J. Indian Soc. Coastal agric. Res., 15 (1), 1-14, 1997.

Vertisols and Associated Soils Development and Lithological Discontinuity in Coastal Godavari Delta Region

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Typic Endoaquerts were identified in parts of low and high swamp areas (P5 & P6). *Ustic Endoaquerts* (P2) and *Typic Endoaquepts* (P1) were identified in parts of deltaic lowlands and *Typic Endoaquepts* (P3) and *Typic Endoaquents* (P4) were identified in parts of mud flat lands. The latter two profiles exhibited relatively wider lithological discontinuities between horizons based on morphological characteristics, sand/silt, silty/clay, (sand+silt)/clay and sand ratio, moisture retention characteristics, organic carbon, $CaCO_3$ and electrical properties. These two profiles indicated frequent disturbances in their stabilisation to form Vertisols Whereas, profiles P1 and P2 exhibited Vertisol properties, eventhough showing some discontinuities. Profiles in the mangrove swamps (P5 & P6) showed no discontinuity within the observed depth The formation of Vertisols and associated soils in this region may also be attributed to have a marine influence in addition to the effect of Godavari river system.

(**Key words:** *Vertisols, Lithological discontinuity, Sand ratio)*

Vertisols are characterised by a shrink-swell cracking morphology influenced by clay content of more than 30% dominated by smectite mineralogy and governed by an arid to subhumid (dry) climate. Vertisols formed at different agro climatic zones seem to be similar morphologically, but may vary slightly in the mineral composition, which may in turn affect the properties and management of these soils (Dudal and Eswaran, 1988). In the dry subhumid tropical region, particularly in coastal East Godavari district of Andhra Pradesh, soil formation was influenced by shifting of river channels along with marine transgression. This may have resulted in the formation of stratified horizons leading to lithological discontinuities between horizons. There are various methodologies to find out discontinuities between horizons interpreted on the basis of various ratio of particle-size fractions (Wang and Arnold, 1973, Courty and Fedoroff, 1985, Ibrahimi *et al.*, 1986). The present study attempts to highlight these discontinuities based mainly on morphology, particle size fractions. electrical properties and moisture retention data.

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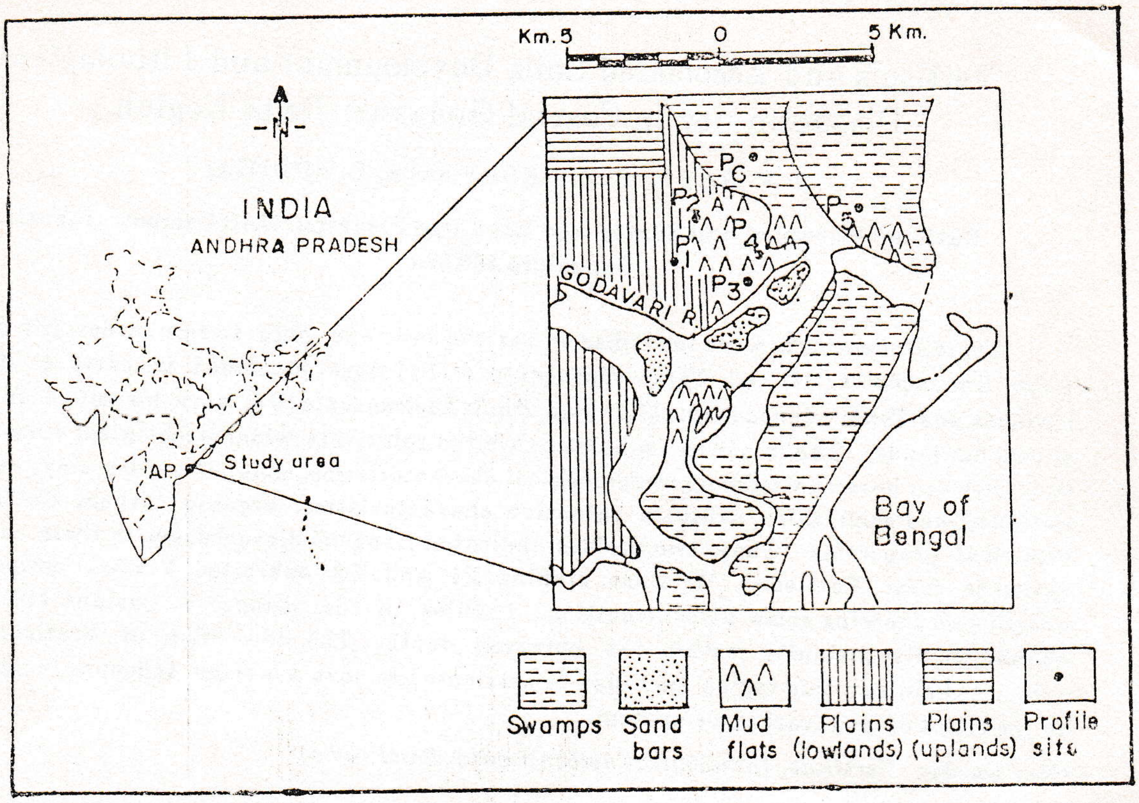

