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Mineralogy and Genesis of Some Paddy-growing Soils of Eastern Vidarbha, Maharashtra

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Abstract: *Representative paddy-growing soils of four districts in the eastern Vidarbha of Maharashtra were studied for their mineralogy and genesis. Paddy-growing soils represent relatively humid part of the eastern Vidarbha (MAR ranging from 1312 to 1551 mm) with altitude ranging from 173 to 300 m above MSL. The mineralogical investigation indicates that these soils have smectitic clay mineralogy along with smectite-kaolin (Sm/K) interstratified minerals. Smectite is transformed to Sm/K due to the weathering process. Smectite was the first weathering product of plagioclase feldspars in an earlier humid climate. The formation of Sm/K interstatification is a post-depositional clay mineral transformation. The genesis of all the minerals of all the soil indicated detachment of weathered materials of basalt and their subsequent transportation and deposition in the valleys and depressions. These soils continue to exist in the valleys. Due to poor drainage conditions the smectite minerals remained in the pedo-environment and only transformed to Sm/K interstratified minerals.*

The genesis of shrink-swell soils (black soils) has been investigated in greater detail (Pal and Deshpande, 1987a; Pal *et al.*, 1989, 1999, 2001; Ghosh, 1997; Pal, 2003; Bhattacharyya *et al.*, 1993, 1997, 1999, 2000). Extensive work has been carried out on genesis and classification of soils with special reference to red (Murli *et al.*, 1974), alluvial (Kapoor *et al.*, 1980) and black soils (Pal, 2003). The research work carried out on the genesis and classification of shrink–swell soils of Maharashtra has been extensive (Pal *et al.*, 1989; Pal, 2003), including western Vidarbha region (Balpande, 1993; Gabhane, 1996; Kadu, 1997; Vaidya, 2001; Nimkar, 2004; Zade, 2007). However, work on the similar aspects on the soils of the eastern Vidarbha is less. It is in view of this the present study has been undertaken to study the mineralogy and genesis of some representative paddy-growing soils from selected districts of the eastern Vidarbha, namely Bhandara, Gondia, Chandrapur and Gadchiroli.

Materials and Methods

The study was carried out on four soil profiles (Fig.1) from the eastern Vidarbha namely, Dighori (P1), Rajegaon (P2), Haldi (P3), and Kurul (P4) with the altitude ranging from 173-300 m above MSL. The mean annual rainfall (MAR) ranges from 1312-1551 mm, mean annual temperature (MAT) from 26-28°C (Fig.2).

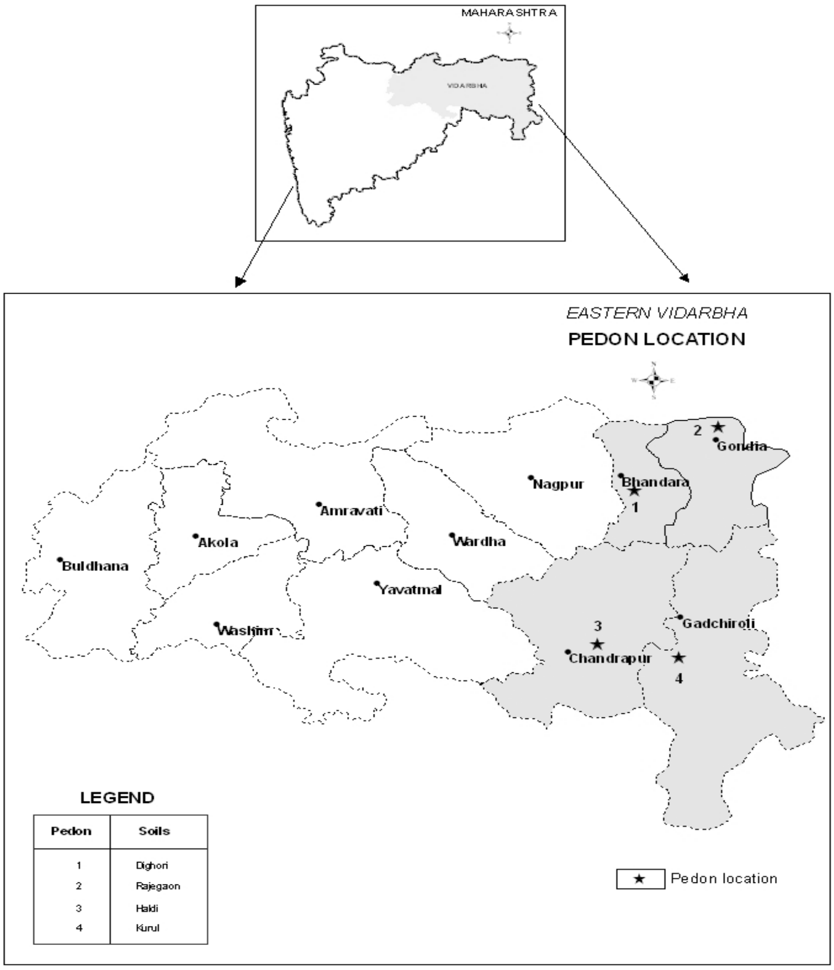

Fig. 1. Study area showing pedon location

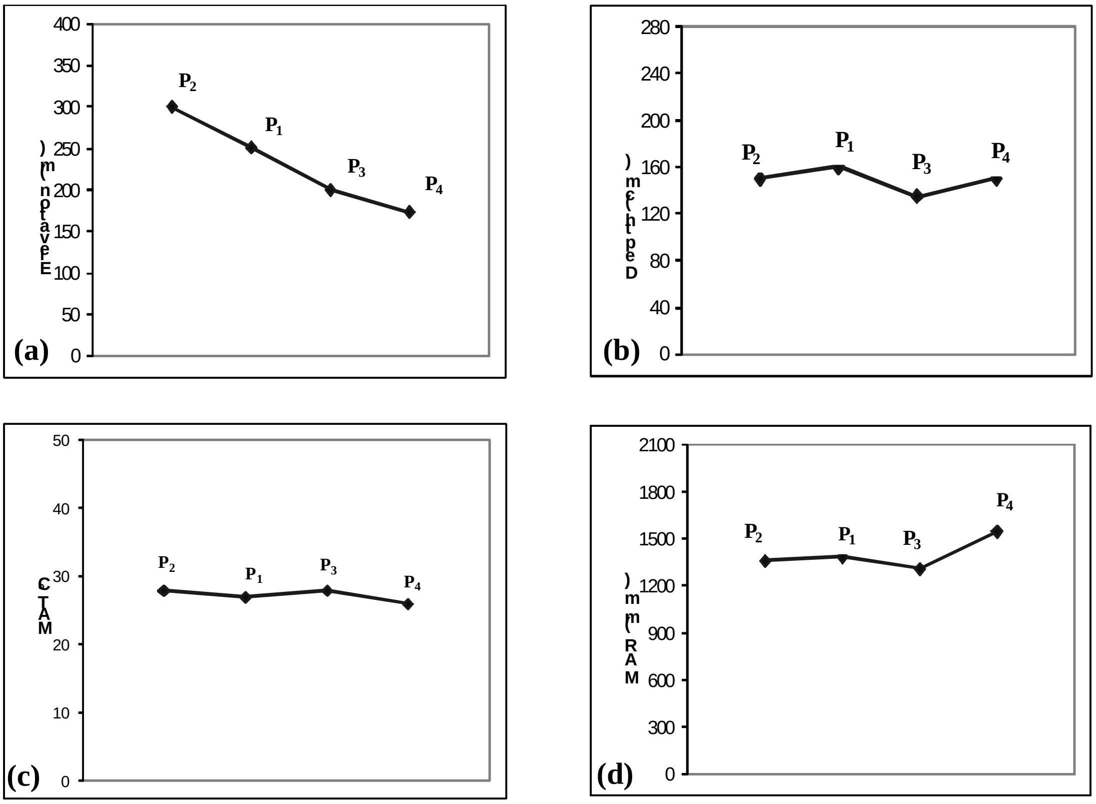

Fig. 2. General trend of (a) elevation (m above mean sea level), (b) soil depth, (c) mean annual rainfall (MAR) and (d) mean annual temperature (MAT) in the study area, P1: Dighori, Bhandara District; P2: Rajegaon, Gondia district; P3: Haldi, Chandrapur district; P4: Kurul, Gadchiroli district.

Horizon-wise soil samples were collected for each benchmark site. The samples were air-dried and processed for physical, chemical and mineralogical analyses. The general properties of the soils were determined following standard procedures (Jackson, 1973); hydraulic conductivity, electrical conductivity, cation exchange capacity, COLE, pH, organic carbon, extractable bases and calcium carbonate were also determined (Richards, 1954; Schaffer and Singer, 1976; Jackson, 1973; Piper, 1950). For particle size distribution, international pipette method was followed after the removal of organic matter, calcium carbonate and free iron oxides. Sand (>50µm), silt (50-2 µm), total clay (<2 µm) and fine clay (<0.2 µm) fractions were separated according to the procedure of Jackson (1979).

