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Genesis of Associated Red and Black Shrink-swell Soils of Maharashtra

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Abstract : *Two associated shrink - swell soils (red and gray coloured) occurring in a catena in the Hingoli district of Maharashtra were taken for this study. Detailed study of the morphological, physical and chemical properties indicated that both the soils have Vertisol characteristics. The low hydraulic conductivity of red Vertisols is due to high Mg^{2+} and Na^{+} in the exchange complex. Mineralogical properties indicate that smectite is the dominant mineral in both the soils. The presence of kaolin in the gray Vertisols indicate that the transformation of smectite to kaolin in the past humid climate. The absence of kaolin in red Vertisol indicates that the parent material (red bole) was not exposed to the earlier humid climate. They have been formed from the red boles observed in the vicinity of the study area containing high amount of smectite along with palygorskite mineral. The presence of palygorskite mineral with smectite in red shrink-swell soils and its absence in other associated soils in a catena indicate that this mineral cannot be considered as an index mineral for arid climate. The release of Mg^{2+} from palygorskite mineral disperses the clay and clogs the pores resulting impeded drainage which adversely affected the crop production.*

Key words: Red shrink- swell soils, red boles, palygorskite mineral, soil management

Introduction

Shrink-swell soils (Vertisols and their intergrades) occupy an area of about 66 m ha in India (Bhattacharyya *et al*., 2009) and constitute about 35% of soils of Maharashtra. These soils are developed in the alluvium of weathering Deccan basalt that occur in central and Peninsular India. They are characterized by dark gray to black in colour (10 YR hue), high smectite-rich clay, neutral to alkaline in reaction, high cation exchange capacity with exchangeable position dominated by Ca^{2+}, Mg^{2+} and in sometimes by Na^{+}. The smectite clay mineral, in seasonally wet and dry climate are responsible for the swelling and shrinking that manifest many special characteristics of these soils (Borchardt, 1989).

There are many reports of the formation of red and black soil association in India (Gawande *et al.,* 1968; Murali *et al.,* 1978;

Pal and Deshpande 1987; Bhattacharyya *et al.*, 1993). In most cases it was reported that the red soils are formed on higher topographic position with clay-enriched argillic horizon and presence of kaolin (smectite-kaolinite interstratified mineral) developed from smectite under more leaching environment and their associated Vertisols are formed in valleys on lower topographic position wherein the drainage is comparatively slow (Pal and Deshpande 1987; Kantor and Schwertmann 1974; Beckmann *et al.*, 1974). However, the present study discusses a unique red and black soil association in Hingoli district of Maharashtra developed in the alluvium and colluvium of basalt which resulted in the formation of Vertisols.

There are some reports that sequences of basalt flows commonly include spectacular red interflow strata widely known as bole beds, which serve as the marker of beds in between two basaltic flows. Bole horizons are weathered horizon (Paleosols) usually recognized in the field by their distinctive red colour suggesting processes of chemical weathering similar to what is observed in case of pedogenesis from basalt (Ghosh *et al.*, 2006). In a few cases they are characterized by polygonal structures indicating shrinkage features developed after deposition (Sarkar *et al.*, 2000). It is referred to as red Vertisol in view of its only contrasting colour features which differentiates it from other colour of Vertisols in the vicinity. Hence the present study was undertaken to understand the genesis of these soils and those of the associated gray coloured Vertisols.

Materials and Methods

The study area is located along a transect in Kesapur village of Hingoli District of Maharashtra at 450 to 500 m above mean sea level (msl) in the semi-arid climate (<700 mm annual rainfall). Here two soils are described, one at the higher elevation of the transect, namely the red Vertisol (pedon 1) and the other is a commonly seen gray Vertisol in the valley floor (pedon 2). These soils are developed in the basaltic alluvium and occur in close proximity to each other (Fig. 1). The morphological properties of the soils were studied as per Soil Survey Manual (Soil Survey Division Staff, 1995) and the soils were classified according to Soil Taxonomy

