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Characterization and Classification of Paleosols in Part of South India

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Abstract: Paleosols, which are known as soils formed during the past climatic conditions, part of south India in Anantapur district of Andhra Pradesh are described here. Morphological properties of five pedons (P1 to P5) like depth, colour, structure, texture, presence of clay cutans, etc. and physical and chemical properties such as particle size distribution, pH, acidity, exchangeable bases and CEC were studied and used to identify Paleosols. Colour of these soils is redder than 5 YR and have patchy clay skins. Sand/silt, fine sand/total sand and very fine sand/total sand ratios showed discontinuity between horizons as a result of several erosion and deposition cycles. Silt/clay ratios are lower, suggesting dominance of secondary over primary minerals. The KCl-pH values are much lower than water-pH values, though the acidity measured by *1 N* KCl is negligible. However, $BaCl_2$-TEA acidity gives higher values due to large amounts of Al. Cation exchange capacity, ECEC and base saturation (by sum of cations) values are usually lower suggesting that the soils are sufficiently leached. The soils were classified as Rhodustalfs (P1, P3, P5) and Haplustalfs (P2, P4) as per Soil Taxonomy and as Luvisols (P1, P2), Acrisols (P3) and Alisols (P4, P5) as per FAO/UNESCO system. A new Ultic subgroup has been proposed under Rhodustalf great group. It has been suggested that the weathering products

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of previous humid climate were eroded as evidenced from mostly shallow or moderately deep soils. It is concluded that Alfisols in this part of south India are Paleosols. (***Key words***: *Paleosols, characterisation, classification, erosion/deposition, South India*)

In India, some soils are presently in an environmental equilibrium. For example, in soils in Kerala, Western Ghats in Maharashtra and in parts of northeastern region having high rainfall (>2500 mm), the weathering and soil formation is still continuing presumably at a constant rate (Bronger & Bruhn 1989). Whereas, some soils in Andhra Pradesh, Tamil Nadu, Karnataka, Orissa (rainfall <700 mm), Bihar, Madhya Pradesh, Maharashtra and West Bengal (rainfall <1600 mm) may not be in an environmental equilibrium as some characteristics are not consistent with their present day climate as climatic conditions have changed drastically. Yet some soils reflect characteristics due to past humid climate (Beckmann 1984; Pal & Deshpande 1986; Bronger & Bruhn 1989; Pal *et al.* 1989). These soils are termed as Paleosols. Ruhe (1956) and Yaalon (1971) defined Paleosols as soils formed during the past and exist today either as relict feature, or buried by allochthonous overburden or exhumed.

Presently problems arise with regard to the recognition and appraisal of Paleosols which are truncated by erosion or modified by diagenetic alterations after burial (Retallack 1990). Moreover, classification of these soils has not been dealt adequately which emphasizes the characteristics of these soils. Though there are sophisticated and detailed methods to determine Paleosols, some field morphological data and basic laboratory analytical data may be adequate in the identication and classification of Paleosols for the purpose of soil survey or for mapping Paleosols which occur extensively in some parts of the country. With this in view, an attempt has been made here to characterise and classify some Paleosols in Anantapur district of Andhra Pradesh with the help of morphological and basic laboratory analytical data.

Materials and Methods

The study area is located in Rayalaseema region of Hindupur, Madakasira, Penukonda and Puttaparti taluks of Anantapur district in Andhra Pradesh lying between 13°45' to 14°20' N latitudes and 77°5' to 77°50' E longitudes. Geomorphologically, the area forms a part of south Deccan plateau. It has been broadly divided into denudational hills, inselbergs, dissected pediments, pediplains and colluvio-alluvium of recent origin (Fig. 1) by Prasannan and Prabhakara Rao (1979). Soils of the hills and inselbergs are not considered here because the soils have been severely eroded leaving behind only weathered rock fragments. The geology of the area is mainly granites and gneisses of Archeans. The rainfall varies from 700 to 750 mm and the climate is semi-arid tropical type. Soils were studied (Soil Survey Division Staff 1997) at mid-slopes of a pediplain on gently sloping lands (P1), mid-slopes of a dissected pediment on undulating lands (P2), upper-slopes of a dissected pediment on undulating lands (P3), foot slopes (concave) of a dissected pediment (P4) and mid-slopes of dissected pediment on rolling lands (P5). They were morphologically described and sampled horizonwise for laboratory analysis. Coarse fragments were recorded on weight basis. Particle size distribution was done by international pipette method (Piper 1947). The pH was determined in water and in 1*N* KCl solution. Organic carbon was determined by wet digestion method of Walkley and Black (1934). Acidity was determined by $BaCl_2$-TEA at pH 8.2 method and by unbuffered KCl solution (Black 1965). Exchangeable bases and CEC were determined by NH_4OAc method (Black 1965). The soils were classified as per Soil Survey Staff (1998) and FAO/UNESCO (1988) systems.

