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Genesis and classification of ferruginous soils in Western Ghat and Coastal region of North Karnataka

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Abstract
Genesis of six ferruginous pedons from the Western Ghats region and coastal hinterland of North Karnataka (India) were studied. Rainfall of the study area ranged from 1792 mm (Khanapur) to 3854 mm (Murdeshwar). All the pedons were very deep (>2 m). The soils of the Western Ghats region were characterised by iron oxide concretions occurring in lower solum whereas in coastal region iron oxide concentrations were distributed throughout the solum. Clay accumulation was evident in thick Bt horizons. In lower solum of some pedons, silt and sand content increased due to formation of pseudoaggregates of iron oxides with clay. The soils were acidic to slightly acidic (pH 5.0 to 6.6). Exchangeable hydrogen constituted major portion of exchange acidity. The $BaCl_2$-TEA [5.86 to 31.19 cmol (+) kg^{-1})] acidity was several times more than KCl acidity [0.10 to 3.91 cmol (+) kg^{-1}]. Intensive leaching of soils resulted in low exchangeable bases with Ca and Mg as dominant cations. In all the soils ECEC-7 [4.94 to 18.62 cmol (+) kg^{-1}] was higher than ECEC [3.98 to 16.35 cmol (+) kg^{-1}] and CEC-S [9.74 to 47.80 cmol (+) kg^{-1}] was 2-4 times higher than CEC-7 indicating the dominance of low activity clay. Fe_d was more than Fe_o in all the pedons. Laterization was the dominant pedogenic process along with illuviation.

Additional keywords: Pedogenesis, laterite soil.

Introduction

Majority of tropical and subtropical soils are ferruginous in nature and are termed as lateritic soils. With reference to laterites, India has a unique place because, it was in Malabar coast at a place known as Angadipuram, laterite was first recognised by Francis Buchanan (1807). Two forms of laterites have been recognised in India; high level and low level. The high level forms are found to cap the summits of hills and plateau on the highlands of central and western India whereas low level laterites are associated with coasts of the Deccan Peninsula and Tamil Nadu. In India, laterite soils occupy an area of 1,30,066 sq. km and are well developed on the summits of Deccan hills of Karnataka and Kerala, the Eastern Ghats, western Maharashtra, central parts of Orissa and Assam.

In northern Karnataka, lateritic soils occur in the Western Ghat region. There is a marked variation in the rainfall of lateritic soil area. Detailed investigations have been conducted on laterite and lateritic soils in different parts of India. Gowaikar and Datta (1971) and Gowaikar (1973) studied the genesis and classification of ferruginous soils of southern India. Murali *et al.* (1974) and Rengasamy *et al.* (1978) studied genesis of ferruginous soils of peninsular India. Except a preliminary study (Narayan Rao *et al.* 1993) on two high level lateritic pedons from Western Ghat region of north Karnataka, not much work on pedogenesis of these soils is available. In view of this, present investigation was undertaken with the objective to study the properties to understand the pedogenesis and to classify these soils according to Soil Taxonomy (Soil Survey Staff 1998).

Materials and methods

Six sites from northern Karnataka located around Sirsi, Siddapur, Khanapur, Londa, Kumta and Murdeshwar (Fig. 1) were selected for the study, the characters of which are presented in table 1. Sirsi, Siddapur, Khanapur and Londa sites belong to high level laterites in western ghat region, whereas Kumta and Murdeshwar sites belong to coastal tract (low level laterites). In Western Ghats, which run almost north-south at right angles to the path of the south-west monsoon current cause orographic rains over coastal and ghat region. The elevation in high level laterite area ranges from 450 to 900 m above mean sea level (MSL) and that in low level laterite area ranges from 18 to 30 m above MSL.