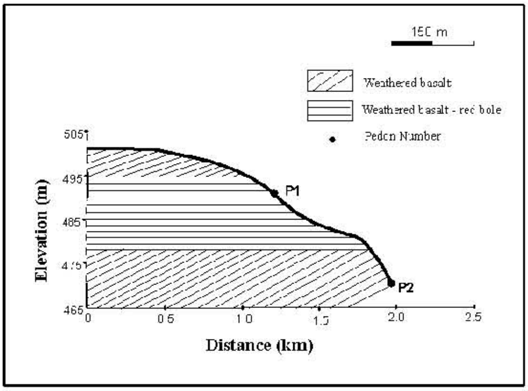

Fig. 1. *Schematic diagram showing the landscape representing the pedon sites in Hingoli district, Maharashtra (broken lines on Y axis indicate tentative thickness of basalt and red bole)*

(Soil Survey Staff, 2003). Horizon-wise samples were collected for laboratory analysis.

Physical and chemical properties of soils were determined as per standard procedures (Jackson, 1973). For mineralogical analysis, particle size fractions were separated as per size segregation procedure of Jackson (1979) after removal of $CaCO_3$, organic matter and free iron oxides. Silt and clay fractions were subjected to X-ray examination of the parallel oriented Ca/K saturated samples with a Philips diffractometer using a Ni-filtered Cu-Kα radiation and a scanning speed of 2°2θ per minute. Semi-quantitative estimation of the clay minerals was based on the principles outlined by Gjems (1967).

Results and Discussion

Morphological properties indicate that the red shrink-swell soils are very deep with dark reddish brown colour (2.5YR 3/4 to 2.5YR 3/6) throughout the depth. These soils have 4-5 cm wide cracks at the surface which extends up to 50 cm. The associated shrink-swell soils (pedon 2) have an Ap horizon with very dark gray (10YR 3/2) colour. The B horizon up to a depth of 81 cm is very dark gray to dark grayish brown in colour (10YR 3/1 – 10YR 3/2) and below that up to 115 cm, the colour is very dark grayish brown to dark olive brown (2.5Y 3.5/3) (Table 1).

Particle size distribution indicates both the soils are clayey (Table 2) with very less amount of sand. This is common in Vertisols developed in the Deccan basalt areas (Pal 1988; Bhattacharyya *et al*., 1993). Fine clay constitutes more than 50% of the total clay in almost all the horizons. The bulk density increased with depth in pedon 2, but no such trend was found in red Vertisols. The saturated hydraulic conductivity (sHC) in pedon 2 (black soils) varied from 1.85 to 3.85 cm h^{-1} and in red Vertisol it is very low (0.02 to 0.2 cm h^{-1}). Kadu *et al*., (2003) observed that low sHC in soil is associated with high sodium or magnesium in exchange complex that disperse the clay to clog the soil pores.

Soils of pedon 1 are strongly to very strongly alkaline (pH 8.5 to 9.4) whereas pedon 2 is moderately alkaline (pH 8.1 to 8.3). Red Vertisol (pedon 1) showed higher amount of carbonate (11.6 to16.6 percent) than pedon 2 (5.82 to 7.1 per cent) (Table 3). CEC varied from 55.6 to 65.2 cmol (p+)kg^{-1} in these soils. Among the extractable cations calcium is dominant in the exchange complex in pedon 2, followed by Mg, Na, and K (Table 4). However in pedon 1, Mg is dominant followed by Ca, Na, and K. Exchangeable sodium percent (ESP) in pedon 1 is high and varied from 16.4 to 37.6 cmol(p+) kg^{-1}, whereas it is low (1.1 to 1.2) in pedon 2. This indicates that exchangeable sodium in pedon 1 affects the moisture retention and release behaviour in soils and can be considered as sodic according to Soil Taxonomy (Soil Survey Staff, 2003). Pal *et al*., (2000) suggested