Fig. 1. Location map of the study area in East Godavari district of A.P. and Yanam region of Pondicherry

MATERIALS AND METHODS

Six soil profiles (P1 to P6, Fig. 1) located in parts of coastal East Godavari district in Andhra Pradesh and parts of Yanam in Union Territory of Pondicherry were selected for the study. The general physiographic location of all the six profiles is the coastal plain over which the Godavari delta has formed resulting in the formation of various micro-physiographic landforms having slopes ranging from 0-4%. Profiles P1 and P2 are located in deltaic lowlands (coastal plains). These lands are flooded occasionally and ground water is high by virtue of its vicinity with the river system. Profiles P3 and P 4 occur in the mud flats and are flooded when there is an unusual rise in the the level of Godavari and its tributaries. Soils of P1 to P4 profiles support scarce vegetation of thorny bushes, grasses and some salt resistant species of halophytic plants and herbs (*Trienthema portulacastrum L., Acalypha indica L., Jatropha gessypifolia Roxb , Trichoderma spp., Salicornia brachiata Roxb.,* etc). Profiles P 5 and P 6 are located in the low and high swamps area, respectively. Low swamp lands are usually flooded during each high tides, whereas high swamp lands are sometimes flooded during tides. Both these soils support scarce mangrove vegetations (*Avicennia martine*, etc.). An empirical diagram showing some coastal deltaic landforms is illustrated in Fig. 2.

