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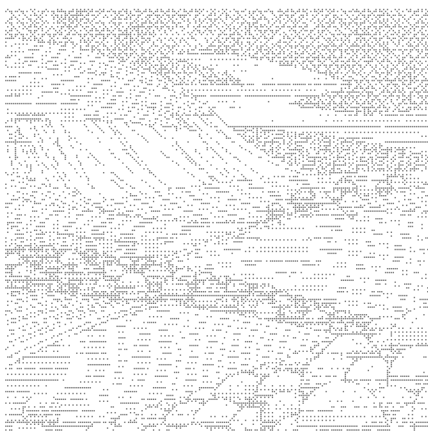

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Minimum threshold value of smectite for vertic properties

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Abstract

From a significant positive correlation between linear extensibility (LE) and the smectite content in the soil control section (SCS) of 8 soils (2 red soils, Alfisols, and 6 black soils, Vertisols, and their intergrades), the present study indicates an excellent compatibility between the marked shrink–swell characteristics and the smectitic mineralogy. The initiation of vertic properties at LE of 6 in shrink–swell soils corresponded to a minimum threshold value of 20% smectite. In order to highlight the inherent relationship between vertic properties and the swelling minerals, the mineralogy class for shrink–swell soils in US Soil Taxonomy should be only smectitic.

Additional keywords: Mineralogy class, taxonomic rationale.

Introduction

It is well documented that vertic properties of soils are primarily regulated by the nature of clay minerals, particularly their surface properties (Anon. 1975, 1998). Although soils containing all other clays shrink and swell with changes in moisture content, changes are particularly extreme in smectites (Borchardt 1989). Despite this, non-smectitic and mixed mineralogy classes are recognised in Vertisols and their intergrades at the family level in Soil Taxonomy (Anon. 1975, 1994, 1998). This basic contradiction has led soil scientists to express concern about mixed (Smith 1986) and kaolinitic mineralogy classes among shrink–swell soils (Eswaran *et al.* 1988). It was earlier proposed in Soil Taxonomy (Anon. 1975, 1994) that the montmorillonitic mineralogy class comprised soils with vertic properties when smectite content exceeds 50% of total mineral suite in clay fractions (<2 μm). In the revised version, Soil Taxonomy (Anon. 1998) proposed a qualitative smectitic mineralogy class for soils that have more smectite by weight than any other single kind of clay mineral. It thus indicates that there is a scope for a quantitative estimate of smectites for such soils.

From a comprehensive study on the correlation between vertic properties and type of clay minerals, it recently has been indicated (Bhattacharyya *et al.* 1997) that vertic properties of soils can only be a function of smectite content, even though its content is small, and cannot be induced by kaolinite, despite its presence in large amounts. This indicated a need to determine the minimum threshold value of smectite in the soil control section (SCS) for the manifestation of vertic properties in order to remove the existing ambiguity in the mixed mineralogy class. To work out a minimum threshold value of smectite in shrink–swell soils, qualitative and quantitative mineralogy of the clays of Vertisols and their intergrades spread in different climatic and geographical regions of India have been investigated in the present study.

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Table 1. Soil site characteristics of the pedons
MAT, mean annual temperature; MAR, mean annual rainfall; MSL, mean sea level

Geology	Parent material	Physiography	Ecological region	MAT (°C)	MAR (mm)	MSL (m)	Natural vegetation and land use
Pedon 1—Jambori series—Typic Hapludalf: Village, Jambori; Tahsil[A], Ambegaon; District, Pune; State, Maharashtra							
Deccan basalt	Basalt–alluvium	Plateau top	Tropical humid	25.5	>5000	1100	Neem (*Azadirachta indica*), mango (*Mangifera indica*) and millets
Pedon 2—Jambori series—Typic Hapludalf: Village, Jambori; Tahsil[A], Ambegaon; District, Pune; State, Maharashtra							
Deccan basalt	Basalt–alluvium	Plateau top	Tropical humid	25.5	>5000	1100	Neem (*Azadirachta indica*), mango (*Mangifera indica*), and millets
Pedon 3—Selu series—Vertic Ustochrept: Village, Tamasvada; Tahsil[A], Selu; District, Wardha; State, Maharashtra							
Deccan basalt	Basalt–alluvium/ colluvium	Narrow entrenched valley	Tropical subhumid	28.6	982	300	Babul (*Acacia arabica*), ber (*Ziziphus jujuba*), palas (*Butea frondosa*), sorghum, pigeonpea, wheat, gram, and linseed
Pedon 4—Pokhari series—Vertic Eutropept: Village, Pokhari; Tahsil[A], Ambegaon; District, Pune; State, Maharashtra							
Deccan basalt	Basalt–alluvium	Micro depression on plateau	Tropical humid	25.5	>5000	1000	Neem (*Azadirachta indica*), mango (*Mangifera indica*), paddy, wheat, and millets
Pedon 5–Sholmarigaon series–Vertic Ustochrept: Village, Sholmarigaon; District, Morigaon; State, Assam							
Alluvium	Brahmaputra alluvium	Flood plain	Tropical humid	24.9	1860	60	Sissoo (*Dalbergia sissoo*), bamboo (*Dendrocalamas* spp), grasses, and paddy
Pedon 6–Katur series–Vertic Haplustalf: Village, Vilayatkalan; District, Katni; State, Madhya Pradesh							
Sandstone	Alluvium	Plain land	Tropical subhumid	25.0	1250	500	Palas (*Butea frondosa*), paddy, and millets
Pedon 7—Aroli series—Typic Haplustert: Village, Aroli; Tahsil[A], Ramtek; District, Nagpur; State, Maharashtra							
Deccan basalt	Basalt–alluvium	Piedmont plain	Tropical subhumid	26.9	1127	340	Grasses and shrubs
Pedon 8—Sarol series—Typic Haplustert: Village, Binjalai; Tahsil[A], Indore; District, Indore; State, Madhya Pradesh							
Deccan basalt	Basalt–alluvium	Piedmont plain	Tropical subhumid	24.4	1050	560	Babul (*Acacia arabica*), ber (*Ziziphus jujuba*), palas (*Butea frondosa*), sorghum, pigeonpea, wheat, gram, and linseed