Table 1. *Morphological properties of soils.*

Horizon	Depth (cm)	Matrix colour (M)	Texture (1)	Coarse Fragments (%) (2)	Structure (3) (S)	(G)	(T)	Efferve-cence dil. HCl (4)	Other features (5)
Pedon 1: Fine, smectitic, hyperthermic Sodic Haplusterts									
Ap	0-14	2.5YR3/4	c	3-5 (fg)	m	2	sbk	es	-
Bw1	14-29	2.5YR3/4	c	1-2(fg)1-2(cg)	m	1	sbk	es	-
Bw2	29-49	2.5YR3/4	c	1-2(fg),1-2 (cg)	m	1	sbk	es	PF
Bw3	49-71	2.5YR3/4	sic	1-2(fg),2-3(cg)	m	1	sbk	es	PF
Bss1	71-103	2.5YR3/4	sic	2-3(cg),1-2(fg)	m	1	abk	es	SS
Bss2	103-155+	2.5YR3/6	sic	2-3(cg),1-2(fg)	m	1	abk	es	SS
Pedon 2: Very fine, smectitic, hyperthermic, Typic Haplusterts									
Ap	0-15	10YR3/2	c	2-3 (fg)	m	1	sbk	e	-
Bw1	15-31	10YR3/2	c	1-2(fg)	m	2	sbk	e	PF
Bss1	31-49	10YR3/2	c	2-3(fg)	m	2	sbk/abk	e	PF
Bss2	49-81	10YR3/1	c	2-3(fg)	m	3	abk	e	SS
BCk	81-115	2.5Y3.5/3	cl	50-60(fg +cg)	f	1	gr/sbk	e	-

Abbreviations are according to Soil Survey Manual (Soil Survey Division Staff, 1995)
1. Texture: c- clay; sic-silty clay; cl- clay loam
2. Coarse fragments:fg-fine gravel; cg-coarse gravel; st- stony, b-boulders
3. Structure: S = size; m = medium; G = grade; 2 = moderate; 3 – strong; T=Type, sbk =subangular blocky, abk =angular blocky
4. e= slightly effervescence, es= strongly effervescence.
5. PF=Pressurefaces, SS=Slickensides

that increase in exchangeable magnesium percent (EMP) and ESP is related with relative decrease in Ca^{2+} ions in soil solution due to precipitation of Ca^{2+} ions as calcium carbonate. High ESP and EMP are also be related with low sHC of the soils of pedon 1.

XRD patterns of the silt, total clay and fine clay fraction of pedon 1 (Red Vertisol) are almost similar. For brevity the XRD of total clay of one horizon (Bss1) is given as fig. 3. The samples on Ca-saturation shows dominant peak at 1.48 and 1.05 nm. On glycolation 1.4 nm shifted entirely to 1.6 nm indicating the presence of smectite in the sample (Fig.2). Persistence of 1.05 nm peak on glycolation and heating up to 110^{o}C indicate the presence of palygorskite mineral (though in small amount) in the sample. The expanding behaviour of 1.0 nm peak to 1.4 nm peak on glycolation after K-saturation and heating at 300^{o}C indicates that the expanding lattice mineral is a low charge smectite. Interestingly the 0.7 nm peak of kaolin was not observed in these soils as generally expected in the

Table 2. *Physical properties of shrink –swell soils*

	Depth (cm)	Particle-size analysis (%)				Bulk density (Mg m^{-3})	sHC (cm h^{-1})*	COLE**
		Sand (2.0-0.05) mm	Silt (0.05-0.002) mm	Clay (0.002-0.0002) mm	Fine clay (<0.0002) mm			
	Pedon 1: Fine, smectitic, hyperthermic, Sodic Haplusterts							
Ap	0-14	2.0	32.3	65.7	45.8	1.47	0.08	0.26
Bw1	14-29	2.5	33.3	64.2	33.7	1.30	0.03	0.26
Bw2	29-49	1.4	39.5	59.1	32.7	1.35	0.04	0.30
Bw3	49-71	1.3	47.3	51.0	25.0	1.26	0.02	0.31
Bss1	71-103	0.5	47.2	52.6	29.0	1.30	0.04	0.30
Bss2	103-150	0.2	53.0	46.9	21.5	1.41	0.22	0.30
	Pedon 2: Very fine, smectitic, hyperthermic Typic Haplusterts							
Ap	0-15	1.2	35.6	63.1	27.2	1.06	1.77	0.32
Bw	15-31	1.0	31.1	67.8	37.3	1.26	2.68	0.30
Bss1	31-49	0.9	31.6	67.5	36.1	1.26	3.85	0.31
Bss2	49-81	1.0	27.4	71.5	44.5	1.40	2.18	0.31
BCk	81-115	39.6	21.7	38.6	29.2	1.49	1.17	0.23