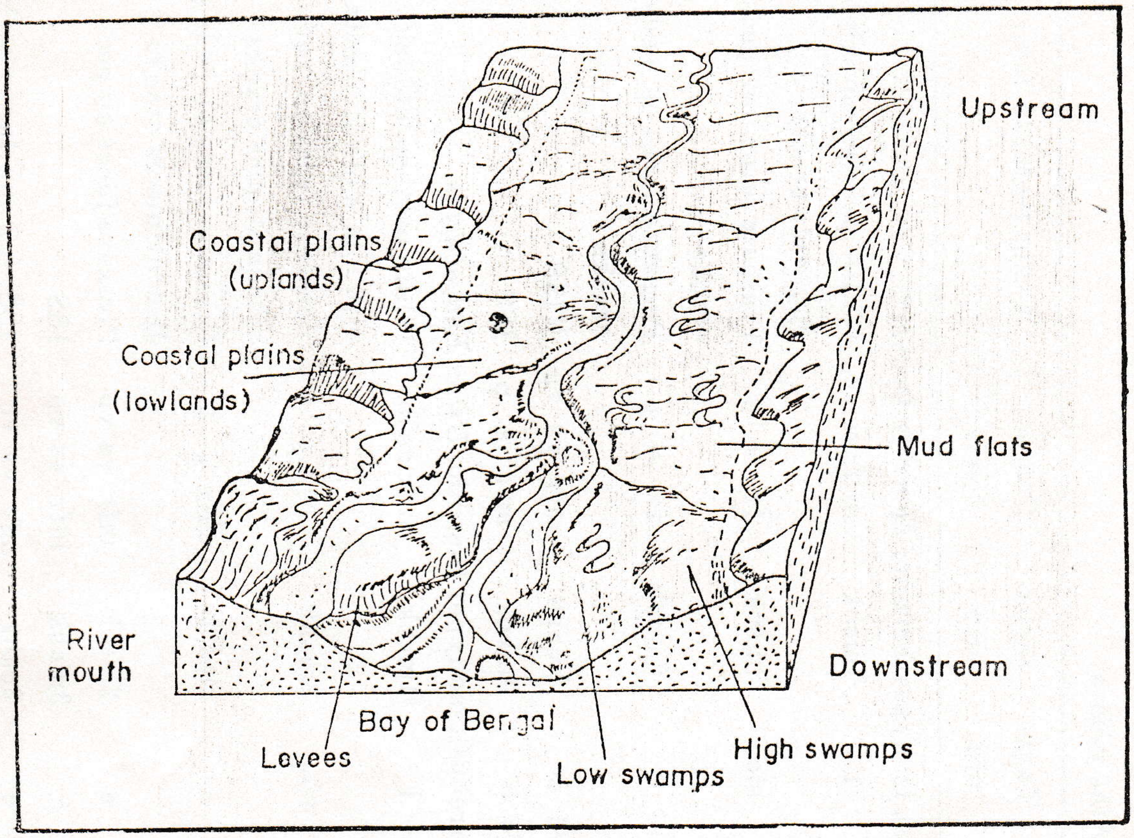

Fig. 2. Empirical diagram showing various landforms in the study area

Field morphological properties were studied using standard methods (Soil Survey Staff, 1992). Soil samples were collected at specific sites and those less than 2 mm size fractions were separated for some laboratory characterisations. Particle-size fractions were analysed by the International Pipette method and various sand fractions were separated with the help of sieves of standard sizes. pH, EC, organic carbon, $CaCO_3$ and moisture retention at 33 kPa and 1500 kPa (Black, 1965) were done by standard methods.

RESULTS AND DISCUSSIONS

Morphological characteristics (Table 1) of the soil profiles show that fine and very fine textured soils have matrix colours ranging from 10YR 3/1 to 10 YR 3/2, whereas loamy textured soils have matrix colours ranging from

Table 1. *Morphological characteristics of the pedons*

Horizon	Depth cm	Colours Matrix	Mottles	Texture	Structure	Consistence	Other features (cm)
P1 : Fine, montmorillonitic (calcareous), isohyperthermic, *Typic Endoaquerts*							
A1	0-9	10YR 3/2	—	l	1msbk	sh/fr ss sp	White patches of salt encrustation ; 5 mm wide cracks
2B1	9-22	10YR 3/1	—	sic	2msbk	fr s p	Pressure faces on peds ; 5 mm wide cracks
2B2	22-40	10 YR 3/2	10YR 5/4	c	2msbk	fr s p	Pressure faces on peds ; 5 mm wide cracks
2Bss1	40-61	10 YR 3/2	10YR 5/4	c	2mabk	mfr vs vp	NISS
2Bss2	61-75	10 YR 3/2	10YR 4/4	c	3mabk	mfr s p	ISS
P 2 : Very fine, montmorillonitic (calcareous), isohyper thermic. *Ustic Endoaquerts*							
A1	0-9	10YR 4/2	—	l	1msbk	sh fr ss sp	White patches of salt encrustation ; 5-10 mm wide discontinuous cracks
2B1	9-25	10YR 3/2	—	sic	2msbk	fr s p	Pressure faces on peds ; 5-10 mm wide discontinuous cracks
2B2	25-43	10YR 3/2	—	c	2msbk	mfr s p	Pressure faces on peds ; 5-10 mm wide discontinuous cracks
2B3	43-62	10YR 3/2	—	c	2msbk	mfr vs vp	Pressure faces on peds
2Bss1	62-84	10YR 3/2	10YR 4/4	c	3mabk	mfr vs vp	ISS
2Bss2	84-110	10YR 3/2	10YR 4/4	c	3cabk	mfr vs vp	ISS, few mollusc shells

(Contd.)

Table 1. (Contd.)

Horizon	Depth cm	Colours Matrix	Colours Mottles	Texture	Structure	Consistence	Other features (cm)
P3 : Fine-loamy, mixed (calcareous), isohyperthermic, *Typic Endoaquepts*							
A	0-13	10YR 3/2	—	sic	2msbk	fr s p	—
2A	13-24	10YR 3/3	—	sicl	1msbk	fr s p	—
2Bw1	24-34	10YR 3/2	—	sicl	2msbk	fr s p	Pressure faces on peds
2Bw2	34-48	10YR 3.5/2	—	sicl	2msbk	fr s p	—
3AC	48-80	10YR 3.5/2	10YR 4/6	l	1msbk	fr s p	—
4AC	80-93	10YR 4/2	7.5YR 5/8	sl	1msbk	fr ss sp	Top 3 cm layer of fine sand
5AC	98-108	10YR 3/2	7.5YR 4/6	sl	1msbk	fr ss sp	—
P4 : Coarse-loamy, mixed (calcareous), isohyperthermic, *Typic Endoaquents*							
A	0-12	10YR 2.5/2	—	cl	2msbk	fr s p	—
2A	12-27	10YR 3/2	—	sicl	2msbk	fr s p	Pressure faces on peds ;
3C	27-42	10YR 4/4	—	s	Ofgr	l so po	—
4AC	42-53	10YR 3.5/2	—	cl	1msbk	vfr ss p	
5C1	53-70	10YR 4/4	10YR 5/8	s	Cfgr	l so po	65-70cm layer is of sic texture
5C2	70-96	10YR 4/4	10YR 5/8	s	Of gr	l so po	—
6AC	96-113	10YR 3/2 (r)	10YR 5/8	cl	2msbk	fr s p	Few mollusc shells