Silt and clay fractions were subjected to x-ray examination of the parallel oriented Ca/K saturated samples with a Phillips diffractometer using Ni-filtered CuKá radiation and a scanning speed of 2°2è/min. The sand fractions were crushed to very fine powder using an agate mortar and pastle. A powder mount of each was made and x-rayed at 25°C. Clay minerals were identified according to the procedure outlined by Jackson (1979). The semi-quantitative estimates were made following standard methods (Gjems, 1967), Ghosh and Dutta, 1972). Information about the chemical structure of the clay fractions, fine clay in particular, was obtained from the 060 reflections of the randomly oriented samples as well as from other diagnostic methods (Harward *et al.*, 1969; Greene-Kelly, 1953).

Results and Discussion

Morphological properties

Morphological studies indicate that the colour of the soils varies from very dark grayish brown (10 YR 3/2) to brown (10 YR 4/3) with clayey texture. The surface horizons of all soils had medium, weak to moderate, sub-angular blocky structures and sub-surface horizons had medium coarse to moderate strong angular blocky structure. Soils showed ~1 to 5 cm wide cracks in surface horizons. These soils possessed pressure faces and slickensides in all the horizons (Table 1).

Physical properties

The Ap horizon had relatively less clay than underlying horizons, clay content increased and correspondingly silt decreased with depth. Sand content of Haldi soils is more than the other soils. Bulk density of soils ranges from 1.48 to 2.14 Mgm^{-3}; Hydraulic conductivity ranges from 0.0001 to 2.25 cm hr^{-1} and deceases down the depth. Coefficient of linear extensibility (0.07 to 0.19) increases with the increase in total clay percent (19.4 to 62.2) along the depth (Table 2).

Chemical properties

All the soils are calcareous. These are moderately acidic to moderately alkaline. Electrical conductivity is low in the soils. Organic carbon content of soils ranges from 0.14 to 1.74 per cent (Table 3).

Extractable bases are found to follow the order of Ca^{2+}>Mg^{2+} in all the soils. The K^+ ions are found in the range of 0.16 to 0.48 cmol (p$^+$) kg^{-1} whereas Na^+ ions vary from 0.08 to 0.87 cmol (p$^+$) kg^{-1} in Dighori and Kurul soils. Na^+ ion concentration is very high in Rajegaon and Haldi which leads to sodicity of soils. Cation exchange capacity of the soils ranges between 13.48 to 41.99 cmol (p$^+$) kg^{-1} (Table 3).

Table 1. *Morphological Properties of Soils*

Hor-izon	Depth (cm)	Boundary[1]		Matrix Colour	Mottle Colour[2]	Tex-ture[3]	Coarse frag ments (%)	Structure[4]			Consistence[5]			Roots[6]		Effer-vescene[7]	Other[8] Feat-ures	Cracks (cm)
		D	T					S	G	Ty	D	M	W	S	Q			
Pedon 1 : Bhandara District – Dighori Soil (Very fine, smectitic, hyperthermic, Chromic Haplusterts)																		
Ap	0 – 13	c	s	10 YR 4/2	f1d 7.5YR 5/6	c	3-5	m	2	sbk	vh	fi	s, p	vf,f	m,c	Nil/e	-	3-5 cm
Bw1	13 – 27	c	s	10 YR 4/3	Nil	c	3-5	m	2	sbk	h	fr	s, p	vf,f	m,f	Nil/e	PF	3-5 cm
Bw2	27 – 53	g	s	10 YR 4/3	Nil	c	3-5	m	3	sbk	vh	fr	s, p	vf,f	m,f	Nil/e	P. F/SS	1 cm
Bss1	53 – 76	g	s	10 YR 4/3.5	Nil	c	1-2	m	2	abk	vh	fr	s, p	vf	c	Nil/e	SS	-
Bss2	76–105	-	-	10 YR 4/4	Nil	c	1-2	m	2	abk	-	fr	s, p	vf	f	e	SS	-
Pedon 2 : Gondia District – Rajegaon Soil (Fine, smectitic, hyperthermic, Vertic, Endoaqualfs)																		
Ap	0 – 10	c	s	7.5 YR 3/3	m1d/p 5YR 4/6	c	1-2	m	2	sbk	h	fr	s, p	vf,f	m	Nil	PF	1-2 cm
Bt1	10 – 25	c	s	7.5 YR 4/6	m1d 7.5YR 5.5/8	c	< 1	m	3	sbk	-	fr	s, p	vf,f	m,c	Nil	PF (weak)	-
Bt2	25 – 55	g	s	10 YR 4/3	Mottles present but not distingui-shable	sc	< 1	m	2	sbk	-	fr	s, p	vf	f	Nil	PF (weak)	-
Bt3	55 – 74	c	s	10 YR 4/3	f1f 10YR 5/6	sc	< 1	m	2	sbk	-	fr	s, p	vf	f	Nil	PF	-
Bt4	74–107	-	-	10 YR 3.5/3	f1f 10YR 5/6	c	1-2	m	3	sbk	-	fr/fi	s, p	vf	f	e	PF	-
Pedon 3 : Chandrapur District – Haldi Soil (Fine, smectitic, hyperthermic, Vertic, Haplustalfs)																		
Ap	0 – 14	c	s	10 YR 3/2	m1p 7.5YR 5/6	c	< 1-2	m	1	sbk	h	fr	ss, ps	vf,f	m,f	-	-	-
Bw	14 – 46	c	w	10 YR3/4	Nil	c	-	m	3	abk	h	fr	s, p	f,m	m,f	-	PF	-
Bsst	46 – 82	g	w	10 YR 3/3	Nil	c	-	c	3	abk	h	fr	s, p	f,m	f,f	es	PF	-
Bsst	82–114	g	s	10 YR 3/3	Nil	c	-	c	3	abk	h	vfi	s, p	f,m	f,f	es	PF	-
Bsst	114–135	-	-	10 YR 3/4	Nil	c	-	c	2	abk	h	vfi	s, p	f,m	f,f	e	PF/SS	-

Pedon 4 : Gadchiroli District – Kurul Soil (Fine, smectitic, hyperthermic, Ustic Endoaquerts)

Ap	0 – 12	-	-	10 YR 3/2	c1d 7.5YR 3/4	c	1-2	f	1	sbk	s	vfr	s, p	vf,f	m	e	PF	~ 1-1.5
Bw1	12 – 28	c	s	10 YR 3/2	c1d 7.5YR 3/4	c	2-3	m	2	sbk	-	fr	s, p	vf,f	m	e	PF	-
Bw2	28 – 50	c	s	10 YR 4/3	m2d 10YR 5/6	c	2-3	m	2	sbk	-	vfr	s, p	vf,f	c	e	PF	-
Bw3	50 – 76	g	s	10 YR 4/3	m2d 10YR 5/6	c	2-3	m	1	sbk	-	vfr	s, p	vf,f	c	e	PF/weak SS	-
Bss1	76 –101	-	-	10 YR 3.5/2	m2d 10YR 4/6	c	1-2	m	2	sbk/ abk	-	Fr	s, p	vf	f	e	SS	-

[1]D:distinctness (c:clear; g:gradual); T: topography (s:smooth; w:wavy); [2] fld : few fine distinct; m1d/p : many fine distinct/prominent; f1f : few fine faint; m1p : many fine prominent; c1d : commonly fine distinct; m2d : many medium distinct; [3] c : clay; sc : sandy clay ; [4] S : Single (m : medium; c " coarse; f : fine); G : Grade (1 : weak; 2 : moderate; 3 : strong); Ty : Typic (sbk : subangular block; abk : anbular blocky); [5] D : dry (s : soft; h : hard; vh : very hard); M : moist (fr : friable; vfr : very friable; fi : firm; vfi : very firm); W : wet (s,p : sticky plastic; ssps : slightly sticky and slightly plastic); [6] S : single (vf : very fine; v : fine, m : medium); Q = quantity (f : few; c : common; m : many); [7] e : slight; es : strong; [8] PF : Pressure faces; SS : Slickensides

Mineralogy of sand and silt fractions

Feldspars, quartz, crystobalite, hematite and anatase were identified in almost all the selected sand fractions of Dighori, Rajegaon, Haldi and Kurul soils (Fig.3). Plagioclase (Ca-feldspars) was identified by 0.645, quartz by 0.424 and K-feldspars by 0.324 nm peak. Hematite and anatase were identified by the peaks at 0.167 and 0.35 nm respectively.