Results and Discussion

The soils in the study area are some of the oldest in India and reported to have formed over several cycles of erosion and sedimentation in South Deccan plateau (Murali *et al.* 1978; Rengasamy *et al.* 1978; Wadia 1985; Bronger & Bruhn 1989). It is an ancient plateau exposed for

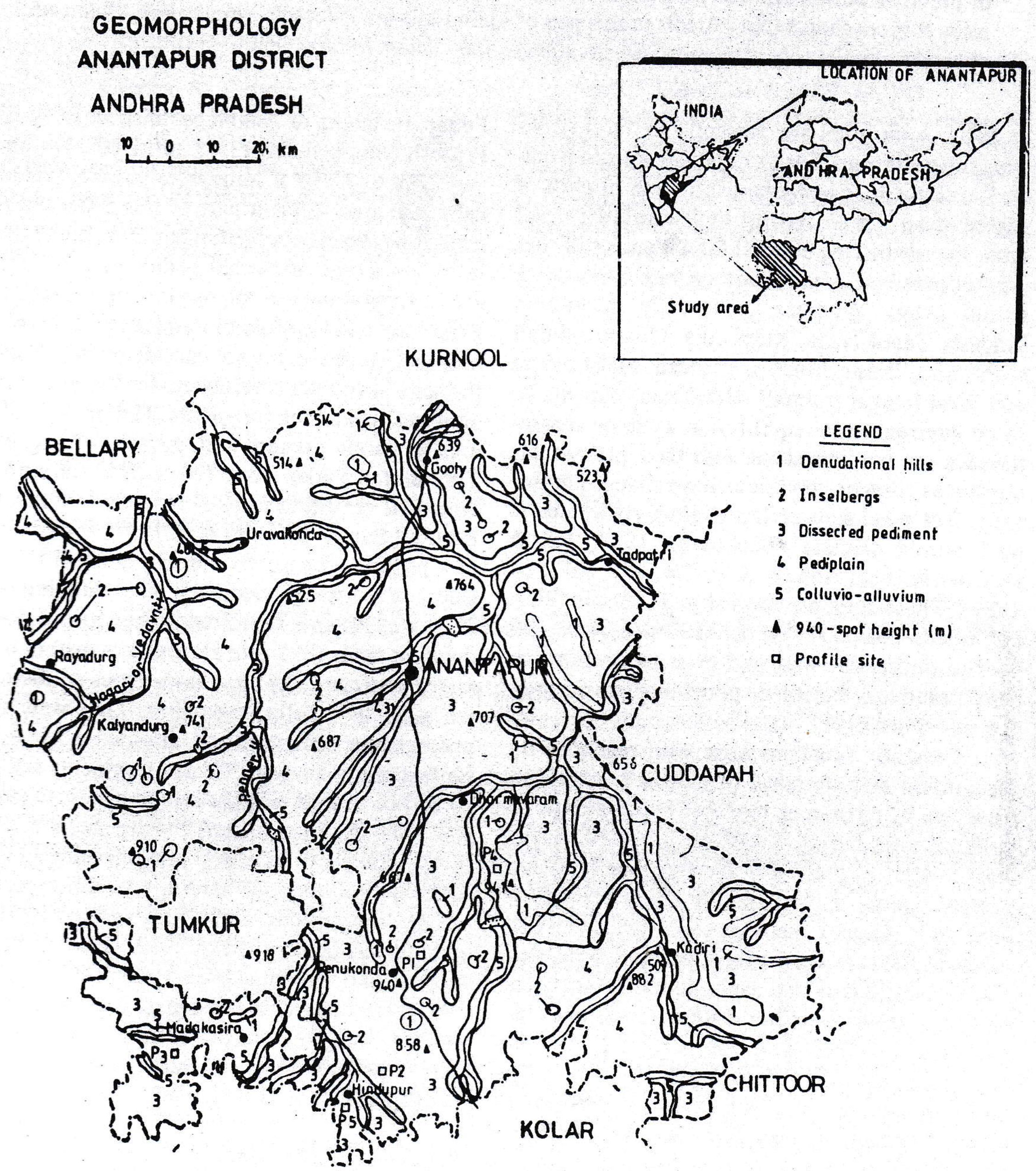

Fig. 1. Geomorphology map of the study area

long ages to denudation and has approached pediplanation. Sheet wash and retreat of hill slopes are the major goemorphic processes responsible for sculpturing of the present day landforms (Bhan & Bhatnagar 1974) under semi-arid to arid conditions. King (1953) considered the pediplain to be the ultimate cyclical landform and inferred that widely separated erosion surfaces in Africa, Asia, Europe, North America, South America and Australia as ancient pediplains dating back as far as Cretaceous. The earlier landforms were formed on a plane surface and the subsequent changes in climate led to changes in the landforms being highly dissected due to several cycles of erosion. This resulted in complexity of slopes and truncation of the profiles followed by deposition of red colluvium over the resistant parent rock (Rengasamy *et al.* 1978).

The soils are shallow (P1, P3 and P5) to moderately deep (P2 and P4) indicating that the process of denudation and erosion were more active than vertical advancement of the weathering front (Bronger & Bruhn 1989; Simonson 1994; Alexander 1995). The soils are well drained and colour of the soils usually has hues between 5 YR to 2.5 YR (Sehgal 1998), mostly on the redder side (Table 1). Therefore, Rhodustalfs are common occurrence in this area. This suggests that iron has been released by weathering to give free iron oxide imparting the soils a redder hue (Evans & Franzmeier 1986; Schwertmann 1933; Peterschmitt *et al.* 1996), which however, requires conditions of high rainfall and temperature. Generally, the soils have redder hues and shallow to moderately deep profiles with weathered granite-gneiss parent material below. Thin patchy clay cutans are observed in the Bt horizon having a slightly lighter colour than the matrix. In profile P3, the A horizon has been truncated, thereby, exposing the Bt horizon. However, there were no observable clay cutans in the surface Bt horizon of this profile. This may be due to the continuous ploughing which must have obliterated the clay cutans.