(Contd.)

Table 1. (Contd.)

Horizon	Depth cm	Colours Matrix	Colours Mottles	Texture	Structure	Consistence	Other features (cm)
P5 : Very fine, montmorillonitic (calcareous), isohyperthermic *Typic Endoaquerts*							
A1	0-16	10YR 3/2	—	c	2msbk	fr vs vp	Structure is weak throughout the profile due to wetness.
Bw1	16-36	10YR 3/2	—	c	2msbk	fr vs vp	Particles of colour 10YR 2/1 are common
Bss1	36-57	10YR 3/2	7.5YR 4/6	c	3mabk	fr vs vp	NISS ; particles of colour 10 YR 2/1 are common
Bss2	57-77	10YR 3/2	7.5YR 4/6	c	3mabk	fr vs vp	NISS ; particles of colour 10YR 2/1 are common
P 6 : Very fine, montmorillonitic (calcareous), isohyperthermic, *Typic Endoaquerts*							
A1	0-13	10YR 3/1.5	—	sic	2msbk	fr s p	Structure is weak throughout the profile due to wetness
Bw1	13-36	10YR 2.5/2	—	c	2msbk	fr vs vp	NISS
Bw2	36-67	10YR 3/2	7.5YR 4/6	c	3mabk	fr vs vp	NISS
Bss1	67-100	10YR 3/1.5	7.5YR 4/4	c	3mabk	fr vs vp	ISS ; few mollusc shells

NISS—Non-intersecting slickensides ; ISS-Intersecting slickensides ; r-rubbed colour

10YR 2.5/2 to 10YR 4/4 Mottles are abundant and distinct especially towards the subsurface horizons which become darker when dry. Flooding by river and sea water and presence of high ground water may suggest that these mottles are partly due to jarosite minerals (Fitzpatrick, 1984). Peds form usually fine to medium subangular blocks in the non-slickenside zones and medium to coarse angular blocks in the slickenside zones except for some horizons of profile P4. Calcareousness is indicated by slight to strong reaction with acid in all the profiles. P1, P5 and P6 profiles have been classified to the subgroup level as *Typic Endoaquerts*, P2 soils as *Ustic Endoaquerts*, P3 soils as *Typic Endoaquepts* and P4 soils as *Typic Endoaquents*. High shrink-swell type of clay (Table 2), cracks (which however, do not extend deep down the profile due to high groundwater), colour, texture, consistence and wedge shaped aggregates are indicative of a Vertisol and associated soil morphology.

Table 2. *Particle size characteristics of the pedons*

Horizon	Depth (cm)	fs*	vfs*	sand (ts)*	silt	clay	fs/ts	vfs/ts	sand/ silt	(sand+silt)/ clay	silt/ clay
		%					Ratio				
P1 : *Typic Endoaquerts*											
A1	0-9	3.3	19 5	30,1	43.8	26.1	0.11	0.65	0.69	2.83	1.68
2B1	9-22	2.3	0.5	4.9	42.5	52.6	0.47	0.10	0.12	0.90	0.81
2B2	22-40	3.1	0.4	5.6	35.7	58.7	0.55	0.07	0.16	0.70	0.61
2Bss1	40 61	3.5	0.4	4.8	31.6	63.6	0.73	0.08	0.15	0.57	0.50
2Bss2	61-75	8.6	0.8	12.4	32 8	54 8	0.69	0.06	0.38	0.82	0.60
P2 : *Ustic Endoaquerts*											
A1	0-9	3.6	31.2	36.7	43.3	20.0	0.10	0.85	0.85	4.00	2.17
2B1	9-25	1.1	0.4	2.0	43 5	54.5	0.55	0.20	0.05	0.83	0.80
2B2	25-43	1.0	0.5	1 8	38.8	59.4	0 56	0.28	0.05	0.68	0.65
2B3	43-62	0.8	0.4	1.6	26.3	72.1	0.50	0.25	0.06	0.39	0.36
2Bss1	62-84	2.8	0.6	4 0	17.3	78.7	0.70	0.15	0.23	0.27	0.22
2Bss2	84-110	6.0	1.1	8.0	15.9	76.1	0.75	0 14	0.50	0 31	0.21

(Contd.)