The silt fractions (50–2µm), in general, contain smectite, chlorite, mica, kaolinite, quartz and feldspars (Fig.4). In Dighori (Pedon 1), chlorite was identified by the appearance of 1.4 nm peak in all samples except K550°C samples where a hump at 1.36 nm was identified. A part of 1.4 nm peak in Ca-saturated sample which indicates that smectite minerals also present in silt fractions of Dighori soils. The peak at around 1.0 nm with its 002 reflection at 0.498 and 003 at 0.333 indicate the presence of mica. XRD examination of silt fractions indicates the peak of kaolin at around 0.72 nm and 0.35 indicating 001 and 002 reflection. A slight shift of this peak on glycolation and gradual reinforcement of the 1.0 nm peak of mica with a corresponding decrease in intensity of 0.72 nm peak and subsequent heating from 110°C to 550°C suggest that these kaolins are to some extent interstratified with smectites (Fig. 4). The peak at 0.424 indicates the presence of quartz (SiO_2), 0.352 nm due to anatase (TiO_2), 0.324 due

Table 2. *Physical properties of soils*

Horizon	Depth (cm)	Particle-size distribution: Sand (%)	Silt (%)	Total clay (%)	COLE[1]	HC[2] cm hr^{-1}	BD[3] Mgm^{-3}
Pedon 1 : Bhandara District – Dighori Soil (Very fine, smectitic, hyperthermic, Chromic Haplusterts)							
Ap	0 - 13	22.2	30.4	47.4	0.15	0.42	1.68
Bw1	13 - 27	21.5	22.4	56.1	0.17	0.84	1.83
Bw2	27 - 53	18.3	34.5	47.2	0.17	0.99	1.67
Bss1	53 - 76	17.0	25.1	57.9	0.18	1.09	1.81
Bss2	76 - 105	17.9	19.9	62.2	0.19	0.77	1.75
Pedon 2 : Gondia District – Rajegaon Soil (Fine, smectitic, hyperthermic, Vertic, Endoaqualfs)							
Ap	0 – 10	34.9	45.7	19.4	0.08	0.20	1.58
Bt1	10 – 25	35.0	37.1	27.9	0.08	0.28	1.79
Bt2	25 – 55	40.5	30.4	29.1	0.08	0.09	2.01
Bt3	55 – 74	38.6	23.8	37.6	0.10	0.002	1.72
Bt4	74 – 107	28.4	24.8	46.8	0.14	0.0001	1.74
Pedon 3 : Chandrapur District – Hldi Soil (Fine, smectitic, hyperthermic, Vertic, Haplustalfs)							
Ap	0 – 14	46.2	21.4	32.4	0.09	2.25	1.66
Bw	14 – 46	47.9	23.1	29.0	0.07	0.20	1.82
Bsst	46 – 82	48.0	12.9	39.1	0.11	1.44	1.99
Bsst	82 – 114	44.8	18.7	36.5	0.12	0.23	1.91
Bsst	114 - 135	50.9	15.1	34.0	0.12	0.01	2.14
Pedon 4 : Gadchiroli District – Kurul Soil (Fine, smectitic, hyperthermic, Ustic Endoaquerts)							
Ap	0 – 12	30.9	27.9	41.2	0.13	0.50	1.48
Bw1	12 – 28	41.8	24.3	33.9	0.13	0.78	1.92
Bw2	28 – 50	44.6	22.6	32.8	0.12	0.53	1.83
Bw3	50 – 76	43.3	23.7	33.0	0.13	0.48	1.68
Bss1	76 – 101	46.2	24.3	29.5	0.12	0.33	1.83

[1] COLE : Coefficient of linear extensibility; [2] HC : Hydraulic conductivity; [3] BD : Bulk density.

Table 3. *Chemical properties of soils*

Horizon	Depth	pH (1 : 2.5) Water	pH (1 : 2.5) KCI	EC[1] (dSm^{-1})	SOC[2] (%)	$CaCO_3$ (%)	Extractable Bases Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Sum	CEC[3] cmol (p^{+}) kg^{-1}	ESP[4]	EMP[5]	Base Saturation	Clay CEC (p^{+}) kg^{-1}
Pedon 1 : Bhandara District – Dighori Soil (Very fine, smectitic, hyperthermic, Chromic Haplusterts)																
Ap	0 – 13	6.8	5.5	0.2	1.07	1.72	23.40	11.16	0.08	0.50	35.14	32.00	~1	35	109.81	67.51
Bw1	13 – 27	7.9	6.7	0.2	0.39	4.02	24.74	4.51	0.35	0.45	30.05	35.99	1	13	83.50	64.15
Bw2	27 – 53	8.0	6.8	0.1	0.29	2.10	25.18	5.41	0.35	0.44	31.08	41.99	1	13	74.74	88.96
Bss2	53 – 76	8.0	6.8	0.2	0.24	2.43	25.16	5.32	0.35	0.48	31.31	33.99	1	16	92.12	58.70
Bss3	76–105	8.0	6.9	0.2	0.25	0.75	27.25	3.44	0.35	0.33	31.37	35.99	1	10	87.16	57.86
Pedon 2 : Gondia District – Rajegaon Soil (Fine, smectitic, hyperthermic, Vertic, Endoaqualfs)																
Ap	0 – 10	5.8	4.6	0.1	0.93	0.86	7.92	3.96	0.04	0.30	12.22	13.48	~ 1	29	90.65	69.48
Bt1	10 – 25	7.6	6.0	0.1	0.28	0.57	7.84	1.99	0.69	0.19	10.71	16.00	4	12	66.94	57.35
Bt2	25 – 55	8.1	6.1	0.1	0.20	1.15	7.08	3.94	1.39	0.22	12.63	19.99	7	20	63.18	90.45
Bt3	55 – 74	8.8	6.8	0.3	0.90	1.15	7.74	3.59	3.65	0.20	15.18	23.99	15	15	63.28	63.80
Bt4	74–107	8.9	7.1	0.3	0.14	1.72	9.48	5.56	8.17	0.35	23.56	27.99	29	20	84.17	59.81
Pedon 3 : Chandrapur District – Haldi Soil (Fine, smectitic, hyperthermic, Vertic, Haplustalfs)																
Ap	0 – 14	6.7	5.1	0.0	0.25	1.01	13.97	5.04	0.05	0.20	19.26	24.48	~ 1	21	82.03	72.47
Bw	14 – 46	6.3	4.7	0.1	0.53	0.89	8.93	4.15	0.17	0.16	13.41	15.99	1	26	83.86	55.14
Bsst	46 – 82	8.4	7.0	0.2	0.19	2.83	16.78	4.54	1.04	0.26	22.62	23.99	4	19	94.29	61.36
Bsst	82–114	8.8	7.3	0.3	0.18	3.58	12.53	4.88	3.48	0.24	21.13	30.00	12	16	70.43	82.19
Bsst	114–135	9.2	7.5	0.5	0.17	3.68	7.85	7.6	5.04	0.20	20.69	23.99	21	32	86.24	70.56
Pedon 4 : Gadchiroli District – Kurul Soil (Fine, smectitic, hyperthermic, Ustic Endoaquerts)																
Ap	0 – 12	8.0	7.1	0.4	1.74	2.01	16.54	8.46	0.09	0.40	25.49	28.87	~ 1	29	88.29	70.07
Bw1	12 – 28	8.1	6.8	0.2	0.54	1.15	17.33	2.44	1.04	0.24	21.05	25.99	4	9	80.99	76.66
Bw2	28 – 50	8.2	6.8	0.2	0.31	1.15	16.57	2.79	0.87	0.22	20.45	25.99	3	11	78.68	76.24
Bw3	50 – 76	8.4	6.8	0.1	0.21	1.15	14.71	4.28	0.87	0.21	20.13	23.98	4	18	83.94	72.66
Bss1	76 – 101	8.5	6.9	0.1	0.16	1.43	14.17	4.19	0.70	0.22	19.28	21.99	3	19	87.68	74.54

[1] EC : Electrical conductivity; [2] SOC : Soil organic carbon; [3] CEC : Cation exchange capacity; [4] ESP : Exchangeable sodium percentage; [5] EMP : Exchangeable magnesium percentage.

Fig. 3. Representating X-ray diffractograms of sand fraction (>50µ) of Dighori (P1), Rajegaon (P2), Haldi (P3), and Kurul (P4). P = Plagioclase (Ca-feldspars), Q = Quartz, An = Anatase, K = K-feldspars, H = Hematite.

to K-feldspars and 0.318 due to Ca-feldspars. A characteristic peak with the range of 0.443-0.446 nm has been ascribed to phyllosilicates.