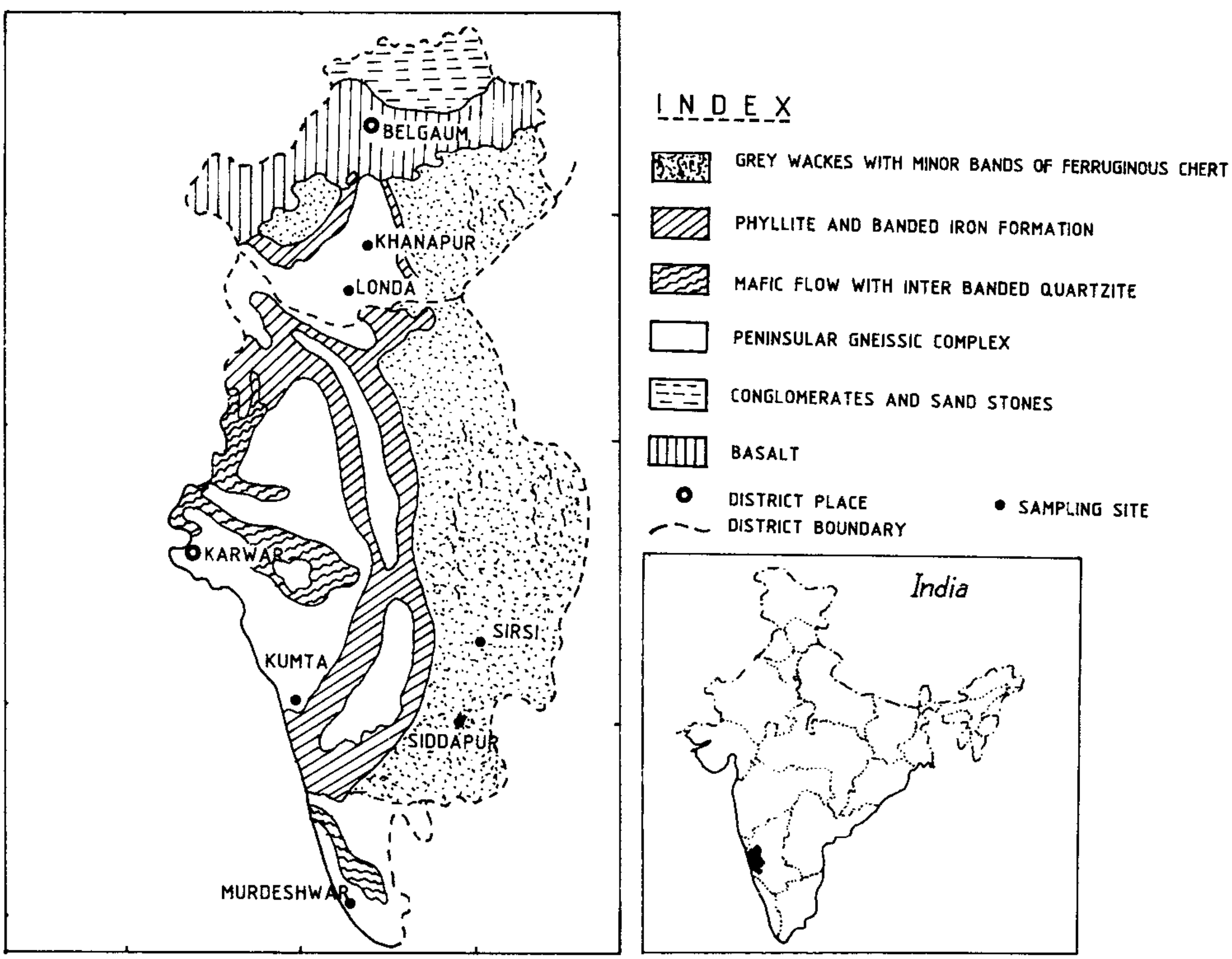

Fig. 1. Geological map of study area.

Table 1. Morphological features of pedons

Horizon	Depth (cm)	Colour		Texture	Structure	Special Features
		Dry	Moist			
			Sirsi			
Ap	0-17	7.5YR 4/4	7.5YR 3/2	scl	c3 sbk	
B1	17-33	7.5YR 4/6	5YR 4/4	scl	c2 sbk	Iron concretions of various size throughout profile
Bt1	33-60	5YR 4/6	5YR 3/4	c	m2 sbk	
Bt2	60-95	5YR 5/8	2.5YR 3/4	c	m2 sbk	
Bt3c	95-125	5YR 5/6	2.5YR 3/6	gc	m2 sbk	
BC1	125-154	5YR 5/8	5YR 4/6	gc	m2 sbk	
BC2	154-220+	5YR 5/6	2.5YR 4/6	gsc	m2 sbk	
			Siddapur			
A1	0-18	7.5YR 4/6	5YR 4/4	cl	c3 sbk	
Bt1	18-38	5YR 5/6	5YR 3/4	c	m3 sbk	Brown to dark gray coloured iron concretions of various sizes throught profile
Bt2	38-65	2.5YR 4/6	2.5YR 3/6	c	m3 sbk	
Bt3c	65-110	2.5YR 4/6	2.5YR 4/4	gc	f2 sbk	
BC1	110-155	2.5YR 4/6	2.5YR 3/6	gsc	vf1 sbk	
BC2	155+	2.5YR 4/6	2.5YR 3/6	gsc	vf1 sbk	
			Londa			
A1	0-10	10YR 3/3	10YR 3/2	c	m3 sbk	
A2	10-23	7.5YR 4/4	7.5YR 3/2	c	m3 sbk	
BAc	23-42	5YR 4/4	5YR 3/3	gc	m2 sbk	
Bt1c	42-70	5YR 5/6	5YR 4/4	gc	f1 sbk	Iron concretions of various sizes throughout the profile
Bt2c	70-110	2.5YR 5/6	2.5YR 3/6	gc	vf1 sbk	
Bt3c	110-169	2.5YR 5/6	2.5YR 4/6	gc	vf1 sbk	
Bt4c	169-198	5YR 5/8	2.5YR 4/6	gc	m2 sbk	
BC1	198-225	5YR 6/6	2.5YR 5/6	gc	m2 sbk	
BC2	225-261+	5YR 5/8	2.5YR 4/6	gc	m2 sbk	
			Khanapur			
A1	0-10	10YR 3/3	10YR 3/2	scl	m3 sbk	Iron concre-tions of various sizes throughout the profile. Vesicular structure with yellow, brown & black colour with quartz grains in lower layers.
A2	10-30	7.5YR 3/4	7.5YR 3/2	scl	m3 sbk	
BA	30-58	5YR 4/4	5YR 3/3	scl	m2 sbk	
Bt1c	58-100	5YR 4/6	5YR 3/4	gsc	m2 sbk	
Bt2c	100-130	5YR 5/6	2.5YR 4/4	gc	m2 sbk	
BC	130-170+	5YR 5/8	2.5YR 4/6	gsc	m2 sbk	
			Kumta			
A1c	0-8	5YR 5/6	5YR 4/6	c	vf1 gr	
A2c	8-24	5YR 4/6	5YR 4/4	c	m2 sbk	Hard laterite structure with pores having yellow & pink material inside throughout the profile
BAc	24-43	5YR 4/6	2.5YR 3/4	gc	f2 sbk	
Bt1c	43-66	5YR 5/6	2.5YR 4/4	gc	f2 sbk	
Bt2c	66-98	2.5YR 4/6	2.5YR 3/6	gc	vf1 sbk	
Bt3c	98-200	2.5YR 4/8	2.5YR 3/6	gc	vf1 sbk	
BC	200+	5YR 5/8	2.5YR 3/6	gcl	vc3 m	
			Murdeshwar			
A1c	0-35	10YR 4/3	7.5YR 4/2	gsc	m2 sbk	Iron concretions and slag-like structure of various sizes throughout the profile
Bt1c	35-80	5YR 5/6	2.5YR 4/6	gc	f2 sbk	
Bt2c	80-150	5YR 5/8	2.5YR 5/6	gc	f2 sbk	
BC	150-200+	5YR 6/8	2.5YR 4/6	gc	f2 sbk	

The climate in the study area is characterised by high humidity nearly all the year round. Sirsi, Siddapur, Kumta and Murdeshwar have perhumid climate whereas, it is moist humid in Khanapur and Londa. Rainfall ranges from 1792 mm in Khanapur to 3854 mm in Murdeshwar. The average maximum temperature recorded is 30.2°C in Kumta and Murdeshwar and minimum of 18°C in Khanapur and Londa.