Table 2 (Contd.)

Horizon	Depth (cm)	fs*	vfs*	sand (ts)*	silt	clay	fs/ts	vfs/ts	sand/silt	(sand+silt)/clay	silt/clay
		%					Ratio				
P3 : *Typic Endoaquepts*											
A	0-13	7.0	5.1	13.1	44.6	42.3	0.54	0.39	0.29	1.36	1.05
2A	13-24	0.9	12.3	14.1	58.7	27.2	0.06	0.87	0.24	2.68	2.16
2Bw1	24-34	0.7	3.1	4.4	57.9	37.7	0.16	0.70	0.08	1.65	1.54
2Bw2	34 48	1.9	8.0	10.7	61.7	27.6	0.18	0.75	0.17	2.62	2.24
3AC	48-80	11.0	25.0	37.2	36.5	26.3	0.30	0.67	1.02	2.80	1.39
4AC	80-98	3 7	13.9	54.8	29.6	15.6	0.69	0.25	1.85	5.42	1.89
5AC	98-108	40.3	27.0	68.4	18.1	13.5	0.59	0.39	3.78	6.41	1.34
P4 : *Typic Endoaquents*											
A	0-12	15.6	4.6	26.3	35.6	38.1	0.59	0.17	0.74	1.62	0.93
2A	12-27	14.4	2.9	18.5	45.2	36.3	0.78	0.16	0.41	1.75	1.25
3C	27-42	79.7	9.8	91.9	3.2	4.9	0.87	0.11	28.72	19.41	0.65
4AC	42-53	13.8	7.6	23.4	48.2	28.4	0.59	0.32	0.49	2.52	1.70
5C1	53-70	72.5	3.3	94.4	1.6	4.0	0.77	0.03	59.00	24.00	0.40
5C2	70-96	68.4	3.5	95.4	1.2	3.4	0.72	0.04	79.50	26.83	0.35
6AC	96-113	6.7	14.2	22.6	47.5	29.9	0.30	0.63	0.48	2.34	1.59
P5 : *Typic Endoaquerts*											
A1	0-16	ND	ND	0.0	27.3	72.7	—	—	—	0.38	0.38
Bw1	16-36	ND	ND	0.2	21.4	78.4	—	—	0.01	0.28	0.27
Bss1	36-57	ND	ND	0.1	17.0	82.9	—	—	—	0.21	0.21
Bss2	57-77	ND	ND	0.3	23.3	76.4	—	—	0.01	0.31	0.30
P6 : *Typic Endoaquerts*											
A1	0-13	ND	ND	1.2	47.8	51.0	—	—	0.03	0.96	0.94
Bw1	13-36	ND	ND	0.8	28.9	70.3	—	—	0.03	0.42	0.41
Bw2	36-67	ND	ND	1.0	21.8	77.2	—	—	0.05	0.30	0.28
Bss1	67-100	ND	ND	1.2	16.8	82.0	—	—	0.07	0.22	0.20

* Fs-fine sand, vfs-very fine sand, ts-total sand

ND-Not determined as the total sand is very low

Particle size analysis shows that the profiles P1, P2, P5 and P6 have very high amounts of clay (51 to 82 9%) with an irregularly increasing trend down the profile (Table 2). In these profiles, the increase in the amount of clay down the profile virtually appears to be at the cost of corresponding decrease in the amount of silt, the amount of sand being almost constant. This suggests that it may be due to the prevailing depositional environments or due to the breakdown of silt into clay size fractions or both considering tropical climatic conditions. The picture is entirely different for profiles P3 and P4 where there are abrupt variations of clay which may indicate that this part of the landform was more prone to frequent shifting of river channels and thus the nature of deposition may have differed. Sand/silt ratio shows remarkable differences between adjacent horizons of profiles P3 and P4 indicating lithological discontinuity (Smith and Wilding, 1972). Based on these studies, profile P3 has 5 and profile P4 has 6 different layers of deposition within depths of 1 8 cm and 113 cm, respectively. In general, sand/silt ratio for profiles P1 and P2 are much narrower than profiles P3 and P4 suggesting a relatively greater uniformity in the former two profiles than in the latter two. Though it is difficult to quantify and fix a value for difference in sand/silt ratio between adjacent horizons, Sidhu *et al.* (1976) arbitrarily envisaged a minimum difference in value of 0.2 for the same to indicate discontinuity between adjacent horizons. Based on this value, discontinuities are observed at 9 cm depth in both P1 and P2 profiles. However, discontinuities at 61 cm in P1 and 84 cm in P2 are less conspicuous and are not observable in the field by virtue of well developed slickensides forming a continuum. In case of profiles P5 and P6, sand/silt ratio are of no consequence.

