21	65-140	5.0	4.4	-0.6	0.7	7.5	0.1	0.1	0.1	0.1	1.2	5.9	6	9.5
B22	140-180	5.2	4.4	-0.8	0.7	6.4	0.1	0.1	0.1	0.2	0.9	5.7	7	-
	400-450	5.6	5.0	-0.4	-	5.5	0.1	tr	tr	0.1	tr	4.2	6	9.7
						Profile 2								
Ap1	0-12	5.3	4.4	-0.9	1.5	8.6	3.6	0.4	0.2	0.1	0.7	7.3	35	10.0
Ap2	12-33	5.3	4.4	-0.9	1.6	9.0	9.2	0.5	0.1	0.1	0.8	7.0	56	-
B11	33-64	4.9	4.1	-0.8	1.4	8.6	2.1	0.1	0.1	0.1	2.1	5.8	24	9.3
B12	64-90	5.0	4.3	-0.7	1.4	7.8	2.2	0.1	0.1	0.1	1.6	5.9	25	10.6
B21	90-140	5.2	4.6	-0.6	0.8	7.6	0.6	0.1	0.1	0.1	0.7	5.2	13	-
	450-500	5.3	4.3	-1.0	-	3.4	0.1	tr	0.1	0.2	1.1	3.6	9	10.9
	520-550	5.7	3.9	-1.8	-	6.4	0.1	0.1	0.1	-	3.4	2.6	4	10.5
						Profile 3								
Ap1	0-10	5.0	4.2	-0.8	1.5	8.6	3.8	0.5	0.4	0.2	0.8	7.6	36	9.2
Ap2	10-25	4.9	4.2	-0.7	1.6	9.5	3.9	0.5	0.2	0.2	1.0	8.0	35	-
B2	25-40	5.0	4.2	-0.8	1.7	9.8	4.8	0.6	0.2	0.2	0.5	7.4	42	-
B21	40-57	5.3	4.4	-0.9	1.2	7.5	2.8	0.6	0.1	0.2	tr	6.5	36	-
B22	57-82	5.1	4.2	-0.9	1.0	7.0	1.5	0.5	0.1	0.2	0.9	6.2	25	9.6
B23	82-100	5.0	4.1	-0.9	0.8	5.9	0.7	0.2	0.1	0.2	1.5	5.9	15	-
B32	130-165	5.5	4.3	-1.2	-	5.3	0.2	0.1	0.1	0.2	0.8	5.8	8	10.0
	350-400	5.5	4.2	-1.3	-	-	0.1	0.1	-	-	1.3	4.3	-	-
	400-450	5.6	3.8	-1.8	-	8.4	0.1	0.1	0.1	0.1	4.0	3.5	5	-
						Profile 4								
Ap1	0-10	6.0	5.1	-0.9	1.3	10.6	8.5	1.1	0.6	0.1	tr	4.7	68	8.0
Ap2	10-19	5.7	4.6	-1.1	1.3	9.2	7.8	0.6	0.3	0.1	tr	3.1	73	-
A3	19-27	5.7	4.6	-1.1	1.3	9.3	6.6	0.6	0.2	0.1	tr	5.7	57	-
B21t	27-64	5.8	4.8	-1.0	0.8	9.7	5.3	0.8	0.1	0.1	tr	4.8	57	8.9
B22t	64-95	5.8	4.9	-0.9	0.6	8.6	4.5	0.8	0.2	0.1	tr	4.6	55	-
B3	95-150	5.5	4.6	-0.9	0.4	8.6	2.4	0.7	0.3	0.1	tr	5.7	39	9.0
C1	150-190	5.3	3.9	-1.4	-	8.3	1.1	0.4	0.3	0.2	2.5	5.0	21	-
IIC2	190-260	5.2	3.6	-1.6	-	11.7	0.6	0.3	0.3	0.2	6.5	4.2	11	8.3

tent, both downslope and in the shale, suggests that parent material of profiles 2, 3, and 4 received contributions of different amounts of the underlying shale and that these contributions increased downslope.

The results of X-ray diffraction analyses and DTA (Table 4) indicate that kaolinite is the dominant mineral in all clay fractions. Other clay minerals present in amounts between 10 and 50% were the chlorite/vermiculite intergradient, gibbsite, vermiculite, and mica. Quartz was detected to be present only as traces in the coarse clay fraction.