Mineralogy of total clay and fine clay fractions

The dominant minerals present in total clay fractions are smectite, mica, smectite-kaolinite interstratified minerals with quartz and feldspars in fewer amounts. The peak identified at around 1.4 nm in calcium saturated samples shifted to lower angle side and registered peak at 1.8 nm indicating the presence of smectite minerals. On K-Saturation the peak in the form of a hump was identified in the range of 1.2 to 1.4 nm. This peak gets reinforced on heating at 110º C and 300º C till at 550º C. A peak at 1.0 nm becomes dominant with a tailing towards lower angle indicating smectite. The 0.72 and 0.35 nm peaks identified in Ca-saturated samples indicate the presence of kaolin. In Ca-saturated and glycolated sample 0.72 nm peaks is slightly shifted to low angle side with a concomitant decrease in intensity. This shows that these kaolin minerals are interstratified with smectite, which are again

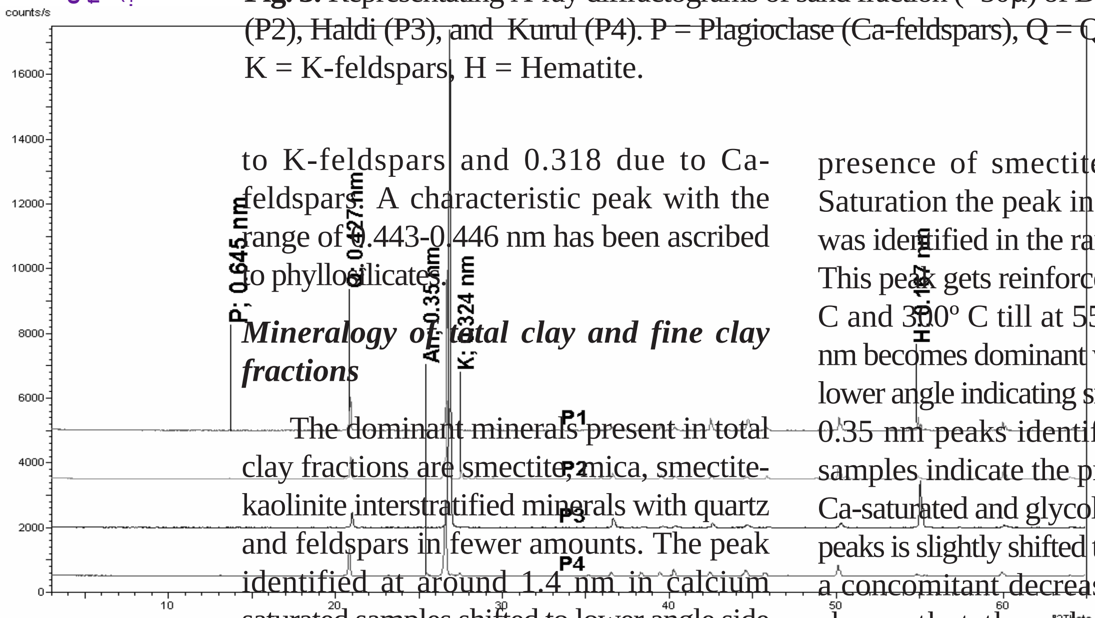

Fig. 3. Representating X-ray diffractograms of sand fraction (>50µ) of Dighori (P1), Rajegaon (P2), Haldi (P3), and Kurul (P4). P = Plagioclase (Ca-feldspars), Q = Quartz, An = Anatase, K = K-feldspars, H = Hematite.

Fig. 4. Representating X-ray diffractograms of silt fraction (50-2 μ) of Dighori, Rajegaon, Haldi, and Kurul. Ca = Ca-saturated, CaEG = Ca-saturated plus ethylene glycol vapour, K25/110/300/500°C = K-saturated and heated at 25°C, 110°C, 300°C and 550°C, K300EG = K-saturated and heated to 300°C plus glycol vapour, Sm = Smectite, Ch = Chlorite, M = Mica, Sm/K = Smectite-kaolin interstratified mineral, Q = Quartz, K = K-feldspars, P = Plagioclase.

chloritised as discussed earlier. This was further confirmed when K-saturated samples with various thermal treatments (110º - 550º C) indicates a gradual reinforcement of 1.00 nm peak with a corresponding decrease in the intensity of 0.72 nm peak (Fig.5).

In fine clay fractions chloritised-smectite is the dominant mineral with small amount of Sm/K interstratified minerals; mica is present only in Rajegaon (Gondia) samples (Fig.6). The presence of interstratified Sm/K is indicated by a peak around 0.72 nm in Ca-saturated sample which shifts after glycolation to low angle side. Besides, the intensity of this peak also decreased on glycolation, suggesting that these kaolins are interstratified with smectite. A closer examination of diffractograms indicate that the shift of 0.72 nm peak is more pronounced in Rajegaon and Kurul soils (Fig. 6)

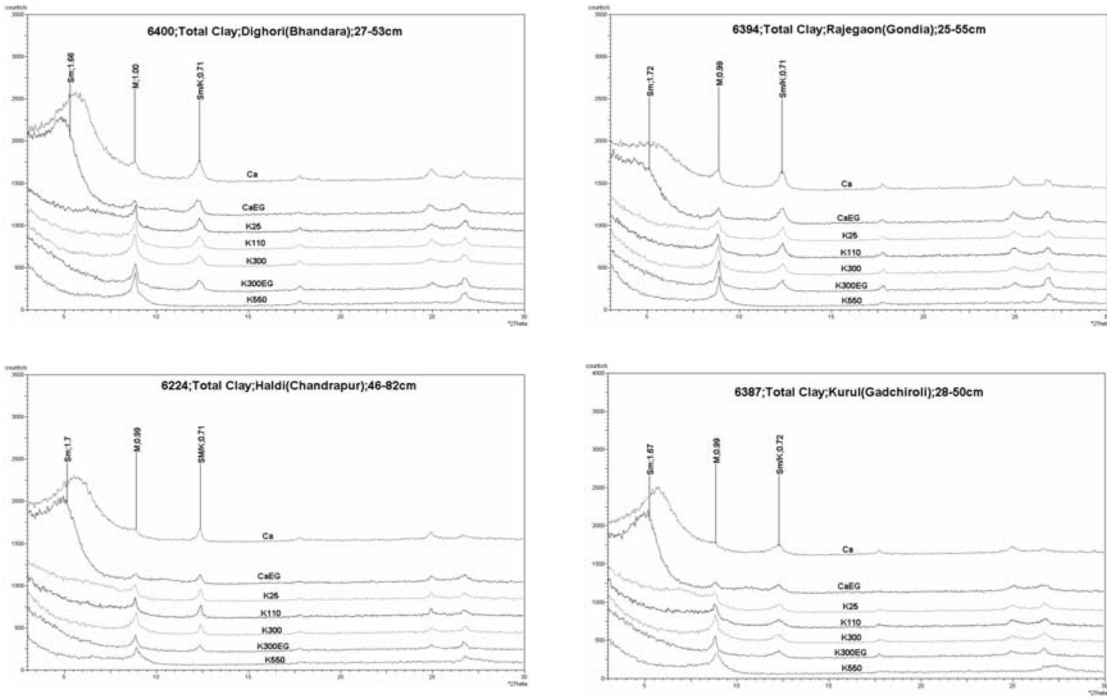

Fig. 5. Representating X-ray diffractograms of total clay fraction (<2 μ) of Dighori, Rajegaon, Haldi, and Kurul. Ca = Ca-saturated, CaEG = Ca-saturated plus ethylene glycol vapour, K25/110/300/500°C = K-saturated and heated at 25°C, 110°C, 300°C and 550°C, K300EG = K-saturated and heated to 300°C plus glycol vapour, Sm = Smectite, M = Mica, Sm/K = Smectite-kaolin interstratified mineral.

indicating that the extent of interstratification of smectite with kaolinite is more in these samples. Moreover, the subsequent thermal treatments indicate that the peak at 1.0 nm gets reinforced with the reduction in the intensity of 0.72 nm peak. This observation confirms the presence of Sm/K interstratified minerals in the samples.

The smectite of Sm/K is also found to be chloritised. The peak at 1.4 nm in Ca-saturated sample was found to be the strongest peak. On glycolation, this peak shifts to 1.7 nm and also registers a peak at around 0.8 nm. This confirms the presence of smectite in all the soil horizons. The K-saturation and thermal treatments of fine clay samples provide an interesting observation. Ideally smectite on K-saturation registers a strong peak at 1.2 nm which gradually collapses to 1.0 nm on thermal treatment