[A]Tahsil is equivalent to subdivision of a district.

Materials and methods

Soils

Eight soils representative of Vertisols and vertic intergrades of Inceptisols and Alfisols of India were selected and examined following the standard method (Anon. 1951). These soils occur extensively in the States of Maharashtra (Pedons 1, 2, 3, 4, and 7), Madhya Pradesh (Pedons 6 and 8), and Assam (Pedon 5). Pedons 1 and 3 are Alfisols, Pedons 7 and 8 are Vertisols, and Pedons 3, 4, and 5 are Inceptisols (Table 1).

Pedons 1 and 2 are red soils with acidic reaction. Similar soils have been grouped under the kaolinitic mineralogy class (Anon. 1975) according to their clay cation exchange capacity (CEC), even though the clay is dominated by chloritised smectite–kaolin interstratified mineral (Bhattacharyya *et al.* 1993, 1997). These soils are spatially distributed in the landscape in association with Vertisols and/or vertic intergrades of Inceptisols. Besides, these red soils do not manifest vertic properties in spite of containing little smectite and can, therefore, be used as reference soils to decide the boundary conditions between vertic and non-vertic characteristics.

Pedon 1 (red soil) consists of a 9-cm-thick Ap horizon reddish brown in colour (5YR4/4) with moderate, medium, and subangular blocky structures. The Bt horizon is 98 cm thick, dark reddish brown (5YR3/3), with weak-to-strong medium subangular blocky structures. These soils are clayey and non-calcareous showing clay cutans throughout the Bt horizon.

Pedon 2 (red soil) has an Ap horizon about 14 cm in thickness and a Bt horizon about 132 cm thick. Both the horizons are dark reddish brown (2.5YR3/4), with moderate medium and subangular blocky structure. The soil has clay cutans in the Bt1 horizon from a depth of 14 cm onwards. Texturally, the soils are clayey and noncalcareous.

Pedon 3 (black soil) consists of the Ap horizon (19 cm thick), Bw horizon (46 cm thick), and Bk horizon (25 cm thick). These soils are clayey and dark greyish brown (10YR3/2) with moderate, medium subangular blocky structures showing pressure faces in the Bw2 and Bk horizons. Surface cracks (>5 mm) do not extend beyond the Ap horizon. These soils are moderately alkaline and calcareous throughout the solum depth.

The Ap horizon of Pedon 4 (black soil) is 16 cm thick with a dark brown colour (10YR3/3), and moderate, medium subangular blocky structures. The Bw horizon is about 246 cm thick and is characteristically dark greyish brown to very dark greyish brown (10YR3/2–10YR3/3). These soils have typical subangular and angular blocky structures of black soils showing pressure faces; they are slightly acidic and noncalcareous throughout the solum.

Pedon 5 (black soil) has a 20-cm-thick Ap horizon which is very dark greyish brown (10YR3/2) in the Ap1 horizon and very dark grey (10YR3/1) in the Ap2 horizon with moderate, medium subangular blocky structure to coarse, strong angular blocky structure. The B horizon is 153 cm thick and is dark grey (10YR4/1) in the Bwg1 and Bwg2 horizons, dark yellowish brown (10YR4/4) in the Bw horizon, and grey (10YR6/1) in the Bwg horizon with moderate, medium subangular blocky structure. Texturally, the Bwg1 horizon is clayey, the Bwg2 and Bw horizons are silty clay, and the Bwg horizon is silty clay loam. The soils are almost neutral in reaction and non-calcareous throughout the solum.