Table 4—Quantitative estimations of clay mineralogy by differential thermal analysis and X-ray diffractograms

Horizon	Depth	Fine clay (<.2μm) Gib*	Kaol*	Am*	Others†	Coarse clay (2-.2μm) Gib*	Kaol*	Am*	Others†
	cm	%				%			
				Profile 1					
A1	0-15	7	86	14	I^t	20	50	5	$I^2 Q^t$
B1	36-65	7	76	14	I^t	--	--	--	$I^2 Q^t$
B21	65-140	7	76	19	I^t	20	65	5	$I^1 Q^t$
-	400-450	8	86	15	I^t	28	50	--	$I^1 Q^t$
				Profile 2					
Ap1	0-12	10	83	9	IV^t	12	51	8	$I^2 M^t Q^t$
B11	33-64	9	86	10	I^t	15	53	4	$I^2 M^t Q^t$
B12	64-90	8	76	8	I^t	14	47	8	$I^2 M^t Q^t$
-	450-500	7	88	9	$I^t M^t$	--	--	--	$I^t M^t V^t Q^t$
(shale)	520-550	3	86	7	$M^1 V^t$	3	74	5	$M^1 V^t$
				Profile 3					
Ap1	0-10	5	86	04	$I^t V^t$	14	61	4	$I^1 M^t V^t Q^t$
B22	57-82	5	85	10	$I^t M^t$	14	63	4	$I^1 M^t V^t Q^t$
B32	130-165	5	77	11	$I^t M^t$	10	64	7	$I^1 M^t V^t Q^t$
				Profile 4					
Ap1	0-10	tr	73	10	$V^1 M^t$	4	46	5	$V^1 M^1$
B21t	21-64	1	76	12	$I^t M^t V^t$	3	40	--	$V^1 M^1$
B3	95-150	tr	64	11	$I^t M^t V^t$	tr	76	11	$V^1 M^1$
IIC2 (shale)	190-260	0	60	7	$M^2 V^t$	tr	49	4	$M^2 V^t$

* Gib = gibbsite; Kaol = kaolinite; Am = amorphous material; tr = trace (less than 1%); - = not determined.
† I = intergradient chlorite/vermiculite; M = mica; Q = quartz; V = vermiculite; 2 = medium (25-50%); 1 = small (10-25%); t = trace (<10%).

Mica was not detected in profile 1. It was detected in amounts less than 10% in the fine clay of profile 2, in the fine and coarse clay of profile 3, and in the fine clay of profile 4. The coarse clay in profile 4 presented mica in amounts varying from 10 to 25%. The shale samples presented considerable amounts of mica, estimated to vary from 20 to 50%. Chlorite/vermiculite intergrade minerals were found mainly in the coarse clay fractions of profile 1 (Fig. 2) and 2 where they are estimated to be in amounts varying from 25 to 50%. The content of vermiculite/chlorite minerals decreases from profile 1 to profile 4; whereas mica and vermiculite increase in the same direction.

Quantitative determination of gibbsite (Table 4) shows a greater content in the coarse clay fractions than in the fine clay fractions. A comparison of the gibbsite content as calculated for the total clay shows no apparent difference between profiles 1 and 2, but profile 3 shows a relative decrease of 30% and profile 4 contains only traces of gibbsite. The trend in gibbsite content suggests a decrease in the weathering of the clay minerals from the upper member to the lower member of the toposequence.

The clay mineralogy data suggest that profiles 1 and 2 are in the same weathering stage since they show similar amounts of clay minerals. Profile 4 is considerably less weathered, containing very small amounts of gibbsite and considerable amounts of vermiculite and mica. Profile 3 seems to be in an intermediate stage of weathering, as evidenced by smaller amounts of gibbsite than profile 1 and 2 and by the presence of some mica and vermiculite.