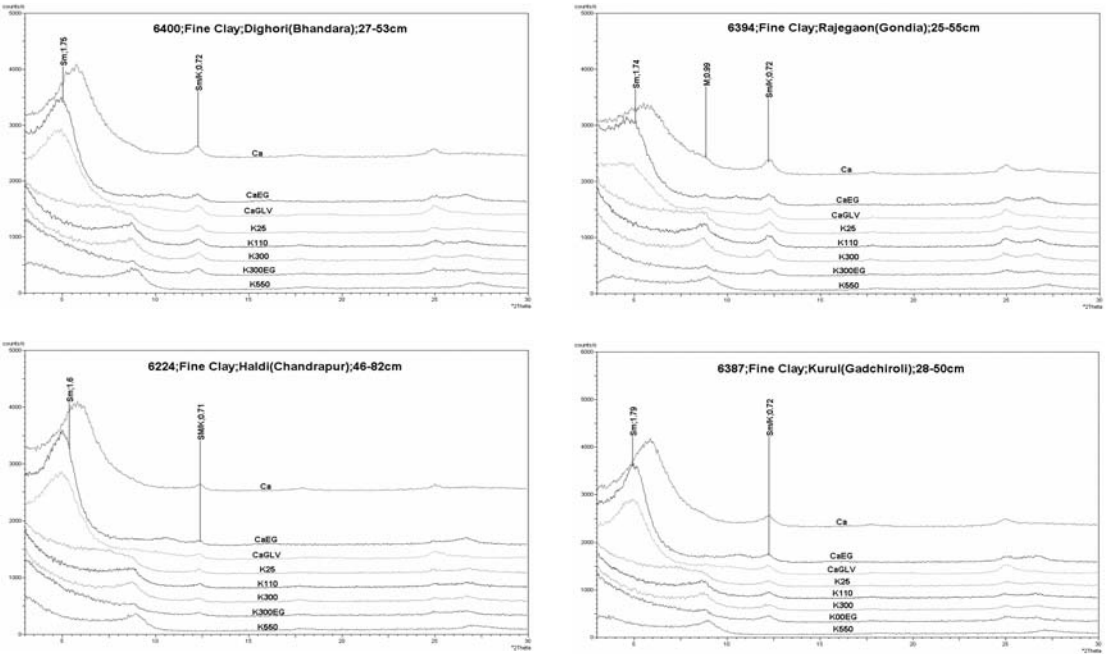

Fig. 6. Representating X-ray diffractograms of fine clay fraction (<0.2 μ) of Dighori, Rajegaon, Haldi, and Kurul. Ca = Ca-saturated, CaEG = Ca-saturated plus ethylene glycol vapour, CaGLV = Ca-saturated plus glycol vapour, K25/110/300/500°C = K-saturated and heated at 25°C, 110°C, 300°C and 550°C, K300EG = K-saturated and heated to 300°C plus glycol vapour, Sm = Smectite, M = Mica, Sm/K = Smectite-kaolin interstratified mineral.

(550º C). In the present case, the smectite peak on K-saturation on thermal treatment registers a plateau between 1.2 to 1.3 nm with a tailing towards low angle side. Besides, the K-saturated samples heated to 550º C also produces a broad base of 1.0 nm peak showing a shoulder and broadening on the low angle side. These criteria are indicative of chloritization of smectite interlayers (Wildman *et al.,* 1968) due to induction of hydroxy-interlayering at higher soil pH conditions. (Jackson, 1963). Similar observations were earlier made by Bhattacharyya *et al.* (1993), Bhuse *et al.* (2002) and Pal and Deshpande (1987a). A weak peak at around 1.0 nm followed by 0.5 and 0.33 nm peaks indicates presence of small amount of mica in Rajegaon soils (Fig.6).

Semi-quantitative estimates in soils

Relative proportion of different minerals in sand fraction showed the presence of Ca and K-feldspars, hematite and quartz. Crystobalite and anatase were also present in a few soils (Table 4). Quartz is found to be dominant in all the horizons ranging from 60-90 per cent.

In silt fraction other than quartz, the dominant minerals are smectite, mica and Sm/K interstratified minerals. Chlorite is present in subdominant proportion (Table 5).

Table 6 indicates semi-quantitative estimates of three major minerals in the total clay fractions of all soils with smectite as dominant and Sm/K and mica as sub-dominant proportions.

It is interesting to note that Sm/K decreases down the depth in Rajegaon (Gondia) soils whereas smectite follows the reverse trend. Barring last two layers, mica content remains almost similar. Similar observations for Dighori, Haldi and Kurul were also made, although the content of Sm/K is relatively less when compared to that of Rajegaon (Gondia) soils.

Table 4. *Relative abundance of minerals in sand fraction (>50 mm) of representative horizons*

Horizon	Depth (cm)	Minerals[1]					
		Ca-feldspars	Quartz	K-feldspars	Crysto-balite	Hematite	Anatase
			Dighori soil (Bhandara)				
Bw1	13-27	Tr	*****	Tr	—	*	—
Bss3	76-105	Tr	*****	Tr	—	*	—
			Rajegaon soil (Gondia)				
Bt1	10-25	*	****	Tr	Tr	*	—
Bt4	74-107	Tr	****	*	—	*	Tr
			Haldi soil (Chandrapur)				
Bw	14-46	—	*****	Tr	—	Tr	—
Bsst	114-135	Tr	*****	—	—	*	—
			Kurul soil (Gadchiroli)				
Bw1	12-28	*	****	Tr	—	*	Tr
Bss1	76-101	Tr	****	Tr	—	*	*

[1] * = 15% ;** = 30%,;*** = 45%,;**** = 60%; ***** = 90% Tr = Traces; — = Nil;

Table 5. *Semi-quantitative estimates of minerals present in representative horizons in silt fraction (50-2 µm)*

Horizon	Depth (cm)	Minerals (%)[1]							
		Sm	Ch	M	Sm/K	Q	An	K	P
		Dighori soil (Bhandara)							
Bw2	27-53	11	10	19	22	19	9	6	4
		Rajegaon soil (Gondia)							
Bt2	25-55	4	—	8	8	42	—	30	8
Bt4	74-107	—	12	17	20	33	6	6	6
		Haldi soil (Chandrapur)							
Bsst	46-82	29	5	11	27	23	—	2	3
Bsst	114-135	47	8	9	20	12	—	—	4
		Kurul soil (Gadchiroli)							
Bw2	28-50	34	3	13	25	15	—	7	3
Bss1	76-101	37	—	10	20	24	—	6	3

[1] Sm = Smectite; Ch = Chlorite; M = Mica; Sm/K = Smectite-Kaolinite interstratified minerals; Q=Quartz; An= Anatase; K = K-feldspars; P = Plagioclase (Ca-feldspars)

In fine clay fraction, content of smectite and Sm/K minerals vary from 73–93 and 7–21 per cent. Mica is present only in Rajegaon soils to the tune of 5-8 per cent (Table 7).

Discussion

The Deccan plateau basalt with the age of about 67 ± 0.3 Ma encompasses an area of 0.5 Mkm^2 in the Indian subcontinent. The Deccan basalt soil forms are distributed from the sea level along the northern part of west coast to 1,642 m at the Kalsubai peak. Within this range, the basalt forms an extensive plateau, mostly dissected at an altitude of 600–700 m. The present study was undertaken which falls in the altitude range from 173–300 m above mean sea level in the eastern part (Vidarbha) of the Deccan province. The landscape of the eastern part of the Deccan plateau is also erosional (Duncan and Pyle, 1988; Subramanyan, 1981;Bhattacharyya *et al.*, 1993) with the degree of erosion gradually becoming less

Table 6. *Semi-quantitative estimates of minerals present in total clay fraction (<2mm)*

Horizon	Depth (cm)	Minerals (%)[1]		
		Sm	M	Sm/K
		Dighori soil (Bhandara)		
Ap	0 – 13	66 (72)[2]	8	26 (28)
Bw1	13 - 27	76 (82)	8	16 (18)
Bw2	27 - 53	77 (83)	8	15 (17)
Bss2	53 - 76	79 (85)	8	13 (15)
Bss3	76 - 105	81 (87)	7	12 (13)
		Rajegaon soil (Gondia)		
Ap	0 - 10	49 (58)	15	36 (42)
Bt1	10 - 25	62 (72)	13	25 (28)
Bt2	25 - 55	56 (65)	14	30 (35)
Bt3	55 - 74	69 (76)	9	22 (24)
Bt4	74 - 107	74 (82)	10	16 (18)
		Haldi soil (Chandrapur)		
Ap	0 - 14	80 (85)	6	14 (15)
Bw	14 - 46	83 (88)	6	11 (12)
Bsst	46 - 82	90 (94)	4	6 (6)
Bsst	82 - 114	82 (88)	7	11 (12)
Bsst	114 - 135	85 (90)	6	9 (10)
		Kurul soil (Gadchiroli)		
Ap	0 - 12	88 (91)	4	8 (9)
Bw1	12 - 28	85 (90)	6	9 (10)
Bw2	28 - 50	81 (88)	8	11 (12)
Bw3	50 - 76	92 (95)	3	5 (5)
Bss1	76 - 101	89 (94)	6	5 (6)

[1]Sm: Smectite; M: Mica;Sm/K: Smectite-kaolin interstratified minerals; [2]Parentheses indicate mineral content on mica-free basis.

Table 7. *Semi-quantitative estimates of minerals present in fine clay fraction (<0.2mm)*

Horizon	Depth (cm)	Minerals (%)[1]		
		Sm	M	Sm/K
		Dighori soil (Bhandara)		
Ap	0-13	89	-	11
Bw1	13-27	84	-	16
Bw2	27 - 53	91	-	9
Bss2	53-76	92	-	8
Bss3	76-105	89	-	11
		Rajegaon soil (Gondia)		
Ap	0-10	75(80)	6	19 (20)
Bt1	10-25	73(80)	6	21 (22)
Bt2	25 - 55	74 (80)	8	18 (20)
Bt3	55-74	85(80)	5	10 (11)
Bt4	74-107	82(80)	5	13 (14)
		Haldi soil (Chandrapur)		
Bsst	46 - 82	93	—-	7
		Kurul soil (Gadchiroli)		
Bw2	28 - 50	87	—-	13

[1] Sm = Smectite; M = Mica; Sm/K = Smectite-kaolin interstratified minerals; [2] Parentheses indicate mineral content on mica-free basis.

from north-east (P_1 and P_2) in Bhandara and Gondia to south-east of the study area (Fig.1). The rainfall distribution of the four sites indicates that Kurul site (P_4) experiences maximum rainfall followed by Dighori (Bhandara), Rajegaon (Gondia) and Haldi (Chandrapur) (Fig.2).