Pedon 6 (black soil) has a 15-cm-thick Ap horizon which is dark brown (10YR4/3), with moderate, medium subangular blocky structure and loamy texture. The Bt horizon is 135 cm thick, dark brown (10YR3/3), with moderate, very coarse columnar structures that break into moderate, medium, subangular blocky structures, and broken and thin clay cutans. These soils are clayey, neutral in reaction, and non-calcareous throughout the solum.

Pedon 7 (black soil) has a 16-cm-thick Ap horizon which is very dark greyish brown (10YR3/2), with moderate, medium subangular blocky structures and clayey texture. The AB horizon is 29 cm thick with moderate, coarse prismatic-to-coarse subangular blocky structures. The B horizon is 129 cm thick, of which the first 93 cm is represented by the Bss horizon. The slickensides present in the Bss horizons are sufficiently close to intersect, and are characterised by strong, coarse angular blocky structures. The lower part of the B horizon does not show the development of slickensides. The Bss horizon is 93 cm thick with dark to very dark greyish brown colour (10YR4/2–10YR3/2). This horizon is very dark greyish brown (10YR3/2), with medium-to-strong, coarse-to-medium, subangular-to-angular blocky structures. The soils are clayey, slightly to moderately alkaline, and calcareous.

Pedon 8 (black soil) consists of the Ap horizon (20 cm thick), B horizon (Bw, 30 cm thick; Bss, 130 cm thick), and BC horizon (20 cm thick). Both the Ap and B horizons are very dark greyish brown (2.5Y3/2), with moderate, medium subangular blocky structures; shiny pressure faces are present in the B2 horizon. The Bss horizon is characterised by intersecting slickensides which break into strong, coarse

Table 2. Physical and mineralogical properties of soils

TC, total clay (<2 mm); FC, fine clay (<0.2 mm); COLE, coefficient of linear extensibility (values in parentheses are LE); EC, electrical conductivity; CEC, cation exchange capacity; control, control section

Soil	Depth (cm)	Horizon	Munsell colour[A]	TC (g/kg)	FC (g/kg)	FC/TC	COLE	pH[B]	EC[C] (dS/m)	$CaCO_3$ (g/kg)	Clay CEC[D]	Smectite[E] (g/100g)
Pedon 1	0–9	Ap	5YR4/4	558	330	0.59	0.04 (4.0)	5.7	0.15	—	15	13
Typic	9–31	Bt1	5YR3/3	564	358	0.63	0.04 (4.0)	5.3	0.12	—	17	15
Hapludalf	31–60	Bt2	5YR3/3	502	371	0.74	0.05 (5.0)	5.3	0.10	—	21	16
	60–107	Bt3	2.5YR3/4	666	452	0.68	0.06 (6.0)	5.6	0.09	—	23	21
	107–155	C	5YR4/4	692	318	0.46	0.08 (8.0)	5.6	0.08	—	21	22
	Control						0.057 (5.7)				21	19
Pedon 2	0–14	Ap	2.5YR3/4	630	430	0.68	0.04 (4.0)	4.7	0.12	—	25	12
Typic	14–60	Bt1	2.5YR3/4	650	408	0.63	0.05 (5.0)	4.5	0.11	—	26	16
Hapludalf	60–97	Bt2	2.5YR3/4	730	474	0.65	0.04 (4.0)	4.7	0.10	—	23	14
	97–151+	Bt3	2.5YR3/4	650	426	0.65	0.05 (5.0)	5.4	0.08	—	24	16
	Control						0.045 (4.5)				24	15
Pedon 3	0–19	Ap	10YR3/2	672	377	0.56	0.18 (18.0)	8.4	1.16	124	94	65
Vertic	19–39	Bw1	10YR3/2	659	366	0.56	0.18 (18.0)	8.4	0.15	133	95	66
Ustochrept	39–65	Bw2	10YR3/2	722	476	0.67	0.19 (19.0)	8.4	0.17	154	92	70
	65–90	BK	10YR 3/2	711	523	0.74	0.20 (20.0)	8.4	0.16	187	90	72
	Control						0.191 (19.1)				92	70
Pedon 4	0–16	Ap	10YR3/3	608	330	0.54	0.06 (6.0)	6.6	0.21	—	50	20
Vertic	16–40	Bw1	10YR3/3	599	481	0.80	0.06 (6.0)	6.4	0.14	—	48	22
Eutropept	40–79	Bw2	10YR3/3	593	445	0.75	0.07 (7.0)	6.8	0.10	—	49	27
	79–123	Bw3	10YR 3/2	658	461	0.70	0.07 (7.0)	6.7	0.16	—	46	27
	123–165	Bw4	10YR 3/2	612	425	0.69	0.08 (8.0)	6.5	0.11	—	64	28
	165–190	Bw5	10YR 3/3	623	429	0.69	0.06 (6.0)	6.5	0.08	—	56	20
	190–215	Bw6	10YR 3/3	640	437	0.68	0.07 (7.0)	6.5	0.07	—	56	27
	215–240	Bw7	10YR 3/3	612	403	0.66	0.07 (7.0)	6.5	0.07	—	55	27
	240–265+	Bw8	10YR3/2	603	412	0.68	0.08 (8.0)	6.4	0.07	—	58	28
	Control						0.068 (6.8)				48	26