It has been shown that even though the difference in sand/silt values between adjacent horizons for profiles P1 and P2 show discontinuities, they were identifiable actually by virtue of dramatic increase in the amount of sand. Sand ratio, such as very fine sand to total sand (vfs/ts) and fine sand to total sand (fs/ts), as shown in Table 2, reasonably validate this fact (Hartgrove *et al.*, 1993). The trends for fs/ts and vfs/ts ratio are more or less reciprocal, as one ratio increases with the decrease in the other and vice-versa, however, without the values being proportionate. This picture is clear from Fig. 3 where curves for fs/ts and vfs/ts are approximately mirror images of each other. Although, inflections are shown at 9 cm for both P1 and P2 profiles (as shown by sand/silt ratio), indicating discontinuity, there are no corresponding inflections at 61 cm for P1 and 84 cm for P2 as indicated by sand/silt ratio. This may be due to mixing of the 61-75 cm

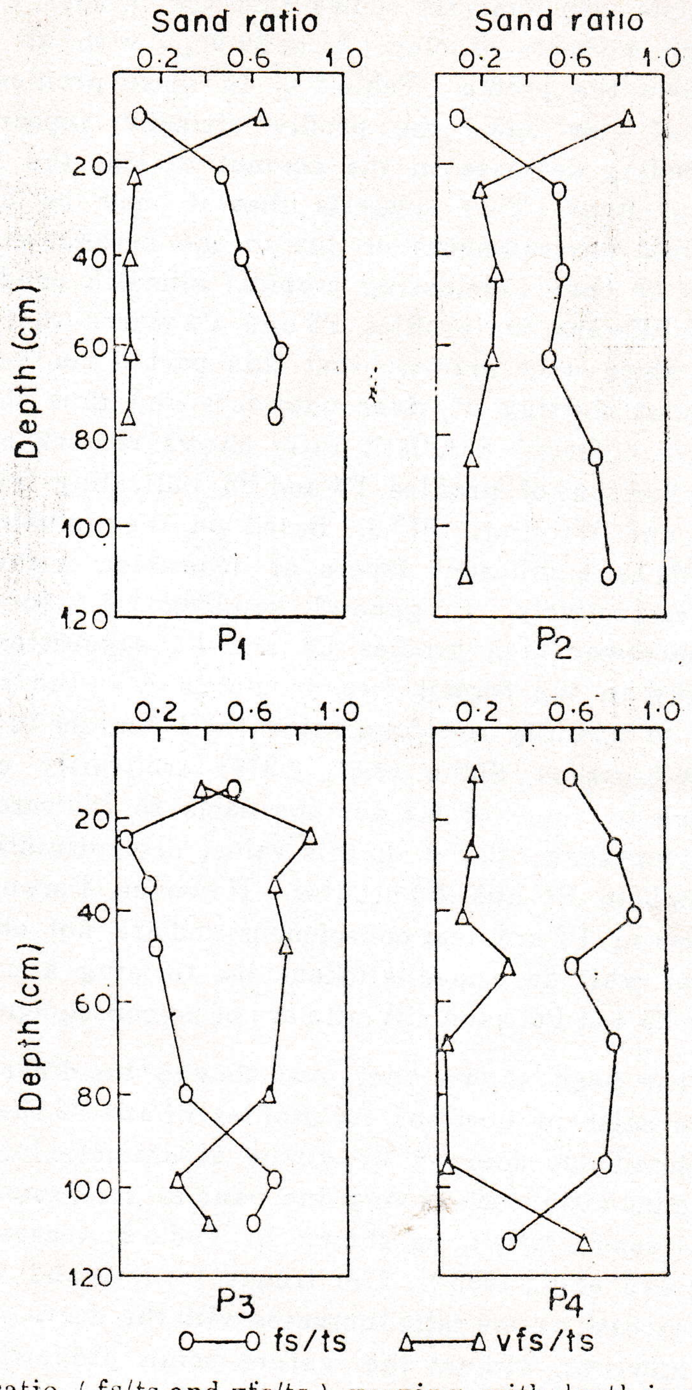

Fig. 3. Sand ratio (fs/ts and vfs/ts) varying with depth in profiles P1, P2, P3 and P4