Sirsi and Siddapur pedons are developed on greywack with banded iron formations whereas Kumta, Murdeshwar, Khanapur and Londa are developed on peninsular gneiss (Fig. 1). Tropical evergreen and semi-evergreen forests are found in Sirsi and Siddapur. Tropical thorny and evergreen forests are found in Kumta and Murdeshwar. Tropical moist deciduous forest is found at Khanapur and Londa.

Morphology of soils was described as per Soil Survey Manual (Soil Survey Staff 1951). The horizonwise samples were processed. The fraction >2 mm was washed with water, dried and weighed as coarse fragments. The <2 mm fraction was used for all analyses. Particle size analysis of the soil samples was carried out by international pipette method as described by Jackson (1969). Moisture retention at 33 kPa and 1500 kPa in soil samples were determined using soil moisture equipment (Richards 1954).

Soil pH was determined in 1:2.5 soil : water suspension and 1:2.5 soil : 1*N* KCl solution (Jackson 1967). Organic carbon was determined by Walkley and Black method (Jackson 1967) and cation exchange capacity by ammonium acetate method (Black 1965). Exchangeable cations were extracted by 1*N* NH_4OAc (pH 7.0). Calcium and magnesium in the extract were determined by versenate titration and Na and K by flame photometry (Thomas 1982). KCl acidity and $BaCl_2$-TEA acidity were determined as explained by Thomas (1982). Effective CEC (ECEC) was calculated by adding exchangeable Ca, Mg, Na, K and Al. CEC-sum (CEC-S) was estimated by adding exchangeable Ca, Mg, Na, K and $BaCl_2$-TEA acidity. Free iron and aluminium oxides in soil were extracted by citrate-bicarbonate-dithionite (Mehra and Jackson 1960). Iron in the extract was determined colorimetrically with orthophenanthroline (Jackson 1969) and aluminium after digesting an aliquot of the extract with HNO_3 and H_2SO_4 (Wang and Wood 1973).

Results and discussion

Morphological features

All the pedons were very deep (Table 1). Surface horizons of the pedons were dark grayish brown to dark reddish brown with hue ranging from 10YR to 5YR. The redness increased with depth (5YR to 2.5YR) consequent to decrease in organic matter and increase in free iron oxides. The chroma increased from 2 at the surface to 8 in lower solum. Low chroma in the surface horizons is due to higher organic matter content. Lower solum of Murdeshwar, Kumta and Khanapur pedons exhibited variegated colours. The structural development was weak except at the surface horizons due to large amount of coarse fragments. The soils of high level laterite regions have ferruginous gravels of various sizes throughout the profile and in the form of horizon at different depths in profile whereas in coastal region, the gravels are distributed throughout the solum. Similar observation was also made by Reddy *et al.* (1993) for laterite soils of India. Plinthite was observed in Siddapur, Londa, Murdeshwar and Kumta pedons.

Physical characteristics

Texture of soils were sandy clay loam to sandy clay at the surface and clay to sandy clay in subsurface horizons (Table 2). A decrease of sand fraction