Genesis of minerals in paddy growing soils

In the soils studied for this work, smectite, Sm/K and the two other phyllosilicate minerals such as chlorite (in silt fractions, 50–2μm) and mica (in both clay and silt fractions) were identified. Chlorite was detected in one of the two layers studied for Gondia and Gadchiroli. Vermiculite, as detected by Pal and Deshpande (1987a) in the benchmark series of black soils was not found in the paddy growing soils studied for the present work. These authors explained vermiculite as the weathering product of biotite through an intermediate 10 to 14º A mixed layer minerals. Such transformation, these authors opined, might have taken place during transportation or after the deposition of alluvium. The silt to clay-size mica and silt-size chlorite might be the result of a physical comminution of the primary forms of mica and chlorite, respectively (Pal and Deshpande, 1987a).

Formation of paddy-growing soils

All the soils are situated in the eastern part of Vidarbha, Maharashtra and are formed in basaltic alluvium. The distribution of smectite and Sm/K in total clay showed an increase of smectite and corresponding decrease of Sm/K with depth (Fig.7a,b,c,d), indicating a probable transformation of smectite to Sm/K. It has been suggested that the possible mechanism by which 2:1 layer silicate structure converts to the 1:1 structure involve hydroxy Al-interlayering in the expandable 2:1 layer silicates and / or mixed layering between 2:1 and 1:1 layers and also conversion of 2:1 layers to double kaolin layers. The present study indicates interstratification of hydroxyl-Al interlayered smectite with kaolin. Such interstratification has been reported earlier (Pal *et al*., 1999; Bhattacharyya *et al*., 1993). The present work therefore, supports the earlier connotation that in the weathering environment of humid tropical climate with plenty of Al in the soil, interstratification of smectite is an important ephemeral stage during the transformation of smectite to kaolinite.

The above description of the four sites of the paddy growing soils with special reference to distribution of smectite and Sm/K interstratified mineral indicate that smectite is transformed to kaolin in the following path-way of mineral transformation:

Smectite→(Chloritised) smectite → (Chloritised) Sm/K ⟶ Kaolin

In the study area kaolin was not identified.

The above transformation took place under the humid climate which prevailed in an earlier geological period. Similar observations were made in the Bhimashankar plateau on the Western Ghats of Maharashtra (Bhattacharyya *et al.*, 1993); in the Malegaon plateau in the eastern Maharashtra (Pillai *et al.*, 1995); in the basaltic terrain of Nizamabad district of Andhra Pradesh (Bhuse *et al.*, 2002). It may be recorded that the soils in the Western Ghats and in the Nizamabad district, as just mentioned (Bhuse *et al.*, 2002) were non-calcareous. The soils under the present study, on the contrary, are all calcareous. The formation of calcium carbonates took place during the later part of soil formation which involves drying of climate as compared to earlier period (Pal *et al.*, 2000; Shrivastava *et al.*, 2002)

The paddy-growing black soils in the lower elevations were formed in the basaltic alluvium and continue to exist in a relatively low lying position. These soils continued to exist in the valleys due to retention of characteristic smectite minerals which favors poor and imperfect drainage as is evidenced by the formation of mottles in the profile (Table 1).

Formation of paddy-growing soils in Dighori, Bhandara

Pedon1, (P_1) is situated in Dighori village of Bhandara district, Maharashtra and is formed in basaltic alluvium (Fig. 7a). The pedon site is relatively flat with the highest elevation towards the north-east of pedon site. A north-east to south-west transect in this study area shows the fall in elevation and then a nearly level flat landscape at around 250 m above MSL. At the end of this flat surface pedon (P1) is situated (Fig. 7b). The distribution of total clay indicates a clay increase between 20 to 40 cm of depth (Fig. 7c). The distribution of smectite and Sm/K minerals in total clay showed an increase of smectite and corresponding decrease of Sm/K with depth (Fig. 7d), indicating a probable transformation of smectite to Sm/K. It has been suggested that the possible mechanism by which 2:1 layer silicate structure converts to the 1:1 structure involve hydroxy Al-interlayering in the expandable 2:1 layer silicates and / or mixed layering between 2:1 and 1:1 layers and also conversion of 2:1 layers to double kaolin layers. The present study indicates interstratification of hydroxy-Al interlayered smectite with kaolin. Such interstratification has been reported earlier (Pal *et al*., 1999; Bhattacharyya *et al*., 1993). The datasets in Dighori soils, therefore, supports the earlier connotation that in the weathering environment of humid tropical climate with plenty of Al in the soil, interstratification of smectite should be an important ephemeral stage during the transformation of smectite to kaolinite. In the lower topography at around 250 m elevation, Dighori soils continue to exist in its present form showing well-developed slickensides (53-166 m depth) and deep (27 m at the time of profile examination) and wide (~2 m) cracks (Fig. 7e).

Formation of paddy-growing soils in Rajegaon, Gondia

Pedon2, (P_2) is situated in Rajegaon village of Gondia district, Maharashtra and is formed in the basaltic alluvium (Fig. 8a). The pedon site is almost flat and slopes towards the north-west of P_2 (Fig. 8b). The distribution of total clay indicates a general trend of clay increase beyond 20 cm depth is observed in this pedon (Fig. 8c). The distribution of smectite and Sm/K minerals in total clay showed an increase of smectite and corresponding decrease of Sm/K with depth (Fig. 8d), indicating a probable transformation of smectite to Sm/K as observed in pedon 1. At an average elevation of 300 m on relatively low and flat landscape, the Rajegaon soils continue to exist showing wide cracks, pressure faces (Table 1) and associated vertic

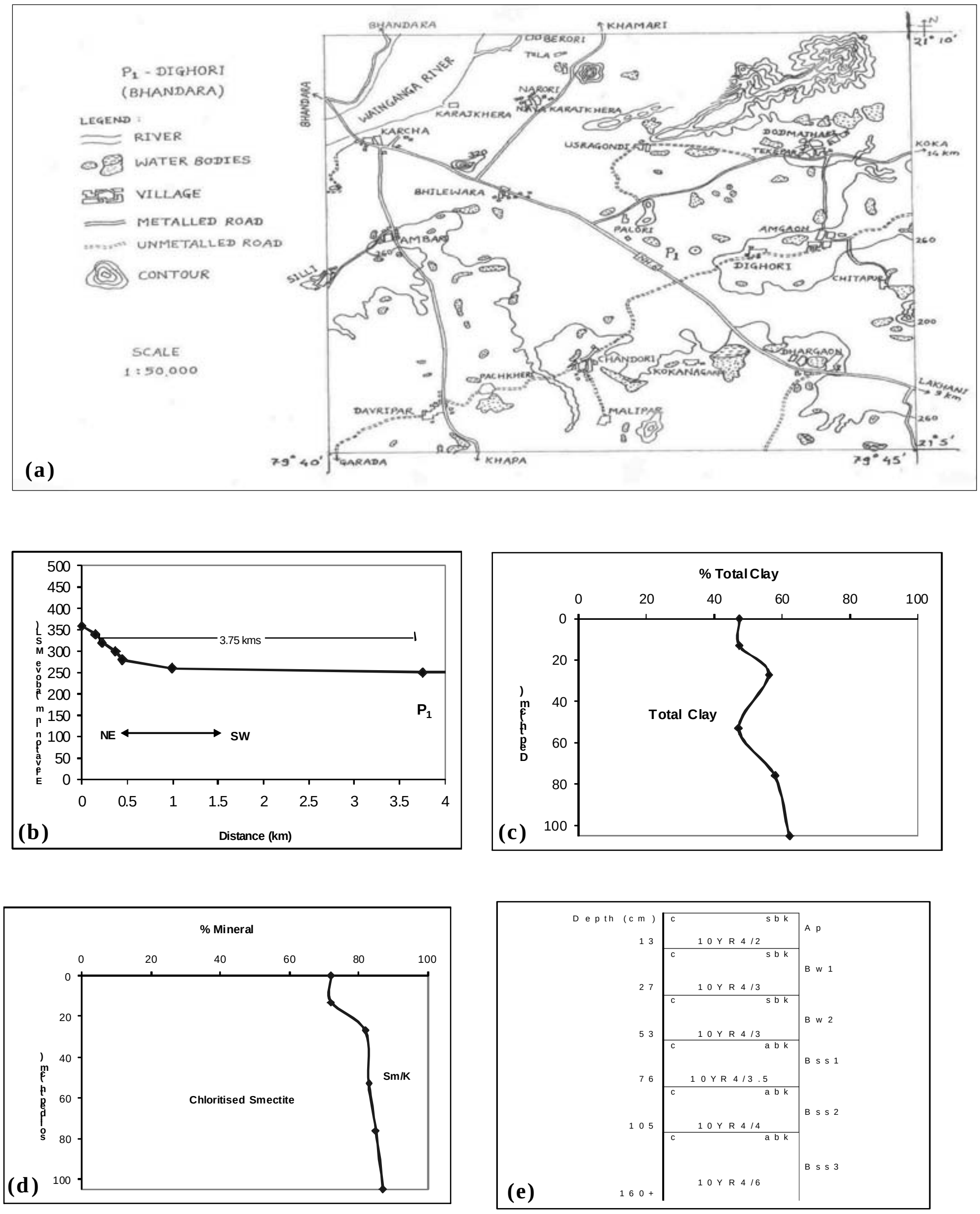

Fig. 7. Formation of paddy soils in Dighori (Bhandara) (a) site map, (b) elevation, (c) clay distribution, (d) clay mineral distribution, (e) profile description.