horizon in case of P1 and 84-110 cm horizon in case of P2 with the corresponding underlying horizons with relatively larger amounts of sand. In profile P3, sand ratio show relatively stronger inflections at depths of 13 cm, 80 cm and 98 cm, and weak inflection at a depth of 48 cm. For the same profile, sand/silt ratio show discontinuities at all the above sites except at the depth of 13 cm For profile P4, relatively strong inflections are obtained at depths of 42 cm, 53 cm and 96 cm, and weak inflections at depths of 12 cm, 27 cm and 70 cm This suggests that profile P4 had relatively lesser time for development than profile P3, and thus classified accordingly. The above discussion also suggests that for these profiles, sand ratio seems to be of more consequence. The (sand+silt) / clay and silt/clay ratio (Table 2) independently follow the same trend as sand ratio to account for any discontinuity. For profiles P5 and P6, amounts of sand being very less, sand ratio are of no consequence to indicate discontinuity. Moreover, in these profiles other ratio also do not show discontinuity. Coefficient of correlation between fs/ts and all other ratio (Table 2) calculated independently show that the relationships are significant only for vfs/ts ($r = -0.92^{**}$) and silt/clay ($r = -0.73^{**}$) ratio. However, for these soils, if other combinations are considered, all the ratio discussed above hold good to indicate discontinuity between horizons, but the sand ratio, in particular, are found to be better indices for the same.

The pH of these soils are nearer to the alkaline side and KCl pH shows remarkable buffering (Table 3). Electrical conductivity (EC) shows salinity in all the profiles, and higher EC values observed in the mangrove soils (P5 and P6), in particular, are associated with corresponding lower pH values. As expected, organic carbon values are relatively higher and $CaCO_3$ equivalent values are relatively lower in mangrove soils. The latter may be due to relatively lesser dry conditions and high electrical conductivity for mangrove soils. Moisture retention characteristics of these soils at 33kPa and 1500 kPa tensions are positively correlated with the amount of clay (Table 3). But coefficient of correlation between clay and moisture retained at 1500 kPa is only significant ($r = 0.97^{**}$). Ratio such as 1500 kPa/clay and (1500 kPa—Org.C) / clay, and associated soil morphology suggest these soils are dominant in smectites Some irregular trends of moisture retention values and their ratio with clay may be attributed to the electrolyte concentration and initial moisture content of these smectite-dominant soils (Wilding and Tessier, 1988). It may also be envisaged that the discontinuities between adjacent horizons of profiles P1 to P4 are also reflected to some extent by $CaCO_3$, organic carbon and moisture retention data. On the other hand, these values alongwith particle size ratio for profiles P5 and P6 being comparable (between adjacent horizons), there are no discontinuities in these profiles within the respective depths.