Table 2. Particle size distribution and moisture retention in soils

Horizon	Depth (cm)	Sand (>0.05 mm)	Silt (0.05-0.002 mm)	Clay (<0.002 mm)	Fine clay (<0.0002 mm)	Coarse clay/fine clay	Silt/ clay	Moisture retention 33 kPa	1500 kPa
		----------%----------						------%-------	
				Sirsi					
Ap	0-17	55.9	10.6	33.1	6.4	4.20	0.32	10.8	9.4
B1	17-33	51.1	10.6	38.3	14.0	1.70	0.28	21.5	11.0
Bt1	33-60	43.2	11.0	45.5	17.0	1.70	0.24	25.0	13.6
Bt2	60-95	33.7	12.6	53.3	19.4	1.70	0.24	25.0	14.0
Bt3c	95-125	43.7	8.5	47.4	22.0	1.20	0.18	24.0	14.2
BC1	125-154	41.4	15.5	42.3	20.0	1.10	0.37	22.5	13.4
BC2	154-220+	46.8	18.5	33.9	13.1	1.60	0.55	25.1	15.3
				Siddapur					
A1	0-18	43.5	19.4	37.2	15.6	1.38	0.52	25.1	11.4
Bt1	18-38	34.0	20.6	45.2	15.1	1.99	0.46	27.5	15.3
Bt2	38-65	32.9	19.0	48.0	21.0	1.29	0.40	31.1	17.2
Bt3c	65-110	36.4	15.4	48.2	21.2	1.27	0.32	29.0	16.3
BC1	110-155	45.2	12.2	42.2	16.5	1.56	0.29	23.2	14.4
BC2	155+	50.7	13.3	35.8	15.0	1.39	0.37	23.0	14.5
				Londa					
A1	0-10	29.6	29.7	40.9	14.7	1.78	0.73	25.1	17.3
A2	10-23	28.5	24.1	47.7	18.4	1.59	0.51	22.2	10.2
BAc	23-42	26.0	25.8	48.2	19.5	1.47	0.54	22.8	13.9
Bt1c	42-70	24.3	22.7	53.0	22.5	1.36	0.43	23.4	19.8
Bt2c	70-110	19.3	24.2	55.9	33.8	0.67	0.43	23.5	18.0
Bt3c	110-169	19.7	18.8	61.3	28.6	1.14	0.31	24.8	20.6
Bt4c	169-198	10.3	27.7	62.0	22.7	1.73	0.45	32.5	23.9
BC1	198-225	10.2	31.0	56.1	16.6	2.38	0.55	34.5	20.8
BC2	225-261+	10.7	33.2	56.0	12.9	3.34	0.59	34.3	21.2
				Khanapur					
A1	0-10	54.7	17.3	27.9	8.3	2.36	0.62	18.6	8.9
A2	10-30	55.6	13.9	30.5	10.2	1.99	0.46	16.0	8.4
BA	30-58	14.2	14.2	31.2	10.4	2.00	0.46	17.7	8.2
Bt1c	58-100	13.3	13.3	37.6	18.3	1.05	0.35	20.6	8.3
Bt2c	100-130	12.8	12.8	45.2	23.5	0.52	0.28	15.3	5.6
BC	130-170+	14.8	14.8	38.2	13.5	1.83	0.39	14.4	10.0
				Kumta					
A1c	0-8	69.2	22.8	46.0	15.0	2.06	0.50	37.7	19.6
A2c	8-24	48.9	18.1	47.1	20.8	1.26	0.38	36.3	21.1
BAc	24-43	43.7	24.4	47.1	22.0	1.14	0.52	33.7	21.7
Bt1c	43-66	59.6	16.3	59.3	24.0	1.47	0.27	33.4	21.0
Bt2c	66-98	68.5	15.5	67.9	23.5	1.89	0.23	34.2	20.7
Bt3c	98-200	66.3	12.3	57.3	20.2	1.84	0.21	30.6	20.8
BC	200+	66.1	21.2	38.3	14.0	1.73	0.55	30.5	18.4
				Murdeshwar					
A1c	0-35	61.8	13.9	40.4	6.5	5.20	0.34	28.8	10.9
Bt1c	35-80	61.6	11.8	53.4	12.1	3.30	0.22	26.5	17.2
Bt2c	80-150	63.4	12.2	64.4	15.9	3.05	0.19	29.8	19.9
BC	150-200+	52.4	22.4	43.8	5.2	7.42	0.51	31.5	19.7

upto certain depth except in Kumta pedon indicated weathering of this fraction to finer particles as evidenced by increase in clay content with concomitant decrease in sand fraction. The uniform silt content (Table 3) of all the pedons in relation to other particle fractions is the striking feature of lateritic soils and is in agreement with the defined characteristics of latosols described by Kellogg (1950). Clay was found to accumulate (Table 2) in the subsurface layers of all the pedons as also reported by Gowaikar and Datta (1971). In Sirsi, Murdeshwar, Kumta and Londa pedons clay content of Bt horizons increased by over 20 per cent compared to that in surface horizon. Higher clay content in Londa compared to Khanapur pedon may be the result of high degree of weathering due to excessive rainfall at Londa site.

The moisture retention of soil at 33 kPa and 1500 kPa followed the distribution of clay in the pedons (Table 2). In Murdeshwar pedon and in Bt horizons of other pedons, although clay content increased, moisture retention at 33 kPa and 1500 kPa followed a decreasing trend due to the interaction of coarse fraction with clay which alters the moisture retention of soils significantly. The low values may be attributed to high proportion of large pores due to presence of large iron gravels. As stated by De Alwis and Pluth (1976), large pores drain under very low tension, regardless of lateritic soil texture.

Chemical characteristics

The soils were acidic to slightly acidic (Table 3). Soil pH measured in KCl was low in all the pedons compared to that measured in water. The difference between pH measured in KCl and that in water, i.e., ΔpH, was negative in all the cases and ranged from −0.1 to −1.5. The negative ΔpH values indicate that these soils contain appreciable quantities of clay minerals with relatively constant surface charge (Bleekar and Sageman 1990). The organic carbon content was low in all the pedons (Table 3) except in surface horizons and it decreased with depth. This might be due to the leaching environment existing in the area. Exchangeable hydrogen forms the major portion of exchange acidity in most of the pedons. The KCl acidity in Murdeshwar and Kumta pedons was greater than in other pedons (Table 3). Titratable amount of exchangeable aluminium was present only in Murdeshwar and Kumta pedons indicating that these pedons have undergone relatively high degree of weathering. Low exchangeable Al in other soils is due to the use of neutral salt solutions, which are known to extract little Al in soils whose pH is >5.3 (Thomas 1961).

The $BaCl_2$-TEA acidity was several times more than KCl acidity in all the pedons (Table 3). This suggests that most of the fairly high $BaCl_2$-TEA extractable acidity of these soils can be attributed to Al (and possibly Fe) hydroxy compounds that are held tenaciously on the exchange complex (De Alwis and Pluth 1976) and due to non-exchangeable aluminium embedded in between crystal lattice, which came into solution due to buffering and complexing nature of $BaCl_2$-TEA regardless of soil pH. This may constitute the total potential source of aluminium present in the soil. The high $BaCl_2$-TEA acidity in Londa, Kumta and Siddapur pedons may be due to their high organic carbon component and high intensity of leaching as a result of high rainfall. Patil and Anantanarayana (1990) also attributed the extractable acidity to organic matter and clay content of acid soils due to their buffering action. High rainfall caused intensive leaching of soils resulting in low bases in all the pedons. Exchangeable calcium and magnesium were dominant basic cations followed by sodium and potassium. Exchangeable magnesium was greater than calcium in Sirsi, Siddapur, Murdeshwar and Kumta pedons and in lower solum of Khanapur and Londa pedons. This indicates the preferential leaching of calcium than magnesium as shown by Gowaikar and Datta (1971) in laterite soils of southern India. The effective CEC (ECEC) of the soils