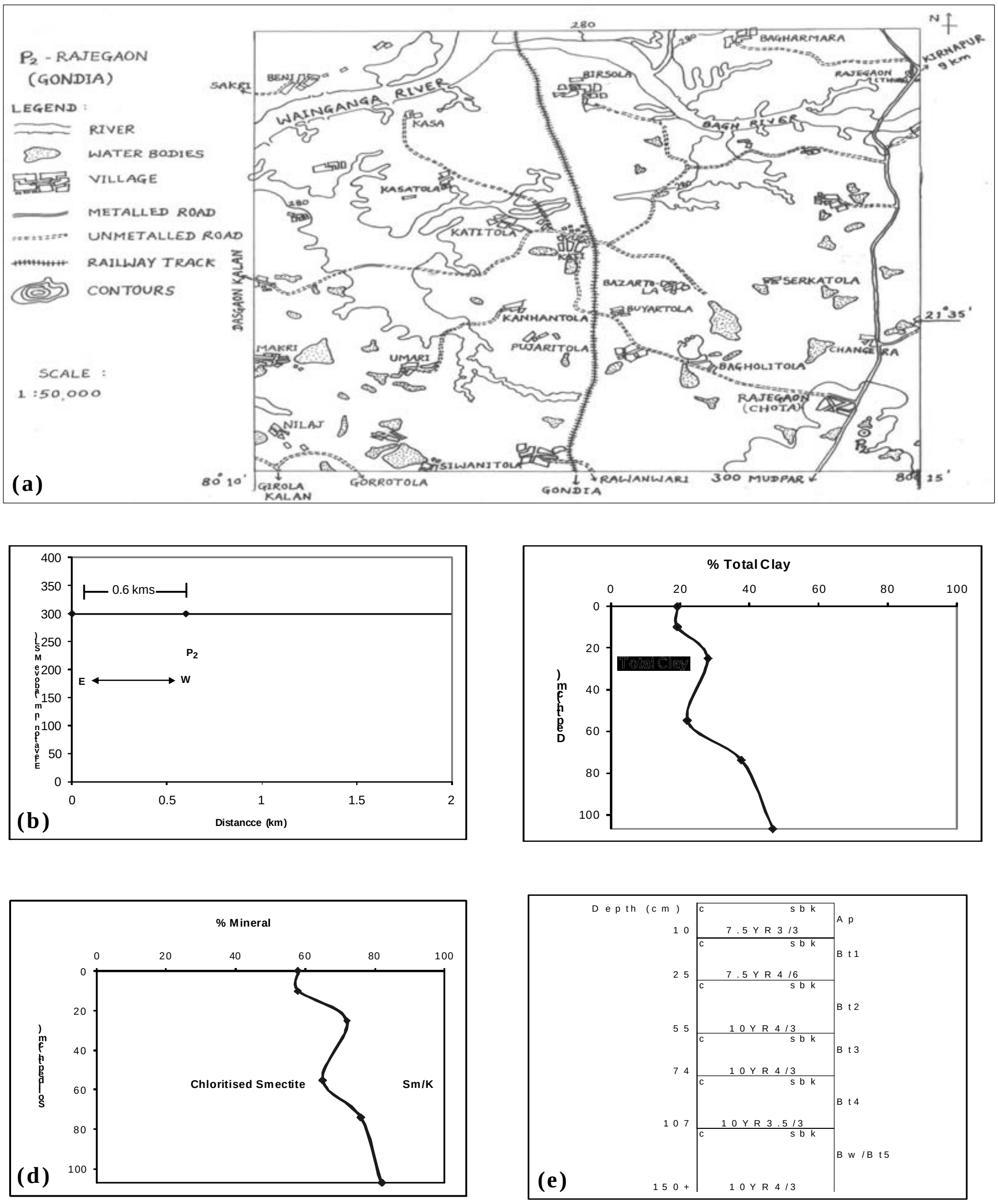

Fig. 8. Formation of paddy soils in Rajegaon (Gondia) (a) site map, (b) elevation, (c) clay distribution, (d) clay mineral distribution, (e) profile description.

characteristics (COLE, Table 2) with Bt horizons (Fig. 8e).

Formation of paddy-growing soils in Haldi, Chandrapur

Pedon3, (P_3) is situated in Haldi village of Chandrapur district, Maharashtra and is formed in the basaltic alluvium (Fig. 9a). The pedon is situated in the site gradually sloping towards south with highest elevation towards north of P_3 (Fig. 9b). The distribution of total clay indicates a clay increase between 60-100 cm of depth (Fig. 9c). The distribution of smectite and Sm/K minerals in total clay showed an increase of smectite and corresponding decrease of Sm/K with depth (Fig. 9d), indicating a probable transformation of smectite to Sm/K. At less than 200 m elevation these Vertisols showing clay illuviation and slickensides (82-135 m depth) continue to exist in the present day climate (Fig. 9e).

Formation of paddy-growing soils in Kurul, Gadchiroli

Pedon4, (P_4) is situated in Kurul village of Gadchiroli district, Maharashtra and is formed in the basaltic alluvium (Fig. 10a). The pedon site is relatively flat with highest elevation towards the south-east of P_4 (Fig. 10b). The distribution of total clay indicates a clay decrease with depth (Fig. 10c). The distribution of smectite and Sm/K in total clay showed an increase of smectite and corresponding decrease of Sm/K with depth (Fig. 10d), indicating a probable transformation of smectite to Sm/K. At nearly 150 m elevation Kurul soils continue to exist in the low lying areas showing well developed slickensides (76-150 cm depth) (Fig. 10e).

Constancy principle vis-à-vis parental legacy of soil and minerals

While searching the parental legacy in soils of Meghalaya plateau in the north-eastern India, it was found that the proportions of kaolin and gibbsite were inversely related in the soil profile. The content of these minerals showed that sum of these minerals within the solum maintains constancy (Bhattacharyya *et al.*, 2000). Although such relation suggests the formation of gibbsite at the expense of kaolin but it was not true due to a few reasons. One of the reasons, reported by Bhattacharyya *et al.* (2000) was that kaolin is still in an intermediate stage as kaolin/hydroxy-interlayered vermiculite (Kl/HIV) which is yet to be fully transformed as kaolin in these soils. Similar relation between minerals was earlier shown in red soils of Mysore plateau (Bhattacharyya and Ghosh, 1990) and the red soils of Hyderabad (Pal *et al.*, 1999). Earlier Murali *et al.* (1978) suggested a possibility of smectite formation from kaolin through constancy relation of these two minerals which may not be true since it is not energetically feasible so far as formation of 2:1 minerals from 1:1 minerals is concerned.