The formation of Vertisols and associated soils in this tropical sub-

Table 3. *Some characteristics of the soils*

Depth cm	pH (1 : 2.5) water	pH (1 : 2.5) KCl	EC (dSm^{-1})	$CaCO_3$ eqvt. (%)	Org. carbon (%)	Moisture retention (w/w) (%) -33 kPa	Moisture retention (w/w) (%) -1500 kPa	Clay %	1500kPa clay Ratio	(1500kPa/Org.C) clay Ratio
P1 : *Typic Endoaquerts*										
0-9	7.8	7.4	9.0	3.9	1.92	25.3	12.7	26.1	0.49	0.41
9-22	8.2	7.6	13.0	5.7	1.04	44.1	24.3	52.6	0.46	0.44
22-40	8.3	7.7	14.0	5.9	0.98	47.1	26.3	58.7	0.45	0.43
40-61	8.3	7.7	12.0	5.9	0.95	51.3	29.9	63.6	0.47	0.45
61-75	8.3	7.6	16.0	5.5	0.88	56.4	33.9	54.8	0.62	0.60
P2 : *Ustic Endoaquerts*										
0-9	8.1	7.4	4.6	4.1	1.12	21.9	10.3	20.0	0.52	0.46
9-25	8.4	7.7	6.3	5.7	0.92	45.2	25.0	54.5	0.46	0.44
25-43	8.4	7.7	9.0	6.0	0.90	47.4	25.0	59.4	0.42	0.41
43-62	8.3	7.6	16.0	6.1	0.92	54.5	31.9	72.1	0.44	0.43
62-84	8.2	7.5	20.0	4.3	0.97	64.1	28.5	78.7	0.36	0.35
84-110	8.0	7.3	27.0	1.9	1.01	66.5	32.8	76.1	0.43	0.42
P3 : *Typic Endoaquepts*										
0-13	8.3	7.8	15.0	4.9	0.87	35.4	19.5	42.3	0.46	0.44
13-24	8.4	7.6	9.0	5.4	0.51	29.5	14.6	27.2	0.54	0.52
24-34	8.4	7.7	10.0	5.7	0.68	33.1	19.1	37.7	0.51	0.49
34-48	8.4	7.6	9.5	5.6	0.52	33.4	14.2	27.6	0.51	0.50
48-80	8.4	7.6	9.6	5.4	0.48	28.6	14.2	26.3	0.54	0.52
80-98	8.4	7.8	7.6	4.8	0.41	18.9	8.2	15.6	0.53	0.50
98-108	8.4	7.7	8.7	3.9	0.33	14.0	7.2	13.5	0.53	0.51

(Contd.

Table 3 (Contd.)

Depth cm	pH (1 : 2.5) water	pH (1 : 2.5) KCl	EC (dSm^{-1})	$CaCO_3$ eqvt. (%)	Org. carbon (%)	Moisture retention (w/w) (%) -33 kPa	Moisture retention (w/w) (%) -1500 kPa	Clay %	1500kPa/clay	(1500kpa-Org. C)/clay Ratio
P4 : *Typic Endoaquents*										
0-12	8.2	7.8	17.0	5.5	1.033	1.2	17.8	38.1	0.47	0.44
12-27	8.4	7.7	5.9	5.8	0.61	31.5	16.5	36.3	0.45	0.44
27-42	8.5	7.9	4.9	1.8	0.11	4.4	2.6	4.9	0.53	0.51
42-53	8.3	7.7	10.0	5.6	0.32	30.1	15.6	28.4	0.55	0.54
53-70	8.6	8.2	4.8	1.0	0.17	2.9	1.5	4.0	0.38	0.33
70-96	8.6	8.2	3.0	1.0	0.05	2.2	1.2	3.4	0.35	0.32
96-113	8.3	7.6	9.8	6.1	0.48	30.1	15.9	29.9	0.53	0.52
P5 : *Typic Endoaquerts*										
0-16	8.1	7.6	21.0	3.9	1.21	58.1	33.2	72.7	0.46	0.44
16-36	8.2	7.7	19.0	4.6	1.16	60.0	34.5	78.4	0.44	0.42
36-57	8.1	7.5	20.0	3.9	0.60	66.9	35.1	82.9	0.44	0.43
57-77	8.0	7.2	24.0	3.9	1.15	65.2	33.2	76.4	0.43	0.42
P6 : *Typic Endoaquerts*										
0-13	8.2	7.7	9.2	5.3	1.86	45.8	29.8	51.0	0.58	0.55
13-36	8.3	7.6	9.0	5.3	1.17	59.4	35.6	70.3	0.51	0.49
36-67	8.2	7.7	18.0	5.3	1.14	64.4	48.1	77.2	0.49	0.48
67-100	8.1	7.6	22.0	5.3	1.14	73.9	39.0	82.0	0.48	0.46

humid coastal deltaic region may be envisaged as the effect of Godavari river systems which deposited sediments rich in smectite minerals formed at other positions. However, it is known that even if the sediments have not originated from a base rich environment, smectite-like minerals may from if marine influence is there during transport (Ahmad, 1988). The presence of mollusc shells and lithological discontinuities discussed above may be evidences of marine influence. Soils formed from these sediments are recent and tend to be Vertisols or Entisols with vertic properties. The annual rainfall in the region is only 1100 to 1150 mm and the topography is usually level, so that exhaustive leaching of bases may not take place, thereby favouring formation and persistence of Vertisols and its associated soils. Moreover, considering the properties (high cracking clay content, low infiltration rate etc.) of these endosaturated soils, knowledge of lithological discontinuities may be beneficial for their classification, management and use.

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