Table 3. pH, OC and exchange acidity of soils

Horizon	Depth (cm)	pH (H_2O)	pH (KCl)	ΔpH	OC (%)	Exchange acidity KCl	Exchange acidity $BaCl_2$-TEA
						[cmol (+) kg^{-1}]	[cmol (+) kg^{-1}]
			Sirsi				
Ap	0-17	5.8	5.1	-0.7	1.23	0.12	15.13
B1	17-33	6.0	5.0	-1.0	0.44	0.14	13.28
Bt1	33-60	6.0	5.2	-0.8	0.38	0.17	13.48
Bt2	60-95	5.7	4.8	-0.9	0.31	0.20	13.43
Bt3c	95-125	5.6	4.7	-0.9	0.30	0.22	13.38
BC1	125-154	5.9	5.3	-0.6	0.24	0.17	11.50
BC2	154-220+	6.2	5.7	-0.5	0.14	0.10	11.41
			Siddapur				
A1	0-18	5.9	4.8	-1.1	1.52	0.22	19.22
Bt1	18-38	6.1	5.0	-1.1	0.86	0.20	19.24
Bt2	38-65	6.2	5.1	-1.1	0.56	0.14	16.38
Bt3c	65-110	6.3	5.2	-1.1	0.46	0.20	14.56
BC1	110-155	6.4	5.6	-0.8	0.17	0.18	14.56
BC2	155+	6.3	5.9	-0.4	0.14	0.12	10.92
			Londa				
A1	0-10	6.1	4.9	-1.2	4.51	0.20	31.45
A2	10-23	6.0	4.9	-1.1	1.85	0.20	21.44
BAc	23-42	6.0	4.9	-1.1	1.50	0.19	20.88
Bt1c	42-70	6.1	5.1	-1.0	1.02	0.20	17.51
Bt2c	70-110	6.2	5.5	-0.7	0.47	0.10	17.77
Bt3c	110-169	6.5	6.0	-0.5	0.34	0.10	13.53
Bt4c	169-198	5.9	6.0	-0.5	0.34	0.10	13.53
BC1	198-225	5.7	5.6	-0.1	0.18	0.12	13.53
BC2	225-261+	5.6	5.4	-0.1	0.15	0.17	9.64
			Khanapur				
A1	0-10	6.2	5.1	-1.1	1.92	0.15	19.27
A2	10-30	6.5	5.0	-1.5	0.72	0.17	15.36
BA	30-58	6.3	4.9	-1.4	0.56	0.17	13.36
Bt1c	58-100	6.2	4.9	-1.3	0.49	0.17	15.54
Bt2c	100-130	6.1	4.9	-1.2	0.25	0.24	15.38
BC	130-170+	6.6	5.3	-1.3	0.07	0.10	9.54
			Kumta				
A1c	0-8	5.5	4.3	-1.2	1.78	1.65	31.19
A2c	8-24	5.2	4.2	-1.0	1.28	2.84	29.24
BAc	24-43	5.1	4.1	-1.0	1.00	3.07	29.13
Bt1c	43-66	5.0	4.1	-0.9	0.81	3.57	25.48
Bt2c	66-98	5.0	4.1	-0.9	0.81	3.91	27.46
Bt3c	98-200	5.1	4.1	-1.0	0.34	3.00	21.24
BC	200+	5.4	4.7	-0.7	0.22	0.27	5.86
			Murdeshwar				
A1c	0-35	5.7	4.4	-1.3	2.29	1.29	26.88
Bt1c	35-80	5.9	5.3	-0.6	0.34	0.15	17.26
Bt2c	80-150	6.1	5.4	-0.7	0.30	0.17	13.31
BC	150-200+	5.3	4.6	-0.7	0.14	0.27	13.30

was quite low (3.68 to 16.35 cmol(+) kg^{-1}) despite high clay content and organic matter indicating dominance of low activity clay minerals. In all the pedons CEC-7 was higher than ECEC due to development of pH dependent negative charges on exchange complex. The CEC-S values were about 2-4 times higher than the CEC-7 and ECEC values in all the pedons (Table 4).