*sHC : Saturated hydraulic conductivity
**COLE: Coefficient of linear extensibility

Table 3. *Chemical properties of soils*

Horizon	Depth (cm)	pH (1:2) H_2O	EC (1:2) (dS m^{-1})	Org. C. (%)	$CaCO_3$ equivalent (%)
	Pedon 1: Fine, smectitic, hyperthermic Sodic Haplusterts				
Ap	0-14	9.08	0.44	0.25	12.0
Bw1	14-29	9.15	0.66	0.13	11.8
Bw2	29-49	9.44	0.78	0.13	14.4
Bw3	49-71	9.3	0.88	0.13	16.6
Bss1	71-103	9.03	1.22	0.05	15.9
Bss2	103-150	8.54	1.00	0.05	10.7
	Pedon 2: Very fine, smectitic, hyperthermic Typic Haplusterts				
Ap	0-15	8.12	0.23	0.97	6.4
Bw	15-31	8.2	0.23	0.79	6.7
Bss1	31-49	8.16	0.19	0.79	5.8
Bss2	49-81	8.23	0.22	0.77	6.9
BCk	81-115	8.2	0.25	0.13	7.1

Table 4. *Exchange properties of soils*

Horizon	Depth (cm)	CEC	Extractable bases				BS (%)	ESP (%)	EMP (%)	ECP (%)
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}				
			... cmol (p^{+}) kg^{-1} ...							
Pedon 1: Fine, smectitic, hyperthermic Sodic Haplusterts										
Ap	0-14	55.65	28.61	23.39	9.13	0.22	110.2	16.4	42.0	51.4
Bw1	14-29	55.65	23.9	24.21	14.78	0.18	113.3	26.5	43.5	43
Bw2	29-49	60.00	21.4	25.97	18.26	0.16	109.6	30.4	43.3	35.7
Bw3	49-71	62.60	19.4	29.52	23.48	0.17	115.9	37.5	47.2	31
Bss1	71-103	62.60	19.89	28.9	23.48	0.20	115.7	37.5	46.2	31.8
Bss2	103-150	64.34	24.15	28.6	23.48	0.25	118.8	36.5	44.4	37.5
Pedon 2: Very fine, smectitic, hyperthermic Typic Haplusterts										
Ap	0-15	62.60	50.72	5.73	0.73	0.70	92.4	1.2	9.2	78.8
Bw1	15-31	64.34	53.36	5.19	0.69	0.35	92.6	1.1	8.1	85.2
Bss1	31-49	64.34	53.94	5.14	0.68	0.30	93.3	1.1	8	79.5
Bss2	49-81	62.60	49.71	5.91	0.75	0.27	90.4	1.2	9.4	77.3
BCk	81-115	65.21	49.61	7.57	0.75	0.18	89.1	1.2	11.6	77.1