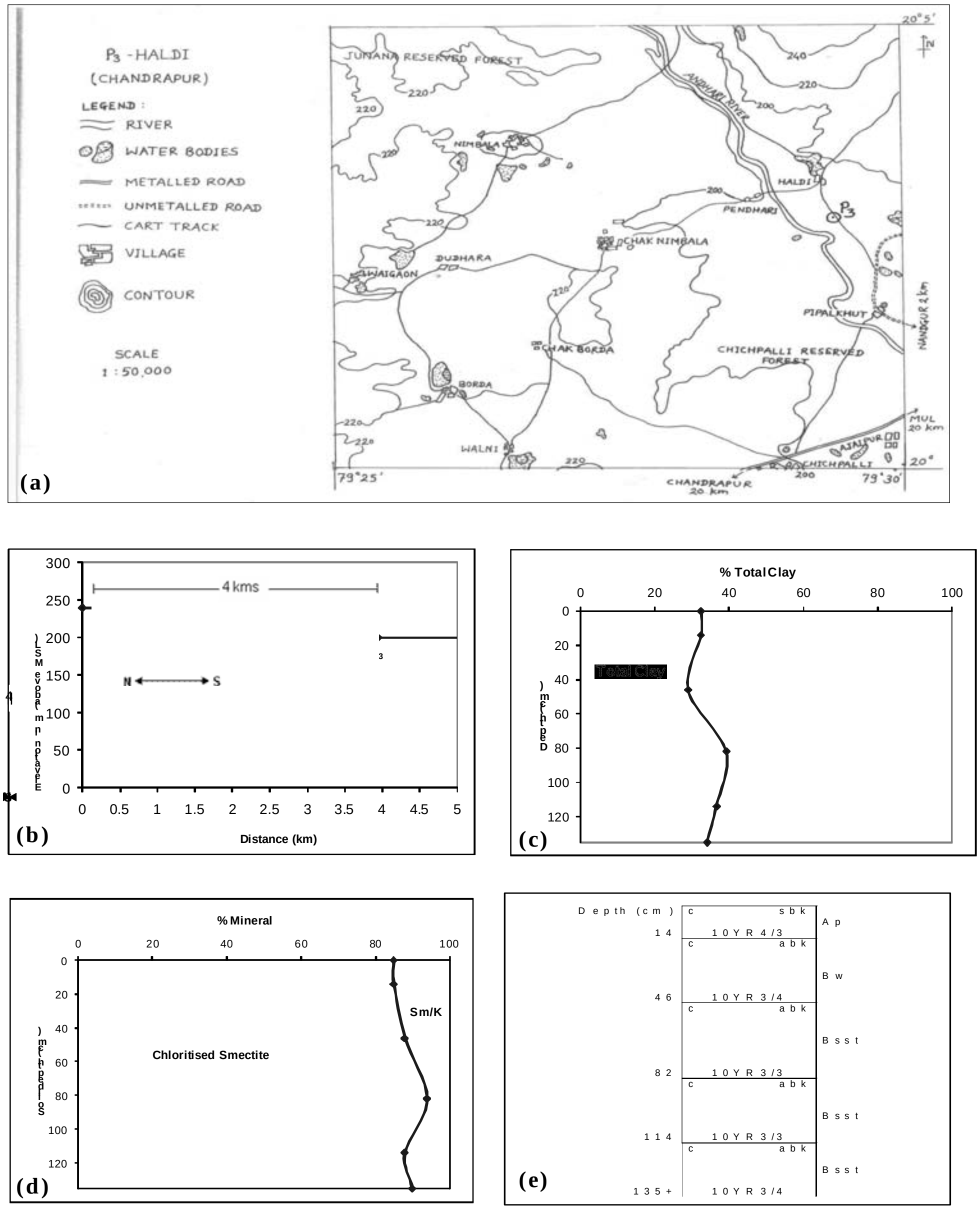

Fig. 9. Formation of paddy soils in Haldi (Chandrapur) (a) site map, (b) elevation, (c) clay distribution, (d) clay mineral distribution, (e) profile description.

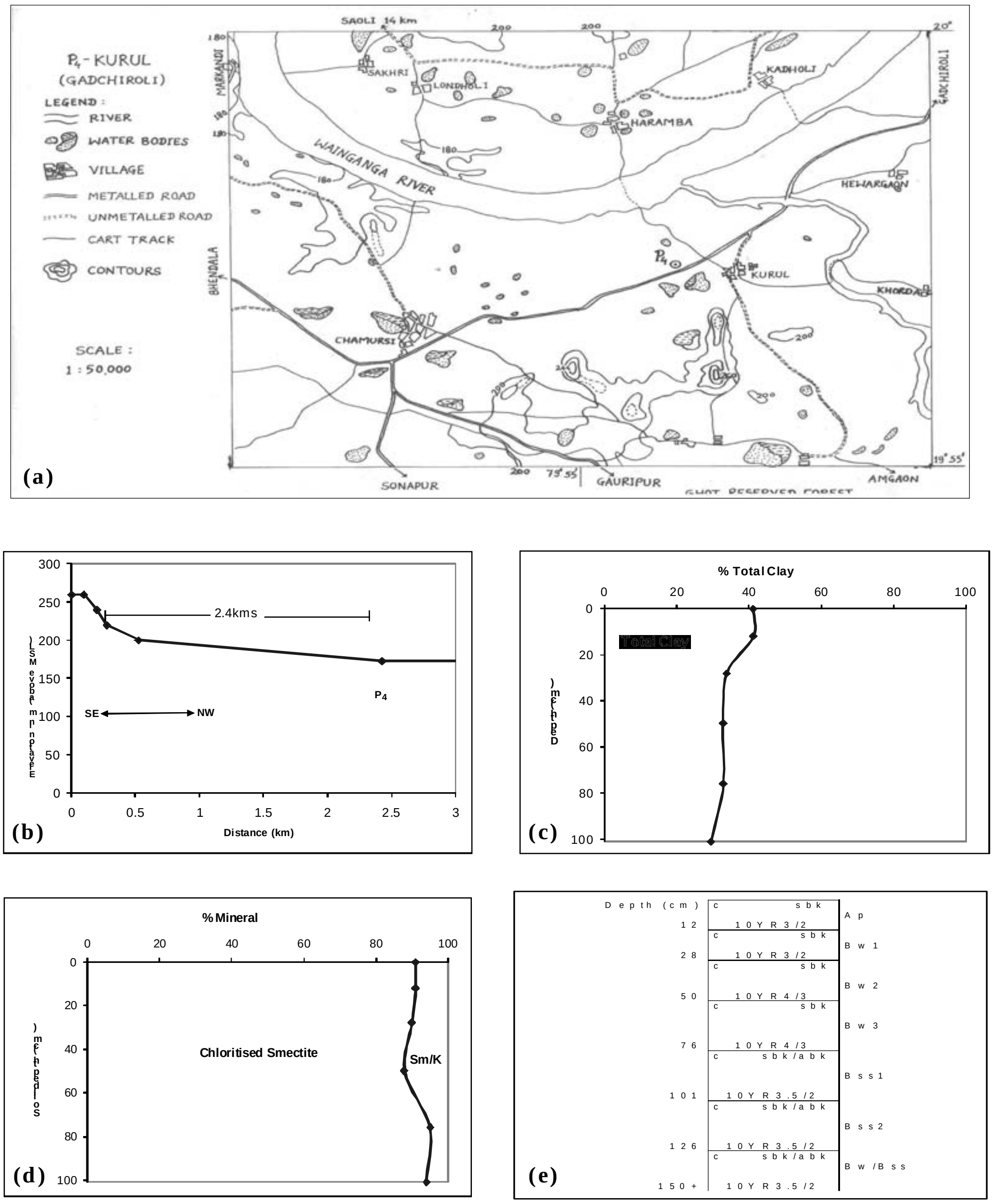

Fig. 10. Formation of paddy soils in Kurul (Gadchiroli) (a) site map, (b) elevation, (c) clay distribution, (d) clay mineral distribution, (e) profile description.

Distribution of clay-size smectite and kaolinite with depth in representative ferruginous soils of southern India (Pal and Deshpande, 1987b) indicated a possible transformation of smectite to kaolinite. While explaining the formation of black soils on the elevated plateau of Western Ghats, Maharashtra, a parental legacy of smectite and Sm/K interstratified minerals was established through a constancy relationship of these two minerals down the depth. It was stated that smectite was the first weathering product of plagioclase feldspars in an earlier humid climate and the formation of Sm/K interstratifications is a post-depositional episode. This is also true for the four paddy growing soils reported here (Figs. 7d, 8d, 9d, 10d).

The four paddy soils in the Deccan plateau in the eastern part of Maharashtra (Vidarbha) resemble mineral make-up so far as mineralogy of black soils of the Western Ghat (Maharashtra) is concerned. The only difference is that the soils (Pokhri soil series, Bhattacharyya *et al.*, 1993) in the Western Ghats were non-calcareous and the paddy soils under investigation are calcareous. The formation of calcium carbonates in these soils is again a post depositional phenomenon which is a signature of climate change from humid to sub-humid dry climate (Pal *et al.*, 2000; Srivastava *et al.*, 2002; Pal *et al.*, 2009). Earlier Pal et.al, (2000) described the process of secondary calcium carbonate formation in semi-arid tropics in the following way:-

$$Ca^{2+} + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 \xrightarrow{-H_2O} CaCO_3 \downarrow$$

The similarity in mineralogical make-up between Pokhri soils and four paddy growing soils suggest a similar geological age (Holocene). The formation of pedogenic carbonates (Pal *et al.* 2000) brings a concommitant development of soil sodicity due to increase in exchangeable sodium percentage (ESP) which is further augmented by more exchangeable magnesium percentage (EMP) (Table 3).

Conclusion

The paddy soils of the eastern Vidarbha are formed in the lower topography (microdepression) within a range of 150-300 m elevation following the landscape reduction process. These soils are dominated by shrink-swell minerals like smectite and smectite-kaolin. Ideally smectite and its interstratified minerals dominate soils when the pedo-environment is poorly drained. The lower topographical positions as evidenced by the mottles developed due to reduced moisture regime (Table 1) and also low hydraulic conductivity especially for P2, P3 and P4 in the lower horizons (Table 3) help smectites to survive the present day climate. Smectite minerals, the first weathering product of basalt in the humid tropical climate, are weathered to smectite-kaolin interstratifications. These soils formed in the lower topography are supporting paddy crop due to (i) poor drainage, and (ii) characterstic smectite minerals which are complimentary to soil drainage. Although these soils are supporting present day agriculture, the formation of calcium carbonate indicates an initiation of chemical degradation of soils.

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