Table 4. Exchangeable cations and CEC of soils

Horizon	Depth (cm)	Ca	Mg	Na	K	ECEC	CEC-7	CEC-S	CEC-7/ Clay	BS %
		[cmol (+) kg^{-1}]								
				Sirsi						
Ap	0-17	3.17	4.57	0.16	0.19	8.10	9.21	23.22	0.28	88
B1	17-33	0.21	5.78	0.10	0.15	6.34	7.41	19.59	0.19	84
Bt1	33-60	0.42	5.18	0.08	0.15	5.86	7.04	19.31	0.15	83
Bt2	60-95	1.37	4.11	0.10	0.15	5.80	6.84	19.66	0.13	84
Bt3c	95-125	2.20	3.10	0.08	0.12	5.60	6.65	18.88	0.14	83
BC1	125-154	2.68	2.90	0.08	0.14	5.87	7.22	17.30	0.17	80
BC2	154-220+	1.67	3.87	0.09	0.12	5.75	6.93	17.16	0.20	83
				Siddapur						
A1	0-18	2.80	4.22	0.11	0.22	7.47	9.02	26.62	0.24	81
Bt1	18-38	3.28	4.22	0.11	0.21	7.81	9.12	27.00	0.20	86
Bt2	38-65	2.25	4.65	0.11	0.18	7.23	8.74	23.58	0.18	82
Bt3c	65-110	3.35	4.15	0.13	0.24	7.93	9.50	22.43	0.20	83
BC1	110-155	1.65	4.10	0.82	0.19	6.08	7.31	20.58	0.17	92
BC2	155+	2.60	3.05	0.87	0.21	5.94	7.21	16.86	0.20	93
				Londa						
A1	0-10	10.04	5.45	0.53	0.33	16.35	18.62	47.80	0.46	88
A2	10-23	5.46	4.07	0.43	0.26	10.22	11.78	31.66	0.25	87
BAc	23-42	4.64	4.12	0.40	0.34	9.51	10.73	30.39	0.22	89
Bt1c	42-70	3.79	3.53	0.48	0.24	8.05	9.40	25.55	0.18	86
Bt2c	70-110	3.31	4.12	0.44	0.25	8.12	9.50	25.89	0.17	85
Bt3c	110-169	2.81	3.88	0.33	0.19	7.21	8.26	20.74	0.13	87
Bt4c	169-198	2.38	4.12	0.15	0.28	6.93	8.07	20.40	0.14	86
BC1	198-225	2.12	3.82	0.11	0.19	6.25	7.70	19.78	0.14	81
BC2	225-261+	3.34	4.24	0.14	0.23	6.94	7.88	16.58	0.14	100
				Khanapur						
A1	0-10	6.83	3.02	0.47	0.28	10.61	12.06	29.87	0.40	88
A2	10-30	3.06	3.74	0.17	0.26	7.24	8.45	22.60	0.28	86
BA	30-58	3.04	3.72	0.12	0.18	7.06	8.26	20.42	0.26	85
Bt1c	58-100	2.99	4.16	0.13	0.19	7.46	8.55	23.01	0.23	87
Bt2c	100-130	3. 01	3.96	0.15	0.26	7.38	8.36	22.76	0.18	88
BC	130-170+	2.99	3.62	0.14	0.35	7.09	8.17	16.63	0.21	87
				Kumta						
A1c	0-8	2.09	3.32	0.27	0.52	6.40	9.02	37.40	0.20	69
A2c	8-24	0.70	3.43	0.12	0.25	5.33	6.84	33.73	0.15	66
BAc	24-43	0.37	2.24	0.13	0.25	4.19	5.40	32.12	0.11	55
Bt1c	43-66	1.29	2.37	0.14	0.29	5.78	6.93	29.57	0.12	41
Bt2c	66-98	1.38	2.97	0.13	0.25	6.05	7.22	31.43	0.11	66
Bt3c	98-200	1.40	2.20	0.07	0.21	3.98	4.94	9.74	0.13	79
				Murdeshwar						
A1c	0-35	1.37	1.74	0.13	0.24	3.68	8.64	30.36	0.21	40
Bt1c	35-80	2.63	4.06	0.09	0.36	7.21	8.45	24.40	0.16	84
Bt2c	80-150	1.88	4.49	0.09	0.27	6.82	7.88	20.06	0.12	85
BC	150-200+	0.77	3.44	0.20	0.34	5.77	6.93	18.97	0.16	69

The ratio of CEC-7/clay followed a decreasing trend with depth in all the pedons (0.11 to 0.46). Higher ratio (>0.25) in surface horizons of Sirsi, Khanapur and Londa pedons is due to high organic matter content. In subsurface horizons of all the pedons CEC-7/clay ratio was <0.25 indicating low activity clay in these pedons (Pujari and Moharana 1993). Dithionite extractable iron (Fe_d) was more than oxalate extractable iron (Fe_o) in all the pedons indicating dominance of crystalline form of free iron (Table 5). Dithionite extractable iron (Fe_d) content increased with depth in all the pedons except in Murdeshwar pedon. The increase may be partly due to increase in clay content and also due to weathering in lower