(Continued)

Table 2. (Continued)

Soil	Depth (cm)	Horizon	Munsell colour[A]	TC (g/kg)	FC (g/kg)	FC/TC	COLE	pH[B]	EC[C] (dS/m)	$CaCO_3$ (g/kg)	Clay CEC[D]	Smectite[E] (g/100g)
Pedon 5	0–10	Ap1	10YR3/2	335	132	0.39	0.09 (9.0)	5.2	0.10	—	64	25
Vertic	10–20	Ap2	10YR3/1	531	261	0.49	0.08 (8.0)	6.4	0.05	—	44	28
Ustochrept	20–47	Bwg1	10YR4/1	549	247	0.45	0.08 (8.0)	7.0	0.03	—	41	29
	47–98	Bwg2	10YR4/1	470	225	0.48	0.07 (7.0)	6.9	0.02	—	45	27
	98–123	Bw	10YR4/4	489	315	0.64	0.10 (10.0)	6.8	0.06	—	56	35
	123–173	Bwg	10YR6/1	366	154	0.42	0.09 (9.0)	6.5	0.01	—	49	35
	Control						0.074 (7.4)				44	28
Pedon 6	0–15	Ap	10YR4/3	201	119	0.59	0.03 (3.0)	6.9	0.12	—	60	11
Vertic	15–41	Bt1	10YR3/3	350	253	0.72	0.09 (9.0)	7.0	0.08	—	57	30
Haplustalf	41–67	Bt2	10YR 3/3	412	287	0.70	0.11 (11.0)	6.9	0.08	—	53	35
	67–100	Bt3	10YR3/3	504	378	0.75	0.12 (12.0)	7.1	0.07	—	47	35
	100–123	Bt4	10YR3/3	457	367	0.80	0.13 (13.0)	7.2	0.08	—	59	36
	123–150	Bt5	10YR3/3	479	372	0.78	0.13 (13.0)	7.3	0.08	—	56	36
	Control						0.11 (11.0)				51	34
Pedon 7	0–16	Ap	10YR3/2	560	358	0.63	0.12 (12.0)	8.2	0.20	52	85	50
Typic	16–45	AB	10YR3/2	542	366	0.67	0.16 (16.0)	8.3	0.19	72	92	58
Haplustert	45–71	Bss1	10YR4/2	565	408	0.72	0.15 (15.0)	8.5	0.33	65	84	55
	71–102	Bss2	10YR3/2	623	415	0.67	0.14 (14.0)	8.6	0.38	78	80	50
	102–138	Bss3	10YR3/2	579	412	0.71	0.14 (14.0)	8.6	0.36	103	81	50
	138–157	Bw1	10YR3/2	576	408	0.71	0.15 (15.0)	8.6	0.28	112	84	55
	157–174	Bw2	10YR3/2	511	274	0.53	0.15 (15.0)	8.7	0.18	168	85	55
	Control						0.148 (14.8)				85	54
Pedon 8	0–20	Ap	2.5Y3/2	649	409	0.63	0.15 (15.0)	8.0	0.13	44	86	52
Typic	20–51	Bs	2.5Y3/2	650	420	0.65	0.14 (14.0)	8.1	0.13	43	92	50
Haplustert	51–100	Bss1	2.5Y3.5/2	643	429	0.67	0.17 (17.0)	8.1	0.17	40	91	62
	100–153	Bss2	2.5Y 3.5/2	631	394	0.62	0.18 (18.0)	8.2	0.20	37	89	66
	153–181	Bss3	2.5Y3.5/2	641	388	0.61	0.18 (18.0)	8.2	0.45	38	90	66
	181–200	BC	2.5Y3.5/2	607	379	0.62	0.20 (20.0)	8.3	0.51	40	92	75
	Control						0.159 (15.9)				91	58

[A] Moist. [B] 1 : 2 water. [C] 1 : 2. [D] cmol(+)/kg. [E] In <2-µm fraction.

angular blocky structures. The BC horizon is very dark greyish brown (2.5Y3.5/2) with strong, coarse angular blocky structures. These soils are clayey, slightly alkaline, and calcareous throughout the solum.

Analytical techniques

The international pipette method was applied for particle size analysis after the sand, silt, and clay fractions were separated according to the procedure of Jackson (1979). The coefficient of linear extensibility (COLE) was determined according to Schafer and Singer (1976). Linear extensibility (LE) was calculated from the COLE value using the formula (Anon. 1975):

$$LE = 100 \times COLE$$

The fine earth (<2 mm) was analysed for pH, calcium carbonate, and CEC (Richards 1954; Jackson 1973).