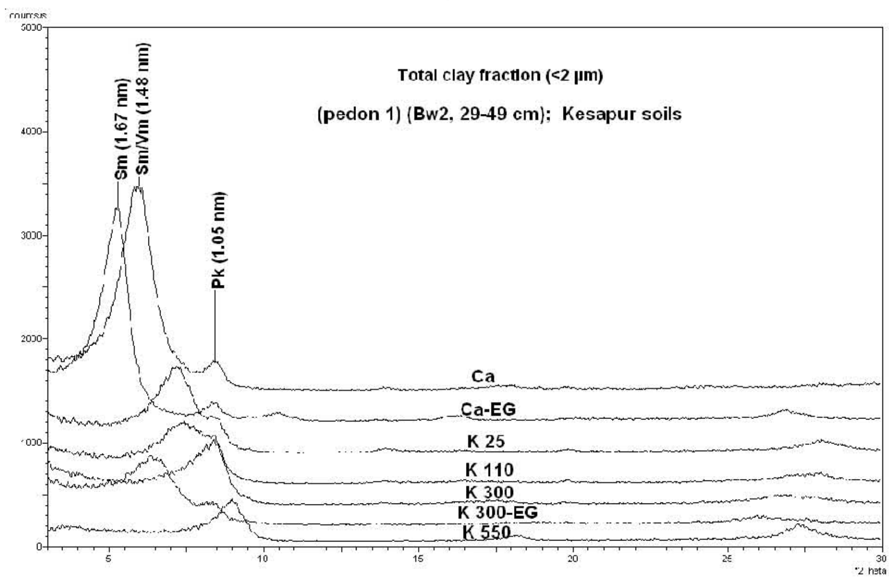

Fig. 2. *Representative X-ray diffractograms of total clay fractions of Pedon 1 (Sm=smectite, Sm/Vm=smectite or vermiculite, Pk=palygorskite, Ca = calcium saturated; CaEG = Ca-saturated and ethylene glycolated; K25°/K110°/K300°/K550° = K saturated and heated at 25, 110, 300 and 550°C. K300°EG= K saturated and heated at 300° and ethylene glycolated)*

associated ferruginous soils in a basaltic catena (Bhattacharyya *et al.*, 1993, Chandran *et al.*, 2000).

X-Ray diffraction patterns of the silt, total clay and fine clay of pedon 2 indicate that smectite is the dominant mineral in all the fractions and it was established by the basal reflection around 1.4 nm of Ca-saturated sample, which expanded to around 1.7 nm on glycolation (Fig. 3). The presence of kaolin was detected by the peak at 0.7 nm which persisted on K-treatment and heating at 300°C, but disappeared at 550°C.

Discussion

Genesis of soils

It has been established that the first weathering product of basalt under the humid tropical weathering is smectite (Pal and Deshpande, 1987). Under acid weathering conditions of the humid climate, the Al-hydroxy cations formed occupy the interlayer spaces of expanding minerals namely smectite (Pal *et al.*, 1989; Bhattacharyya *et al.*, 1999; Chandran *et al.*,

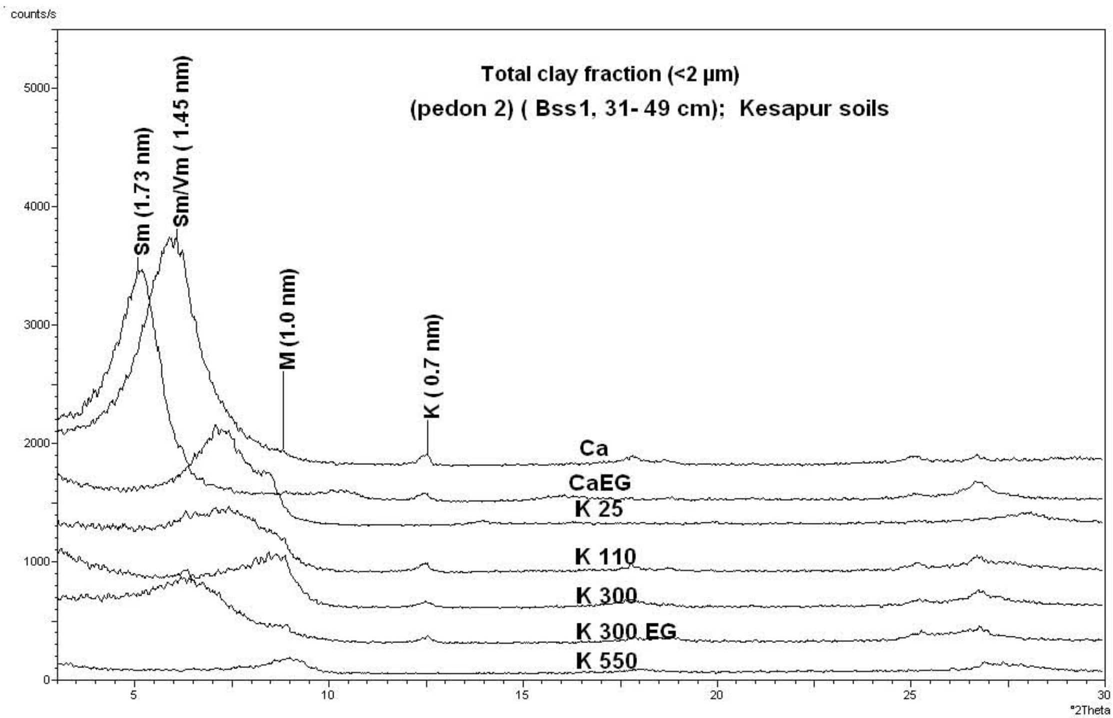

Fig.3. *Representative X-ray diffractograms of Total clay fractions of Pedon 2 (Sm=smectite, Sm/Vm=smectite or vermiculite, M= mica, K=kaolinite, Ca = calcium saturated; CaEG = Ca-saturated and ethylene glycolated; K25°/K110°/K300°/K550° = K saturated and heated at 25, 110, 300 and 550°C. K300°EG= K saturated and heated at 300° and ethylene glycolated)*