Table 5. Free iron oxides and total iron, aluminium and silica content of soils

Horizon	Depth (cm)	Free iron oxides				Total analysis				
		Fe_d	Fe_o	Fe_d/Fe_o	Fe_d/clay	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/Al_2O_3	SiO_2/R_2O_3
		-----%-----				----------%----------				
					Sirsi					
Ap	0-17	6.30	1.12	0.18	0.19	56.57	7.7	16.0	12.5	5.4
B1	17-33	5.67	1.03	0.18	0.15	60.17	14.2	11.0	7.2	4.8
Bt1	33-60	5.29	0.88	0.17	0.12	63.19	19.9	12.3	5.4	3.9
Bt2	60-95	5.35	0.76	0.14	0.10	62.61	23.9	14.5	4.5	3.2
Bt3c	95-125	5.79	0.54	0.09	0.12	57.57	17.1	11.6	5.7	4.0
BC1	125-154	7.12	0.42	0.06	0.17	51.43	20.3	15.1	4.3	2.9
BC2	154-220+	6.68	0.31	0.06	0.20					
					Siddapur					
A1	0-18	5.36	1.29	0.24	0.14	54.71	13.6	9.6	6.8	4.7
Bt1	18-38	5.20	1.50	0.29	0.12	53.72	18.2	10.4	5.0	3.7
Bt2	38-65	5.44	1.18	0.22	0.11	56.13	21.0	12.4	4.5	3.3
Bt3c	65-110	5.20	0.98	0.19	0.11	51.28	21.1	15.2	4.1	2.8
BC1	110-155	7.36	0.62	0.08	0.17	20.20	22.7	20.1	3.8	2.4
BC2	155+	7.44	0.40	0.05	0.21	31.88	25.7	24.8	2.1	1.3
					Londa					
A1	0-10	5.18	1.86	0.36	0.13	53.46	17.0	9.3	5.4	4.0
A2	10-23	7.03	1.71	0.24	0.15	49.15	20.4	12.4	4.1	2.9
BAc	23-42	6.13	1.50	0.24	0.13	45.43	22.7	13.2	3.4	2.5
Bt1c	42-70	8.30	1.35	0.16	0.16	44.80	21.2	15.3	3.6	2.5
Bt2c	70-110	8.85	0.78	0.09	0.16	35.10	27.0	18.4	2.2	1.5
Bt3c	110-169	12.06	0.47	0.04	0.20	31.19	28.2	22.2	1.9	1.2
Bt4c	169-198	13.87	0.44	0.03	0.22	28.25	28.2	23.6	1.7	1.1
BC1	198-225	13.93	0.25	0.02	0.25	25.04	28.7	25.3	1.7	1.1
BC2	225-261+	13.90	0.28	0.02	0.25	28.31	28.8	25.2	1.7	1.1
					Khanapur					
A1	0-10	3.07	1.14	0.37	0.11	60.11	11.5	8.0	8.9	6.2
A2	10-30	3.21	1.06	0.33	0.11	71.02	13.1	8.5	9.2	6.5
BA	30-58	3.36	0.96	0.29	0.11	69.23	13.4	4.0	8.8	6.6
Bt1c	58-100	4.48	0.87	0.19	0.12	59.51	14.0	9.0	5.9	4.5
Bt2c	100-130	4.69	0.61	0.13	0.10	60.81	19.5	11.9	5.3	3.8
BC	130-170+	5.87	0.36	0.06	0.15	58.50	19.2	13.3	5.2	3.6
					Kumta					
A1c	0-8	10.28	1.43	0.14	0.22	34.64	27.3	20.0	2.2	1.5
A2c	8-24	9.08	1.71	0.17	0.19	35.35	28.0	17.4	2.2	1.5
BAc	24-43	10.42	1.73	0.17	0.22	32.04	26.8	17.4	2.0	1.4
Bt1c	43-66	7.93	1.85	0.23	0.13	41.49	31.0	20.4	2.3	1.6
Bt2c	66-98	7.83	1.81	0.23	0.12	35.83	31.0	18.3	2.0	1.4
Bt3c	98-200	10.86	1.23	0.11	0.19	30.11	31.8	22.2	1.6	1.1
BC	200+	12.19	0.45	0.04	0.32	29.77	33.0	27.1	1.5	1.0
					Murdeshwar					
A1c	0-35	10.38	1.06	0.10	0.26	48.74	22.2	15.0	3.7	2.6
Bt1c	35-80	7.16	0.63	0.09	0.13	43.83	29.9	15.6	2.5	1.9
Bt2c	80-150	6.94	0.40	0.06	0.11	37.59	30.1	14.6	2.1	1.6
BC	150-200+	6.01	0.23	0.04	0.14	42.83	31.8	12.0	2.3	1.9

horizons. High Fed/clay ratio also suggests high degree of weathering and accumulation of free iron oxides at lower depths (Rebertus and Buol 1985). Further, the low and decreasing ratios of Fe_o/Fe_d with depth suggests that even the small amount of iron oxides dissolved by ammonium oxalate may be crystalline.

Pedogenesis

Laterization: The distribution of iron gravels throughout the profile in the soils of coastal region (Murdeshwar and Kumta) indicates that these sites have undergone higher degree of laterization compared to the inland hilly region sites of Sirsi, Siddapur, Londa and Khanapur, where iron gravels are in the form of a horizon (Reddy *et al.* 1993). Low pH, high acidity, low CEC, high Fed in Murdeshwar and Kumta pedons compared to others indicates high degree of weathering and leaching due to very high rainfall at pedon sites. In the lower horizons of Murdeshwar and Londa pedons, sand + silt content was higher than SiO_2 content in soil indicating the formation of pseudo-aggregates which are sesquioxidic in nature and these have possibly given higher figures for sand contents. Thus, the coarser fractions are possibly products of both physical and chemical weathering in these soils. Similar observations were also made by Gowaikar and Datta (1971) for laterite soils of southern India.

Uniformly low silt content in relation to other particle size fractions and low silt/clay ratios are generally recognised as indicators of advanced stages of weathering due to the prolonged action of weathering agents on primary minerals (De Alwis and Pluth 1976). When the particle size of primary minerals is reduced to silt size, they become highly susceptible for weathering (De Alwis and Pluth 1976). According to Buringh (1970) critical value for silt/clay ratio is 0.25 for laterization. This ratio is met only in Sirsi, Murdeshwar and Kumta pedons. In case of Londa and Siddapur pedons, silt content was high despite signs of high degree of laterization. High silt in these soils may be related to formation of micro-aggregates of iron oxides (Schmidt-Lorenz 1979). Therefore, silt/clay ratio alone may not characterise laterization adequately.

Illuviation of clay: The increase in clay with depth is possibly due to illuviation and partly due to *in situ* weathering of coarser particle. Illuviation may be favoured in these soils, since the climate is characterised by higher rainfall having a distinct dry season for 3-4 months The surface horizons by virtue of its coarse texture shows illuviation of the fine clay particles down the profile (Narayan Rao *et al.* 1993). Illuviation of clay is evident by increase in the fine clay in the illuvial horizon (Table 2).

Pseudo-aggregate formation: In most of the pedons, there is accumulation of coarse sand at the surface and iron gravels in the intermediate layers. The former is possible due to the eluviation and erosion of the finer material because of open structure at surface horizons, whereas in the later it is due to the separated iron oxides forming nodules or pseudo-aggregates (Gowaikar and Datta 1971) as a result of alternate wet and dry periods, which favour reduction and oxidation (van Schuylenborgh 1971). Oxidation and reducation processes may lead to transformation of free iron oxides to sand and gravel sized fractions. The appearance of 0.713 nm peak of kaolinite along with quartz peak in XRD of deferrated fine sand fraction also suggests the illuviation of clay along with free iron oxides and accumulation in the form of pseudo-aggregates or iron concretions (Gowaikar and Datta 1971; Segalen 1971). During the weathering process, excess iron in solution might have precipitated as hydrous oxides of iron, saturated the surface of kaolin (Oades 1963) and led to the formation of ferruginous gravels.