Particle-size distribution data (Table 2; Fig. 2) show that the total sand percentage is much higher (42.8 to 87.2%) than the silt or clay fractions. The coarser fractions dominate which could be largely of siliceous nature because of the granite-gneiss parent material (Wadia 1985; Simonson 1994). These fractions are inert and are of no consequence in further weathering. Though the fs/ts and vfs/ts ratios are marginal (0.12 to 0.40 and 0.14 to 0.20, respectively), these seem to have some trend, the former ratio decreasing and the latter ratio

Table 1. Morphological properties of the pedons

Horizon	Depth (m)	Boundary	Colour	Texture	Structure	Clay film (cutan)	Consistence
P1 Venkatapuram, Punukonda takluk: Typic Rhodustalfs (Ferric Luvisols)							
Ap	0-0.7	cs	5YR5/6	sl	flsbk	–	1 vfr sopo
2Bt	0.7-0.23	gs	2.5 YR3/4	sc	m 1 sbk	Ttnp	s fr sp
3BC	0.23-0.41	–	2.5 YR 3/4	c	mlsbk	–	s fr sp
P2 Peddareddipalli, Hindupur taluk: Typic Haplustalfs (Haplic Luvisols)							
Ap	0-0.6	cs	2.5 YR 3/6	ls	f 1 gr	–	1 vfr sopo
2Bt1	0.6-0.27	cs	2.5 YR 3/2	sc	mlsbk	Ttnp	fr ss sp
3Bt2	0.27-0.52	–	5 YR 4/3	c	m2sbk	Ttnp	fr sp
P3 Kokali, Madakasira taluk: Kanhaplic Rhodustalfs (Ferric Acrisols)							
Bt1	0-0.5	cs	5 YR 4/6	sl	fl sbk	Ttnp	1 vfr sopo
2Bt2	0.5-0.17	cs	2.5 YR 3/6	sl	mlsbk	Ttnp	1 vfr sopo
2Bt3	0.17-0.32	–	2.5 YR 3/4	sl	mlsbk	Ttnp	1 vfr sopo
P4 Konapuram, Puttaparti taluk: Ultic Haplustalfs (Haplic Alisols)							
A1	0-0.18	cs	5 YR 4/6	sl	mlsbk	–	1 vfr sopo
2Bt1	0.18-0.38	gs	2.5 YR 3/6	sl	mlsbk	Ttnp	sh fr sssp
3Bt2	0.38-0.62	as	2.5 YR 3/6	sl	m2sbk	Ttnp	sh fr sssp
3Bc	0.62-0.82	–	7.5 YR 5/6	sl	mlsbk	–	shfr sopo
P5 Manesamudram, Hindupur taluk: Ultic Rhodustalfs (Ferric Alisols)*							
Ap	0-0.9	as	10 YR3/4	ls	flgr	–	1 l sopo
2Bt1	0.9-0.26	cs	2.5 YR 3/6	sl	mlsbk	Ttnp	sh fr sssp
3Bt2	0.26-0.47	as	2.5 YR 3/4	scl	m 1 sbk	Ttnp	sh fr ss sp