Oriented clay fractions (<2 μm) were subjected to X-ray diffraction (XRD) analysis using a Philips diffractometer and Ni-filtered Cu Kα radiation and also Fe-filtered Co Kα radiation (for Pedons 1 and 2) at a scanning speed of 2°2θ/min. Samples were saturated with Mg/Ca and K, solvated with ethylene glycol, and heated to 110°C, 300°C, and 550°C. Minerals present in the clay fractions of 8 soils were identified following the criteria of Jackson (1979). The presence of chloritised smectite–kaolin interstratified mineral (Sm/Ka) was identified by a slight shift and tailing of the 0.72 nm peak on glycolation, and gradual reinforcement and/or broadening at the base of the 1.0 nm peak, with a corresponding decrease in the 0.72 nm peak intensity on K saturation and subsequent heating (110–550°C) (Bhattacharyya *et al*. 1993, 1997). Semi-quantitative estimates of clay minerals were made by the method of Gjems (1967). Quantitative estimates of smectite in the clay fractions were performed according to the procedure of Alexiades and Jackson (1965). The values of LE, clay CEC, and smectite content are expressed on the basis of SCS, which is defined by a depth of 25 cm to (i) a lithic contact or paralithic contact if it is within a depth of 1 m; or (ii) a depth of 1 m if the regolith is >1 m thick (Anon. 1975).

Results and discussion

General properties of the soils

Soils with vertic properties had an electrical conductivity <1 dS/m, indicating their non-saline character. The soil reaction ranged from acidic to alkaline in both calcareous and non-calcareous groups of these 8 soil profiles (Table 2). All soils were clayey, with fine clay (<0.2 μm) dominating the clay fractions (Table 2). The LE values indicated that, despite the fine textures, these soils do not exhibit shrink–swell phenomena equally. With the exception of the red soils, other soils had LE >6, the limit set (Anon. 1998) for Vertisols and their intergrades.

Mineralogy of the soils

XRD examination of the silt fractions (50–2 μm) of the 8 soils indicated the presence of kaolin, mica, chlorite, and vermiculite. Smectite was not detected in these fractions (XRD patterns not shown).

XRD examination of the clay fractions (<2 μm) of red soils (Pedons 1 and 2) indicated that Sm/Ka was dominant in the clay, together with mica, with minor amounts of chloritised smectite, quartz, and feldspar (Fig. 1). Although these soils were dominated by Sm/Ka (>50%), the clay CEC data in the SCS [$\leq$24 cmol(+)/kg; Table 2] were indicative of the kaolinitic mineralogy class (Smith 1986) and subactive CEC activity class (Anon. 1998). Despite the presence of smectite as discrete mineral, and also as a component in Sm/Ka (Fig. 1), these soils did not manifest vertic properties (LE <6; Table 2).

Clay minerals of black soils developed on Deccan basalts (Pedons 3, 7, and 8) were composed primarily of smectite (>50%), with small amounts of kaolin, chlorite,