2000). The presence of large quantity of smectite and its transformation to kaolin in pedon 2 is possible only under humid climate which prevailed during the geological past. The deep weathering front of the humid climate due to erosion-deposition cycles of the past may have resulted in the formation of soils of the valley floor. This is confirmed by the small amounts of kaolin mineral present in the Vertisols of the valley (pedon 2).

Soils of the red Vertisols (pedon 1) are alkaline and the pH varies from 8.5 to 9.4 which is more than that of the other Vertisols studied in the landscape. These soils have more than 50% clay, and the sHC is very low. Mineralogy of different size fractions indicate the dominance of smectite in all size fractions followed by palygorskite in small amounts. The absence of kaolin in these soils indicates that the soils were not exposed to humid climate of the past. This indicates that the red shrink-swell soils are formed from the exposed bole beds observed in the vicinity of the study area containing high amount of smectite along with palygorskite mineral. Palygorskite has the highest magnesium content among the commonly formed naturally occurring clay minerals (Weaver and Pollard, 1973, Singer, 2002), and is the most strongly disaggregated mineral among phyllosilicates that appear in the soil clay fraction (Neaman *et al*., 1999). In pedon 1, the Ca/Mg ratio is less than 1 indicating the dominance of Mg^{2+} in the exchange complex. Exchangeable Mg^{2+} in soils can influence soil properties by creating alkaline conditions and along with Na^{+} ions cause dispersion of clays compared to calcium dominant soils which tend to flocculate (Rahman and Rowell, 1979, Pal *et al*., 2006). Magnesium is less efficient than calcium in flocculating soil colloids (Rengasamy *et a*l., 1986), and thus might have adversely affected the hydraulic properties of soils. Palaveyev and Penkov (1990) also reported negative effect of high exchangeable magnesium on physical condition of soils with strongly swelling and finely dispersed smectite. Neaman *et al*., (1999) indicated that palygorskite fibers did not associate into aggregates in soil suspension, even when saturated with Ca^{2+} ions. Palygorskite clay particles are thus likely to move downwards the soil profile preferentially over smectite and kaolinite which eventually clog the soil pores (Neaman and Singer, 2004). This results in the development of subsoil alkalinity due to the combined effect of these minerals. There would also be concomitant formation of $CaCO_3$ as in other high ESP soils. The results of the present study indicate that the adverse physical condition of Vertisols in terms of impairment of sHC is not only due to the formation of pedogenic carbonate and concomitant development of sodicity but also due to the presence of magnesium-bearing minerals called palygorskite. This is shown by higher value of EMP than ECP in pedon 1 (Table 4) due to release of Mg^{2+} ions from palygorskite.

The ferruginous (red) shrink-swell soils were developed in the bole beds (red boles) which had not been exposed to humid climate of the past. These soils also contain palygorskite minerals which are rich in Mg^{2+} ions. Consequently there is an increase in exchangeable Mg which causes dispersibility of clay particles forming a 3D mesh in the soil matrix. Such soils on irrigation show drainage problem, a predicament for crop production.

Conclusion

The ferruginous shrink-swell soils are developed from bole beds which were present in the side slopes of the catena and not exposed to humid climate of the past but have been developed in the present semi-arid climate. The presence of palygorskite along with smectite and its absence in other associated soils of the semi-arid climate indicate that this mineral is non-pedogenic and cannot be considered as an index mineral of arid climate. The palygorskite mineral releases Mg^{2+} ions, when irrigated, and the soil pores gets clogged by dispersion of clay. This results in impeded drainage which affects the crop production as experienced by the farmers. Thus basic research of this kind can diagnose the exact reason for poor crop performance due to mineral induced impeded drainage.

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