Symbols are as per Soil Survey Manual (1970); *Ultic subgroup in Rhodustalfs has been proposed increasing with depth as illustrated in figure 2. The sand/silt ratios (Table 2; Fig.2) show marked discontinuity in parent material (Sidhu *et al.* 1976; Simonson 1994; Ray *et al.* 1997). This may be due to erosion processes, which retarded horizon formation and deep weathering. The silt/clay ratios are usually less than 0.5 in all the Bt horizons suggesting that most of the primary minerals have been transformed to clay-sized secondary minerals. This is because the silt/clay ratio reflects the ratio of primary to secondary minerals (Anjos *et al.* 1998). It also suggests that further weathering of primary minerals is limited in the present day environment. It may be noted that all the surface horizons (Ap/Al) have higher silt/clay ratios except P3 which however is a Bt. This may be attributed to the fact that there is an absolute decrease in the amount of clay fraction rather than an absolute increase in the silt fraction due to clay illuviation. In profiles P2, P3 and P4, this ratio is higher in the lower most Bt horizon than the overlying Bt horizon, which may be attributed to proximity to the underlying weathered regolith. The P1, P3 and P4 soils are skeletal in nature as evidenced by higher coarse fragments in these soils.

The water-pH values (Table 3) of most of the these soils are in the range of moderate acid to neutral which are not expected to favour clay dispersion and illuviation (Bronger & Bruhn 1989). The KCl-pH values are lower than the water-pH values and ΔpH varies from 0.7 to 2.4, the highest value is shown by P4 (Ultic Haplustalfs). However, the acidity measured by the same KCl is negligible. The acidity extracted by $BaCl_2$-TEA buffered at pH

Table 2. Physical characteristics of the pedons

Horizon	Depth (m)	Particle-size distribution (%) of various size fractions (mm): Fine sand (0.25-0.1)	Very fine sand (0.1-0.05)	Total sand (2-0.05)	Silt (0.05-0.002)	Clay (<0.002)	fs/ts* (ratio)	vfs/ts* (ratio)	sand/silt (ratio)	Silt/clay (ratio)	Coarse fragments (%)
				P1: Typic Rhodustalfs (Ferric Luvisols)							
Ap	0.0-0.07	31.3	11.8	79.2	9.9	10.9	0.40	0.15	8.00	0.91	34
2Bt	0.07-0.23	14.8	7.8	49.8	9.2	41.0	0.30	0.16	5.32	0.22	60
3BC	0.23-0.41	11.0	7.0	44.3	12.4	43.3	0.25	0.16	3.57	0.29	65
				P2: Typic Haplustalfs (Haplic Luvisols)							
Ap	0-0.06	30.9	12.2	81.3	7.6	11.1	0.38	0.15	10.70	0.68	7
2Bt1	0.06-0.27	22.9	12.5	63.9	7.8	28.3	0.36	0.20	8.19	0.28	7
3Bt2	0.27-0.52	13.9	8.4	42.8	15.6	41.6	0.32	0.20	2.74	0.38	9
				P3: Kanhaplic Rhodustalfs (Ferric Acrisols)							
Bt1	0-0.05	21.5	8.7	80.3	5.7	14.0	0.27	0.11	14.09	0.41	32
2Bt2	0.05-0.17	11.0	4.6	78.4	7.2	14.4	0.14	0.06	10.89	0.50	37
3Bt3	0.17-0.32	13.7	5.3	75.9	11.3	12.8	0.18	0.07	6.72	0.88	39
				P4: Ultic Haplustalfs (Haplic Alisols)							
A1	0-0.18	16.2	7.9	74.6	12.8	12.6	0.22	0.11	6.22	1.01	45
2Bt1	0.18-0.32	9.2	3.1	78.7	6.3	15.0	0.12	0.04	12.49	0.42	33
3Bt2	0.32-0.62	10.6	3.9	71.7	10.2	18.1	0.15	0.05	7.03	0.56	37
3BC	0.62-0.81	13.6	5.3	76.2	10.8	13.0	0.18	0.07	7.06	0.83	38
				P5: Ultic Rhodustalfs (Ferric Alisols)*							
Ap	0-0.09	30.1	11.3	87.2	5.9	6.9	0.35	0.13	14.78	0.86	11
2Bt1	0.09-0.26	26.7	9.2	75.0	6.9	18.1	0.36	0.12	10.87	0.38	15
3Bt2	0.26-0.47	20.2	8.3	66.4	7.3	26.3	0.30	0.13	9.10	0.28	39