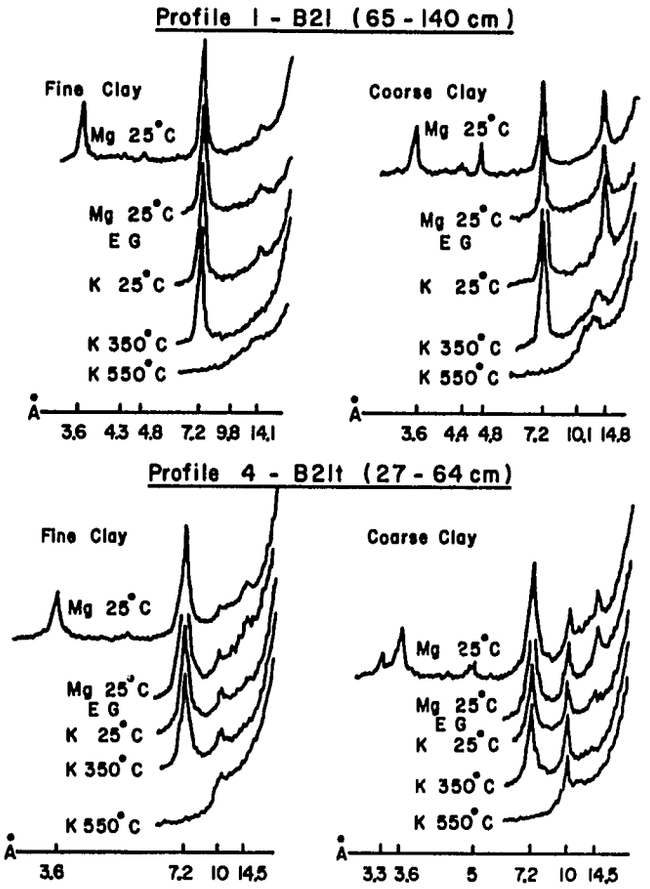

Fig. 2—X-ray diffractograms of the coarse clay (2–.2μm) and fine clay (< 2μm) in the B horizons of profiles 1 and 4.

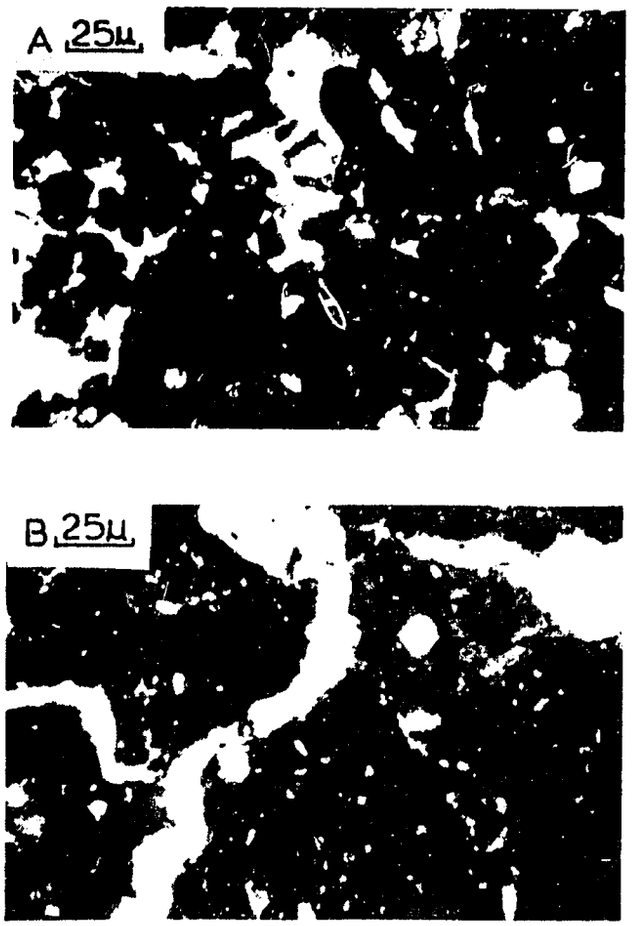

Fig. 3—Photomicrographs in plain light of thin sections from: (*A*) Oxic horizon, profile 1; (*B*) Argillic horizon, profile 4 (magnified 60X).

The data also point to a high degree of weathering to considerable depths in the upper members of the toposequence since samples from 400–450 cm, profile 1 and 450–500 cm, profile 2 presented no apparent difference in clay mineralogy when compared to the overlying soil.