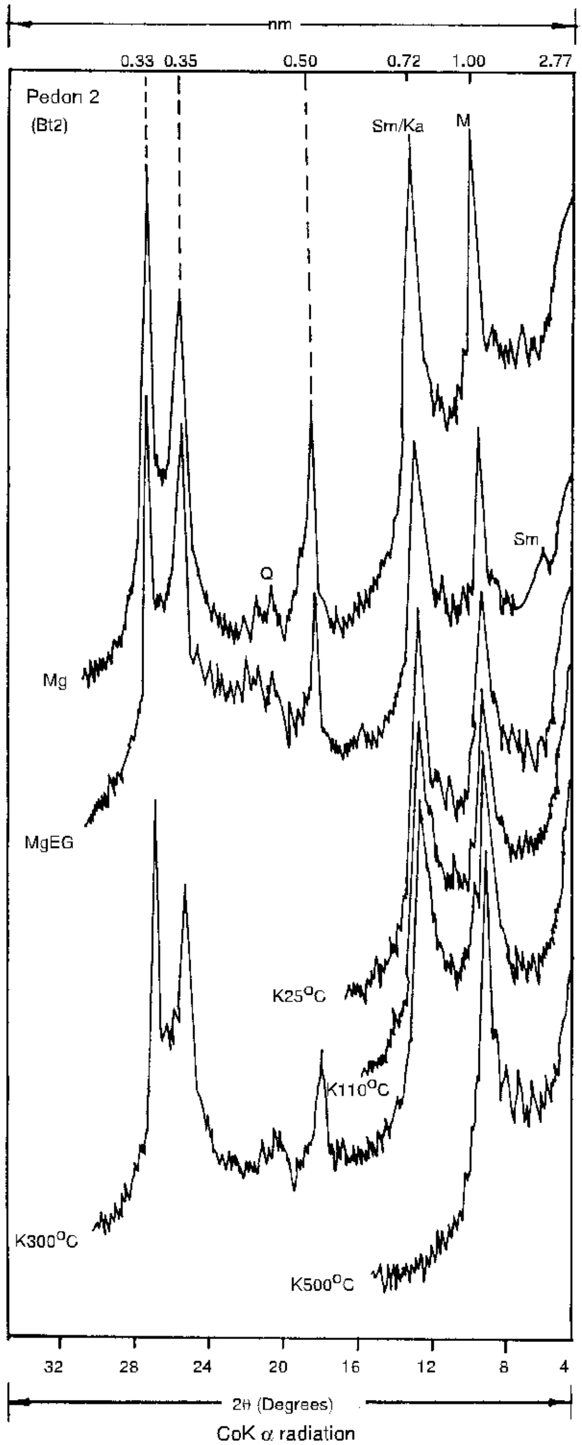

Fig. 1. XRD diagrams of the clay fraction (<2 μm) of the Bt2 horizon of Pedon 2, representative of those in Pedons 1 and 2 (Typic Hapludalfs). Mg, Mg-saturated; MgEG, Mg-saturated plus glycol vapour; K25/110/300/550°C, K-saturated and heated to 25°C, 110°C, 300°C, and 550°C; Sm, smectite; M, mica; Sm/Ka, smectite–kaolin; Q, quartz.

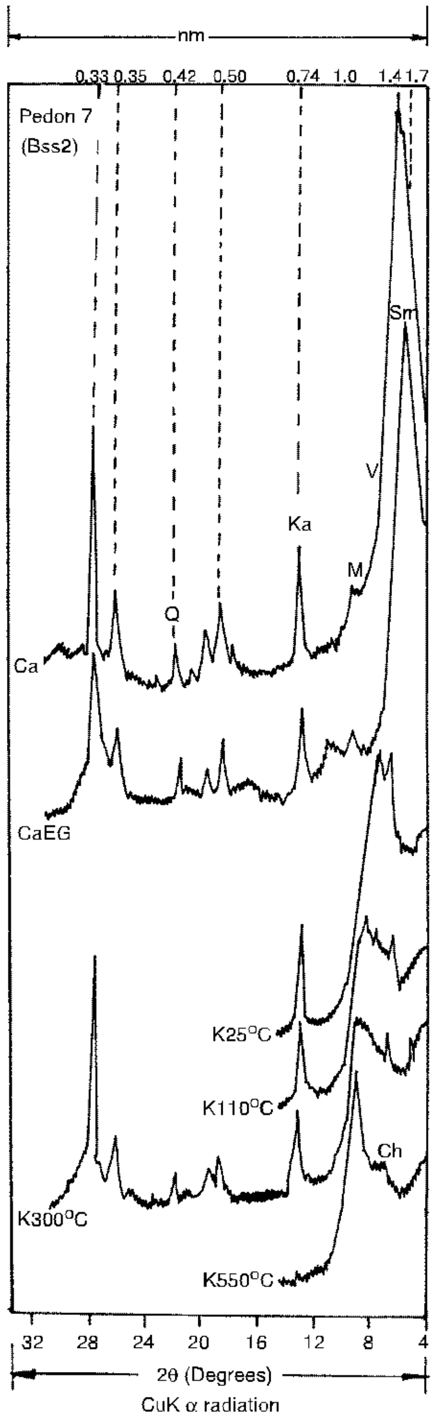

Fig. 2. XRD diagrams of the clay fraction (<2 μm) of the Bss2 horizon of Pedon 7, representative of those in Pedons 3, 7, and 8 (Vertic Ustochrept, Typic Haplustert, and Typic Haplustert, re-spectively). Ca, Ca-saturated; CaEG, Ca-saturated plus glycol vapour; K25/110/300/550°C, K-saturated and heated to 25°C, 110°C, 300°C, and 550°C; Sm, smectite; V, vermiculite; M, mica; Ka, kaolin; Ch, chlorite; Q, quartz.