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

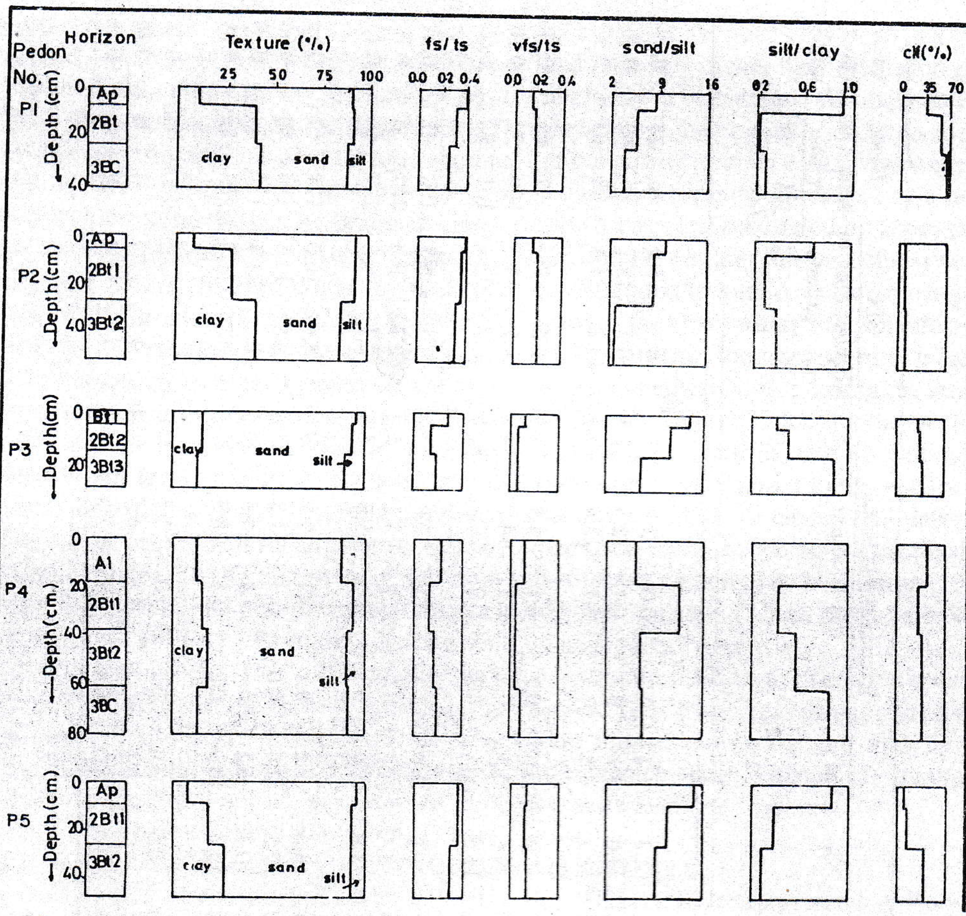

Fig. 2. Profile diagrams of some physical characteristics of the soils; fs-fine sand, vfs-very fine sand, ts-total sand, cf-coarse fragments