Movement of iron oxides and accumulation: The Fe_d/clay ratios showed decreasing trend with depth except in Khanapur and Londa pedons. Higher values near the surface and lower values in the middle of the solum suggests that the migration of clay has been preferred over iron oxides (Juo *et al.* 1974), whereas higher values of Feo/clay down the pedon in Khanapur and Londa indicates that migration of iron oxides has been preferred over clay. In the comparison between iron oxide and clay movement it could be implied that the iron oxides have moved by physical translocation or solution followed by downward leaching which might have caused accumulation of iron oxides to form larger particles.

Desilication: The chemical composition of the soils (Table 6) indicated that there was higher accumulation of Al_2O_3 and Fe_2O_3 in the subsurface horizons. Since Al_2O_3 is considered as an immobile constituent, its accumulation and low silica content suggest removal of other constituents including silica. This indicates that soils are subjected to higher degree of desilication. The degree of desilication followed the pattern of rainfall distribution. Low silica content in the Kumta, Murdeshwar and Londa pedons indicates higher degree of desilication due to heavy rainfall at the pedon sites whereas the degree of desilication in Khanapur, Sirsi and Siddapur pedons was comparatively low due to relatively low rainfall. The higher SiO_2/R_2O_3 ratios of soils followed the views of Mohr *et al.* (1972) for weathering of acidic rocks under tropical conditions. According to them, the acidic rocks do not undergo primary laterization, but gradually change through the catamorphic process into more or less quartziferrous and impure kaolin.

Based on the foregoing discussion it could be concluded that, desilication and laterization are the dominant pedogenic processes operating in the soils studied. Eluviation and illuviation have also played their role in pedogenesis of the soils under study.

Classification: All the soils have more than 35 per cent base saturation (Table 4). Judging by the criteria of clay cutans and clay illuviation (Bt horizon in all the pedons) these soils are grouped as Alfisols (Soil Survey Staff 1998). The moisture regime is ustic in the study area.

Sirsi pedon has a CEC of less than 16 cmol (+) kg^{-1} clay and ECEC of less than 12 cmol (+) kg^{-1} clay (Table 6) in the kandic horizon and have a clay decrease with increasing depth by 20 per cent of maximum clay content (Table 2). Therefore, it keys out as Kanhaplustalf at greatgroup level. Since, the kandic horizon is absent in Siddapur and Khanapur pedons, they can be grouped under Paleustalfs at greatgroup level based on clay distribution. Members of Siddapur soils have plinthic layers and can therefore be classified as Plinthic Paleustalf. On the other hand the members of Khanapur soils centres around the central concept of the greatgroup and are thus grouped as Typic Paleustalf.

Table 6. CEC and ECEC of clays

Horizon	Depth (cm)	CEC	ECEC
		Sirsi	
Ap	0-17	27.8	24.5
B1	17-33	19.3	16.6
Bt1	33-60	15.5	12.9
Bt2	60-95	12.8	10.9
Bt3c	95-125	14.0	11.8
BC1	125-154	17.1	13.8
BC2	154-220+	20.4	16.9
		Siddapur	
A1	0-18	24.2	20.1
Bt1	18-38	20.2	17.3
Bt2	38-65	18.2	15.1
Bt3c	65-110	19.7	16.5
BC1	110-155	17.3	14.4
BC2	155+	20.1	16.6
		Londa	
A1	0-10	43.5	40.0
A2	10-23	24.7	21.4
BAc	23-42	22.3	19.7
Bt1c	42-70	17.7	15.2
Bt2c	70-110	17.0	14.5
Bt3c	110-169	13.5	11.8
Bt4c	169-198	13.1	11.2
BC1	198-225	13.7	11.1
BC2	225-261+	14.1	12.4
		Khanapur	
A1	0-10	43.1	38.0
A2	10-30	27.7	23.7
BA	30-58	26.5	22.6
Bt1c	58-100	22.7	19.8
Bt2c	100-130	18.5	16.3
BC	130-170+	21.4	18.5
		Kumta	
A1c	0-8	19.6	13.9
A2c	8-24	14.5	11.3
BAc	24-43	11.5	8.9
Bt1c	43-66	11.7	9.7
Bt2c	66-98	10.6	8.9
Bt3c	98-200	8.6	6.9
		Murdeshwar	
A1c	0-35	21.4	9.1
Bt1c	35-80	15.8	13.5
Bt2c	80-150	12.2	10.6
BC	150-200+	15.8	13.2

Murdeshwar and Kumta pedons are grouped under Kandiustalf great group owing to a clay content of more than 40 per cent in the fine earth fraction within 18 cm depth from the soil surface (Table 2) and a kandic horizon that has its upper boundary within 150 cm of the mineral soil surface (Table 6). They key out as Plinthic Kandiustalf at subgroup level due to the occurrence of more than 5 per cent (by volume) plinthite within 125 cm of the mineral soil surface. Based on the same key, Londa pedon is classified as Plinthic Paleustalf.

Following is the summary of soil classification of pedons under study.

Sirsi	-	Typic Kanhaplustalf
Siddapur	-	Plinthic Paleustalf
Khanapur	-	Typic Paleustalf
Londa	-	Plinthic Paleustalf
Kumta	-	Plinthic Kandiustalf
Murdeshwar	-	Plinthic Kandiustalf

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