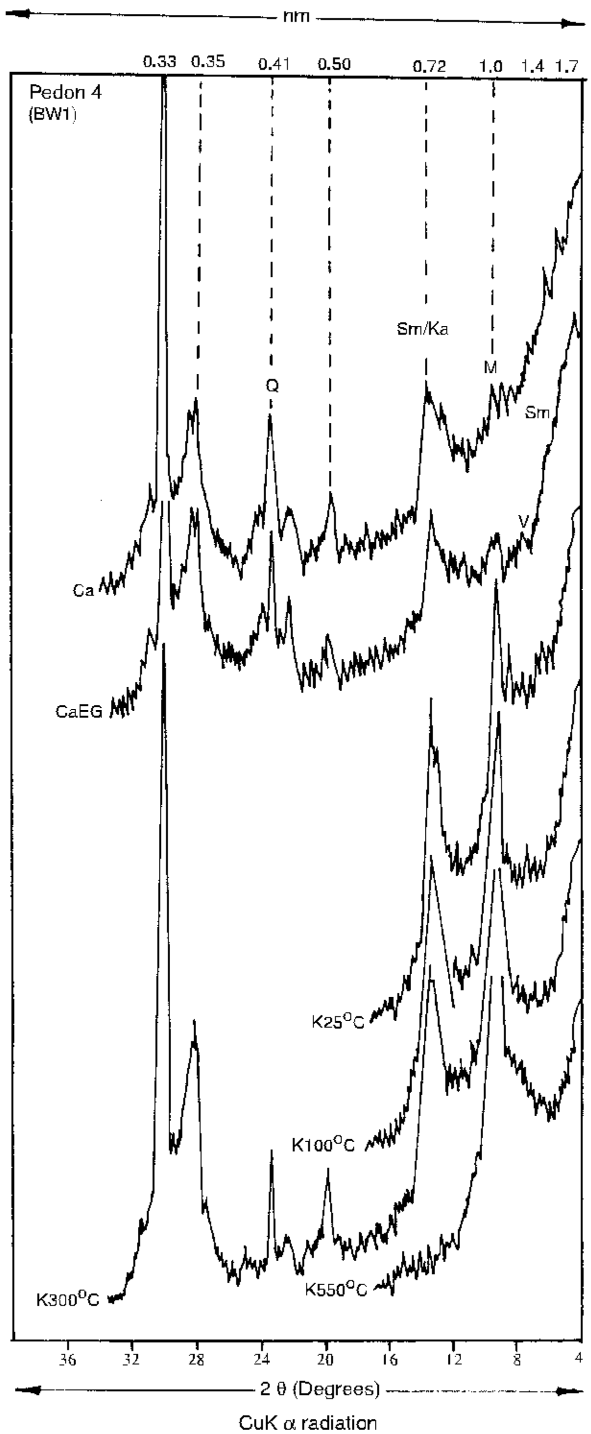

Fig. 3. XRD diagrams of the clay fraction (<2 μm) of the Bw1 horizon of Pedon 4 (Vertic Eutropept), representative of those in Pedons 4, 5 and 6. Ca, Ca-saturated; CaEG, Ca-saturated plus glycol vapour; K25/110/300/550°C, K-saturated and heated to 25°C, 110°C, 300°C, and 550°C; Sm, smectite; M, mica; Sm/Ka, smectite-kaolin; V, vermiculite; Q, quartz.

vermiculite, mica, and quartz (Fig. 2). The smectite was reasonably ordered as it yielded a sharp basal reflection on glycolation and displayed a regular series of short and broad higher order reflections (Fig. 2). The clay CECs of these soils in the SCS [>85 cmol(+)/kg; Table 2] were indicative of the superactive class (Anon. 1998) and thus the clays were part of the montmorillonitic mineralogy class (Smith 1986). The presence of the smectite mineral thus justified very high LE values (LE $\geq$15; Table 2).

The clay fractions of other black soils (Pedons 4, 5, and 6) were dominated by Sm/Ka and mica (>50%), with subordinate amounts of chloritised smectite, vermiculite, and quartz (Fig. 3). The peak value of Sm/Ka (0.7 nm) was sharper and not as broad at the base compared with Sm/K peaks of Pedons 1 and 2. The clay CECs in the SCS [>40 cmol(+)/kg; Table 2] indicated that these soils were part of the active CEC class (Anon. 1998) and mixed mineralogy class (Smith 1986). Thus, the soils showed moderate LE values ($\geq$7), which were sufficient for them to qualify as vertic. This apparently may justify the provision of mixed mineralogy class for shrink–swell soils (Anon. 1975). However, this is not tenable in view of the data obtained and discussed later.

Quantitative determination of smectite

Quantitative determination of minerals present in the clay fractions of soils by XRD analysis is difficult to perform with comparable precision for all mineral components simultaneously. Any attempt in this regard has always yielded semi-quantitative estimates (Gjems 1967). Even such estimation becomes questionable for a mineral when it is interstratified with other minerals.

The presence of smectite–kaolin interstratified minerals (Sm/Ka) in shrink–swell soils is common in India (Pal *et al.* 1989; Bhattacharyya *et al.* 1993, 1997) and elsewhere (Wilson and Cradwick 1972; Herbillon *et al.* 1981; Norrish and Pickering 1983; Churchman *et al.* 1994; Delvaux and Herbillon 1995). The peak shift analysis (Wilson 1987) has been found to be a useful method to determine the smectite content in Sm/Ka (Bhattacharyya *et al.* 1993, 1997). When the smectite component in Sm/Ka is highly chloritised, the swelling of smectites on glycolation is restricted, making peak shift analysis ineffective. The chemical method of Alexiades and Jackson (1965) for the quantitative determination of smectite in soil clays has been found to be effective in circumventing this problem, particularly when attempting to establish a link between bulk soil properties and clay mineral type (Pal and Durge 1987, 1989). In view of the objective of the present study to establish a link between vertic properties and the amount of swelling mineral content, soil clays of both red and black soils were assessed by the chemical method (Alexiades and Jackson 1965) to obtain the quantitative value of smectite (Table 2).