8.2 (Mehlich *et al.* 1976) shows the reserve acidity and it ranges from 1.5 to 11.7 cmol(p$^+$)kg^{-1}. This acidity is highest in P1 and lowest in P5. The base saturation calculated from acidity at pH 8.2 is thus much lower than that calculated from acidity at pH 7.0 which characterises these relatively highly weathered soils. The organic carbon values are low (1.7 to 6.5 g kg^{-1}). The CEC and ECEC values range from 2.1 to 26.2 cmol(p$^+$)kg^{-1} and 3.0 to 28.6 cmol(p$^+$) kg^{-1}, respectively. The clay CEC values (computed from soil CEC) are also low except in profile P4 probably due to an increase in the proportion of 2:1 type of clay minerals. The data show that these soils had undergone moderate to high degree of leaching (Simonson 1994) and some dessication (Moniz & Buol 1982; Hall 1999). However, the present arid to semi-arid climate does not explain the presence of such a clay complex (Bronger & Bruhn 1989), but could be a consequence of an earlier humid climate. Profile P4 is located at the footslope, whereas other profiles are at a relatively higher position in the landscape which may explain the higher values of Ca^{2+}, Mg^{2+}, ECEC, base saturation and CEC/clay, especially in the lower most horizon of P4 (Moniz & Boul 1982). Thus these soils appear to be Paleosols.

Classification of Soils

Classification of these soils under the USDA and FAO/UNESCO systems pose problem because, under the present semi-arid tropical climate a

Table 3. Chemical characteristics of the pedons

Depth (m)	pH (1:2.5) Water	pH (1:2.5) KCl	Org. C (g kg⁻¹)	Acidity: $BaCl_2$-TEA pH 8.2	Acidity: KCl 1*N* un-bufferred (H+Al)	Acidity: Exch. Al	Exchangeable bases: Ca	Mg	K	Na	Sum	ECEC	CEC: NH_4OAc	CEC: Sum of cations	Base saturation (%) pH 7.0	Base saturation (%) pH 8.2	CEC/clay ratio
					[cmol(p⁺)kg⁻¹]												
P1 Typic Rhodustalfs (Ferric Luvisols)																	
0-0.07	6.4	5.4	3.4	11.7	0.0	0.0	2.3	1.2	0.2	0.0	3.7	3.7	4.3	15.4	86	24	0.39
0.07-0.23	6.2	5.0	6.5	7.2	0.0	0.0	9.0	3.1	0.3	0.1	12.5	12.5	14.5	19.7	86	63	0.35
0.23-0.41	6.7	5.3	5.8	8.0	0.0	0.0	8.2	4.8	0.3	0.1	13.4	13.4	15.3	21.4	88	63	0.35
P2 Typic Haplustalfs (Haplic Luvisols)																	
0-0.06	6.6	5.8	3.1	2.7	0.0	0.0	1.0	3.0	0.2	0.1	4.3	4.3	5.6	7.0	77	61	0.50
0.06-0.27	6.9	5.6	4.7	5.5	0.0	0.0	8.6	5.3	0.2	0.1	14.2	14.2	14.2	19.7	100	72	0.50
0.27-0.52	7.4	6.4	5.6	6.6	0.0	0.0	16.6	9.5	0.2	0.2	26.5	26.5	26.2	33.1	101	80	0.63
P3 Kanhaplic Rhodustalfs (Ferric Acrisols)																	
0.0-0.05	6.6	5.4	3.5	3.3	0.0	0.0	1.8	1.0	0.1	0.1	3.0	3.0	3.1	6.3	100	48	0.21
0.05-0.17	6.4	4.8	3.7	4.2	0.1	0.0	3.4	1.5	0.1	0.1	5.1	5.2	2.3	9.3	222	55	0.16
0.17-0.32	6.5	4.8	1.7	3.4	0.0	0.0	3.8	1.6	0.1	0.1	5.6	5.6	2.1	9.0	267	62	0.16
P4 Ultic Haplustalfs (Haplic Alisols)																	
0.0-0.18	6.6	4.9	4.1	6.1	0.0	0.0	6.6	3.2	0.1	0.0	9.9	9.9	8.0	16.0	124	62	0.63
0.18-0.38	6.3	4.9	4.4	5.2	0.1	0.0	7.3	4.0	0.0	0.0	11.3	11.4	9.8	16.5	115	68	0.65
0.38-0.62	6.8	5.1	3.5	6.9	0.0	0.0	9.1	5.2	0.1	0.1	14.5	14.5	10.6	21.4	137	68	0.59
0.62-0.82	6.9	4.5	2.7	7.0	0.1	0.0	17.4	10.9	0.1	0.1	28.5	28.6	14.2	35.5	201	80	1.09
P5 Ultic Rhodustalfs (Ferric Alisols)*																	
0.0-0.09	6.6	5.9	3.4	1.5	0.0	0.0	0.5	3.0	0.2	0.0	3.7	3.7	2.7	5.2	137	71	0.39
0.09-0.26	5.8	4.4	2.5	3.4	0.1	0.1	1.9	2.2	0.1	0.1	4.3	4.4	4.7	7.7	91	56	0.26
0.26-0.47	5.3	4.2	3.3	5.5	0.3	0.2	2.0	1.7	0.1	0.1	3.9	4.2	7.4	9.4	53	41	0.28