Micromorphology

Profile 1—Differences among horizons were due to ped size and void morphology. No plasmic concentrations were noticed. The plasma occurs essentially as a continuous groundmass in which the skeleton grains are set. The primary peds varied in size and shape from 4 to 6 mm, subrounded blocky in the superficial horizon, to 0.4 to 0.6 mm, subrounded and mammilated blocks in the B2 horizon. In the B2 horizon small peds have a very compact plasma in which no voids could be distinguished with the available petrographic microscopic magnifications. It was noticed that plasmic structure was almost completely isotropic without any recognizable anisotropic domain. The bulk of the B horizon appears like a very porous material in which the subrounded and mammillated peds are partially accommodated leaving large pore areas which are interpreted as interpedal voids (Fig. 3A). This structure seems to be very much like the one described for a Eutrustox by Moura Filho and Buol (1972) and explains the high porosity of these soils.

Profile 2—This profile appears to be identical to profile 1 with two exceptions. Some plasma concentrations represented by a few void argillans and papules were observed in the B1 horizon and the depth where the subangular peds seemed to dominate over the very small granular and mammillated ones is deeper. The argillans and papules were estimated to be less than 1% and thus not sufficient to qualify the B1 horizon as argillic (Soil Survey Staff, 1974).

Profile 3—The B2 horizon in this profile is composed of predominantly subrounded blocky structure with few illuvial void argillans and other plasma concentration features such as papules and quasicutans. No cutans were found in the interpedal packing voids. No plasma concentrations were noticed in the B3 horizon. This horizon presented very small subrounded and mammillated structure, very similar to the B2 horizon of profiles 1 and 2.

Profile 4—The B2 horizon presented subrounded blocky structure, partially accommodated, sparse illuviation argillans, as well as neoargillans and quasicutans (Figure 3B). The C1 horizon presented common illuviation argillans, neoargillans, quasicutans, and a few papules. These features are very much in keeping with the other observed features of argillic horizons. Some anisotropic domains with weak striated orientation were present in the B2 and C1 horizons, contrasting somehow with the other profiles which showed dominantly isotropic plasma.

Soil Classification

Diagnostic horizon and classification at the family level (Soil Survey Staff, 1974) are as follows: Profile 1 has an Ochric epipedon, chroma 4 except in the top 15 cm of profile 1, over an oxic horizon; it is classified as clayey, oxidic, isothermic Typic Haplorthox. Profile 2 is similar to profile 1 but contains slightly more organic carbon thus it is classified as an Umbriorthox. Profile 3 has an ochric epidedon over an argillic horizon and is classified as clayey, oxidic, isothermic Orthoxic Palehumult; below the argillic horizon, there is an oxic horizon with composition and morphology very similar to the oxic horizon of profiles 1 and 2. Profile 4 has an ochric epipedon over an argillic horizon and it is classified as clayey, kaolinitic, isothermic Typic Paleudult.

Considerations of Pedogenesis and Taxonomy

There is a toposequence gradation from Oxisols (profiles 1 and 2) to the Ultisols (profiles 3 and 4) with an increase in depth and eventual loss of the oxic horizon and an increase in the degree of expression of the argillic horizon lower in the toposequence. The oxic horizon has its greatest degree of expression where the surface is geomorphically older, and where there is a thicker and more weathered soil mantle. The argillic horizon is more expressed where the surface is geomorphically younger and the soil mantle is shallower and less weathered.

Micromorphological data illustrate the absence or small degree of clay illuviation in the more weathered soils. The occurrence of an almost isotropic plasma in the primary peds of the oxic horizons suggests that the main plasma components are highly flocculated and compacted. Based on that, it is hypothesized that with increase of soil age and stage of weathering, the oxic horizon soil plasma is flocculated and organized into a compacted granular structure. Increased fine/coarse clay ratios seem to be integral to this process. This structure reduced clay illuviation and allows pedoturbation processes to homogenize the profiles.

The maximum expression of these processes is found in profile 1. Profiles 2 and 3 are on younger geomorphic surfaces and were formed from parent material that received contribution both from material identical to profile 1 and, in lesser degree, from the shale layer. The less weathered shale provides clay material susceptible to be illuviated and probably the compact granular structure is not as well developed as in profile 1. Profile 4, on the youngest part of the landscape, presents the best developed argillic horizon due to the fact that it developed from less weathered parent material and time was not sufficient to organize the plasma into a compact granular stucture. Thus, lessivage is at present the dominant process retaining an argillic horizon in the younger sites while pedoturbation exerts dominance in the older Oxisols.