Smectite content of soil clays of Pedon 1 varied from 13% to 22% in the solum and 19% in the SCS, whereas smectite content of soil clays of Pedon 2 varied from 12% to 16% in the solum and 15% in the SCS (Table 2). Smectite content in soil clays of black soils ranged from 26% to 70% in SCSs (Table 2).

Establishment of a minimum threshold value of smectite

In the present study, a highly significant positive correlation (r = 0.98 at P = 0.01) was obtained between smectite content and LE (Fig. 4*a*) when values of each soil horizon of 8 pedons were considered. This indicated that the magnitude of the shrink–swell phenomena is primarily regulated by the smectitic clay mineral. Furthermore, the correlation between these 2 parameters on a SCS basis was also highly significant

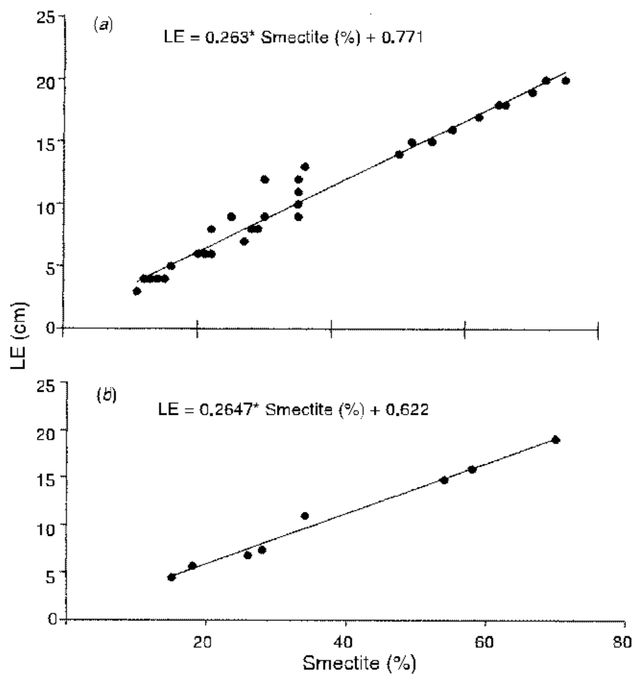

Fig. 4. Relationship between linear extensibility (LE) and smectite content of the clay fractions of 47 soil horizons of (*a*) all the pedons and (*b*) 8 pedons on the SCS basis.

(r = 0.99 at P = 0.01). The regression equation (Fig. 4*b*) yielded a value of 20% for smectite content (LE = 6) in the SCS. It is stipulated in Soil Taxonomy (Anon. 1998) that the minimum value of LE is 6 for soils to be classified as vertic. This means that soils with vertic properties must have a smectite content ≥20% in SCSs. The soils with vertic properties studied here, particularly those with vertic intergrades (Pedons 4, 5, and 6), do have a smectite content ≥20% in SCSs. These soils had a mixed mineralogy class based on both XRD and clay CEC data. If the mineralogy class for these soils is considered to be mixed, the inherent relationship between truly expanding minerals and shrink–swell properties that essentially reflects the genesis of vertic properties (Fig. 4*a* and *b*) will be highly undermined. Moreover, if non-expanding types of minerals such as kaolins, micas, chlorites, and vermiculites are considered to be minerals that do not expand on solvation, it is difficult to reconcile their non-expanding characteristic with the shrink–swell properties. Usually, shrink–swell phenomena are positively correlated with the content of expansible mineral (Franzmeier and Ross 1968; Karathanasis and Hajek 1985; Smith *et al.* 1985), as indicated by high COLE values and clay contents dominated by minerals of the smectite group. Bhattacharyya *et al.* (1997) suggested that deviation from this fundamental fact may still occur if a minimum threshold value of smectite content in the SCS is not established. It was proposed in Soil Taxonomy (Anon. 1994) that soils with vertic properties in which smectite content (semi-quantitative data) was >50% were part of the montmorillonitic mineralogy class. Later, this criterion was revised in Soil Taxonomy (Anon. 1998) and it was proposed that soils with a higher smectite content (by weight) than any other single type of clay mineral were part of a qualitative smectitic mineralogy class. The present study, however, provides a quantitative amount of smectite in the SCS as a minimum threshold value for manifestation of vertic properties in soils. Therefore, for shrink–swell soils, the mineralogy class should be only smectitic. A realistic mineralogy class for Oxisols has already been recognised in Soil Taxonomy (Anon. 1975, 1998) in view of their highly advanced stage of pedogenic development.

Conclusions

The results of the present study demonstrated that the vertic properties were manifested in soils from a group of 8 soils from different soil taxonomic orders in India when they had a smectite content of 20% (as defined by Alexiades and Jackson 1965) in the SCSs. The correlation between smectite content and LE showed that LE ≥6 corresponded to a smectite content ≥20%. Thus, the smectitic mineralogy class appears to be a realistic proposition for shrink–swell soils only.

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