Kanhaplic Rhodustalf would not form. Under the soil classification system of England and Wales (Buol *et al.* 1998), Paleosols are those which have a B, BC or argillic horizon. In the Australian system of soil classification, these soils are Lateritic Podzolic, Lateritic Krasnozems (polymorphic) or Red Podzolic (mesomorphic). The Brazilian classification system classified these soils as Terra Roxa Extruturada which is equivalent to a Typic Rhodustalf. The classification by the FAO/UNESCO system (1988) shows some degree of accuracy as compared to other systems in the context of the soils described here. However, the FAO/UNESCO system lacks information at subgroup and great group level. The P1 to P5 soils in this system are classified as Ferric Luvisols, Luvisols, Ferric Acrisols, Haplic Alisols and Ferric Alisols, respectively. Under the USDA system of soil classification, the soils P1, P3 and P5 are classified as Rhodulstalfs (Table 1); P3 being Kanhaplic Rhodustalfs (having clay CEC <24 cmol(p$^+$)kg^{-1} and P5 as Ultic Rhodustalfs (having base saturation by sum of cations of <75%). An Ultic subgroup in the Rhodustalf great group has been proposed here as there is no such provision in Soil Taxonomy (Soil Surve Staff 1998, 1999). These soils will have a base saturation by sum of cations of less than 75 per cent throughout. The P1 soils are classified as Typic Rhodustalfs as they convey the central concept for Rhodustalfs. Soils of P2 and P4 are classified as Haplustalfs, the former as Typic Haplustalf and the latter as Ultic Haplustalf (having base saturation by sum of cations of <75%).

It is well established that the soils in tropical areas are characterised by reddish colour due to desilication, leaching, illuviation, dessication and lateral movement of soil solute along the slopes (Moniz & Buol 1982; Curi & Franzmeier 1984; Bhattacharyya *et al.* 1993; Peterschmitt *et al.* 1996). According to Thomas (1978) and Bremner (1986), deep weathering requires a tropical climate with rainfall more than 1600 mm per annum so as to form a soil of about 100 m depth in a time interval of 2 to 6 million years. It may be noted that in the study area rainfall during the previous weathering period was not higher than 1600 mm, as otherwise, bases would have been removed to a greater extent and relatively higher base saturation (Table 3) was not likely to be obtained (Bronger & Bruhn 1989). However in the present aridic/semi-aridic tropustic soil moisture regime (Van Wambeke 1985), soil erosion or stripping dominated over deep weathering. It has been postulated by Bronger (1985) and Seuffert (1986) that this part of southern India had a semihumid to humid climate during the cold periods of the Quarternary due to increased influence of the northeast monsoon, during which there was intense weathering. But during the latter warm periods including the Holocene, the weathering products were removed to such an extent that several inselbergs were exposed to the surface resulting in normally shallow to moderately deep soils which bears testimony in the soils described here. This fact is also supported by Das Gupta (1980) indicating that red soils (which are mainly Rhodustalfs) of this part of south India suffer from sheet erosion and thus the depth of soils is usually less than one m. Thus these facts do suggest that these soils were formed during the previous humid climate and as such most Alfisols of this part of south India are therefore Paleosols.

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