As the oxic and argillic horizons merge, both being identified in profile 3, the identification of the argillic horizon by increase of clay content with depth appears to coincide well with accessory features. Water dispersible clay does not appear useful. The slightly greater organic carbon content rendering profiles 2 and 3 as Umbriorthox and Palehumult respectively, appears of no significance to local agricultural practices. The very similar and low (about 10 meq/100 gm clay) clay activities in the argillic horizons of profiles 3 and 4 would seem to dictate a similar intergradation to the Orthox suborder. However, the Orthoxic subgroup, defined as having a CEC of less than 24 meq/100 g clay in the Palehumult great group, is not presently established in the Paleudult great group.

LITERATURE CITED

1. Allison, L. E. 1965. Organic carbon, *In* C. E. Black (ed.) Methods of Soil Analysis, Part 2. Agronomy 9:1367–1378. Amer. Soc. Agron., Madison, Wis.
2. Brewer, R. 1964. Fabric and mineral analysis of soils. John Wiley and Sons, Inc., New York. p. 470.
3. Chapman, H. D. 1965. Cation-exchange capacity, *In* C. E. Black (ed.), Methods of Soil Analysis, Part 2. Agronomy 9:891–901. Amer. Soc. of Agron., Madison, Wis.
4. Comissão do Solos do S.N.P.A. 1960. Levantamento de reconhecimento dos solos do Estado de São Paulo. Rio de Janeiro, Ministério da Agricultura, Brazil. Bol. 12 p. 350.
5. Critchfield, H. J. 1960. General climatology. Prentice-Hall, Inc. Englewood Cliffs, N.J.
6. Hashimoto, I., and M. L. Jackson. 1960. A rapid dissolution of allophane and kaolinite. Clay Clay Minerals. 7: 102–113.
7. Hole, F. D. 1961. A classification of pedutorbation and some other processes and factors of soil formation in relation to istropism and anisotropism. Soil Sci. 91:375–377.
8. Jackson, M. L. 1956. Soil chemical analysis—advanced course. Published by the author. Madison, Wis. p. 991.
9. Kilmer, V. J., and L. T. Alexander. 1949. Methods of making mechanical analyses of soils. Soil Sci. 68:15–24.
10. Kittrick, J. A., and E. W. Hope. 1963. A procedure for the particle size separation for X-ray diffraction analysis. Soil Sci. 96:318–325.
11. Mekaru, T., and G. Uehara. 1972. Anion adsorption in ferruginous tropical soils. Soil Sci. Soc. Amer. Proc. 36: 296–300.
12. Mitchell, J. K. 1956. The fabric of natural clays and its relationship to engineering properties. Proc. Highway Res. Board 35:693.
13. Moura, Filho, W., and S. W. Buol. 1972. Studies of a Latosol Roxo (Eutrustox) in Brazil: Clay mineralogy. Experientiae 13:201–217.
14. Paiva Neto, J. E., A. C. Nascimento, A. Küpper, F. C. Verdade, H. P. Medina, and F. Grohmann. 1961. Solos da bacia Paraná Uruguai. Sao Paulo, Comissao Interestadual da Bacia Paraná Uruguai, 168 p.
15. Penteado, M. M. 1969. A bacia de sedimentação do Rio Claro, Estado de São Paulo. Rev. Geogr. da Soc. Geogr. de Lisboa, 17:38–61.
16. Richards, L. A. 1951. A pressure membrane extraction apparatus for soil solutions. Soil Sci. 51:377–386.
17. Soil Survey Staff. 1961. Soil survey manual. USDA Agr. Handbook no. 18. US Government Printing Office, Washington, D.C. p. 503.
18. Soil Survey Staff. 1974. Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. USDA Agr. Handbook no. 436. US Government Printing Office, Washington, D.C. (in press.)
19. Vettori, L. 1969. Métodos de análise do solo. Ministério da Agricultura. Boletim tecnico no. 7. Rio de Janeiro, Brazil.