Aust. J. Soil Res., 1997, 35, 1245 52

On kaolinitic and mixed mineralogy classes of shrink–swell soils

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Abstract

Spatially associated red (Typic Hapludalf) and black (Vertic Eutropept) soils developed on the Deccan plateau in the Western Ghats of India were analysed for clay mineralogy and also physical properties relating to shrink swell. This was done in order to examine a possible correlation between shrink-swell phenomena and the content of expansible clay minerals, and to reconcile the apparent incompatibility between such a correlation and the classification of some Vertisols into kaolinitic, illitic, and mixed mineralogy classes. The fine clay mineralogy of the red soil was dominated by interstratified smectite/kaolinite with a little amount of smectite, but it had low cation exchange capacities and other associated non-vertic physical properties. Some of the smectite was interlayered with chlorite. This red soil is grouped into the kaolinitic mineralogy class. The fine clay mineralogy of the black soil was dominated by a highly smectitic interstratified smectite/kaolinite and also some smectite, which also shows some interlayering with chlorite. This soil has vertic physical properties but has a mixed mineralogy classification. The results suggest that there is an incompatibility between marked shrink–swell characteristics and mineralogical classification of soils in Soil Taxonomy, in view of the fact that it is smectite content which governs the vertic character of soils.

Introduction

Shrink–swell soils (Vertisols and their intergrades) are widespread in some countries and are one of the most interesting soil groups because of their characteristic morphology. Dominance of smectite minerals in the clay fraction results in an appreciable shrink–swell potential, which induces formation of cracks and distinctive structural elements like sphenoids and wedge-shaped peds with smoothened surfaces or slickensides (Eswaran *et al.* 1988). Usually shrink–swell phenomena are positively correlated with the content of expansible mineral (Franzmeier and Ross 1968; Smith *et al.* 1985; Karathanasis and Hajek 1985), as indicated by a high coefficient of linear extensibility (COLE) and clay contents dominated by minerals of the smectite group. Despite this kaolinitic and mixed mineralogy classes are recognised in shrink–swell soils at the family level in Soil Taxonomy (Soil Survey Staff 1975). Studies of El Salvador Vertisols (Yerima *et al.* 1985, 1987), for example, indicate that kaolinite-rich fine clay systems, because of the large surface area, also have physical properties, including COLE, which are typical of Vertisols. Greene-Kelly (1974) found that soils with equal amounts of kaolinite and montmorillonite were similar to those with montmorillonite alone, while Hajek (1985) reported kaolinitic mineralogy in a few Vertisols of the USA. These observations, however, are exceptions and in contrast to the common montmorillonitic mineralogy class for most of the shrink swell soils of the world (Dudal and Eswaran 1988).

It is well documented that shrink swell behaviour is primarily governed by the nature of the clay minerals, particularly their surface properties. Although

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soils containing all other clays shrink and swell with changes in moisture content, changes are particularly extreme in smectites (Borchardt 1989). Moreover, if kaolinite is understood to be a clay mineral that does not expand on solvation, it is difficult to reconcile its non-expanding characteristics with a high shrink swell capacity. This contradiction probably led soil scientists to question the validity of mixed (Smith 1986) and kaolinitic mineralogy classes among shrink–swell soils (Eswaran *et al.* 1988).

In view of the above information, we have attempted to resolve the prevailing ambiguity between kaolinitic and mixed mineralogy classes and a high shrink–swell capacity by investigating the qualitative and quantitative mineralogy of the clays in spatially associated clayey red and black soils developed on the Deccan basalt plateau in the Western Ghats of India.

Materials and methods

Soils

Spatially associated red and black soils as distinct entities with similar topographical conditions occur on the Bhimashankar plateau of the Deccan basalt in the Pune district of Maharashtra. Three representative soils were selected: 2 red soils (pedons 1 and 2) and 1 black soil (pedon 3). The soils occur in the high rainfall (>5000 mm) zone of the Western Ghats, and are of clay texture and noncalcareous throughout the solum. Pedons 1 and 2 have subangular blocky structure, dark brown to dark reddish brown hue, are slightly acidic, and are classified as Typic Hapludalfs (Soil Survey Staff 1992). Pedon 3, a Vertic Eutropept, has angular blocky structure, dark to very dark greyish brown colours and neutral pH (Table 1).

Pedon 1 has clay cutans in the B2t horizon from 60 cm onwards. Pedon 2 has clay cutans at 16–36 cm depth. Pedon 3, situated in a gently sloping depression, has a solum >300 cm thick with shiny pressure faces from 16 cm downwards and has cracks from surface to subsurface.

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). COLE was determined according to Schafer and Singer (1976). Linear extensibility (LE) was calculated from the COLE value using the formula LE = 100×COLE (Soil Survey Staff 1975). Oriented clay fractions were subjected to X-ray diffraction (XRD) analysis using a Philips diffractometer and Fe-filtered CoKα radiation and also Mn-filtered FeKα radiation at a scanning speed of $1^\circ\ 2\theta$/min. Samples were saturated with Mg and K, solvated with ethylene glycol, and heated to 110, 300, and 550°C. Semi-quantitative estimates of clay minerals were made by the method of Gjems (1967). The proportion of different components of interstratified mineral was calculated following the method of Wilson (1987). The values of COLE, LE, and semi-quantitative estimates of clay minerals are expressed on the basis of the soil control section 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 (pedon 2); (*ii*) a depth of 1 m if the regolith is >1 m thick (pedons 1 and 3) (Soil Survey Staff 1975).

Results and discussion

Mineralogy of shrink–swell soils

Both red and black soils were clay-textured, with fine clay (<0·2 μm) dominating all clay fractions (Table 1). XRD examination of the fine clay fractions of red soils (pedons 1 and 2) indicates a dominant peak of kaolin at 0·72 nm (Fig. 1*a*). A slight shift and tailing of this peak on glycolation and gradual reinforcement of the 1·0 nm peak with a corresponding decrease in intensity of the 0·72 nm peak on K saturation and subsequent heating (110°–550°C) suggest that these kaolins are to some extent interstratified with chloritised smectites (Fig. 2*a*). Thus, the

Table 1. Physical, chemical, and mineralogical properties of soils

Control, control section (see Methods); TC, total clay (<2 μm); FC, fine clay (<0·2 μm); COLE, coefficient of linear extensibility (with linear extensibility in parentheses); minerals of fine clay fractions are semi-quantitative estimates; Sm/Ka, interstratified smectite kaolin; Sm, smectite; Ka, kaolin; M, mica

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Depth (cm)	Horizon	Munsell colour (moist)	TC (g/kg)	FC (g/kg)	FC/TC	COLE	pH (1:2) water	Clay CEC (cmol(+)/kg)	Minerals of fine clay fractions (g/kg) Sm/Ka	Sm	M	Sm/Ka compositional characteristics Sm	Ka	Total Sm^{A}
						Pedon 1: Typic Hapludalf								
0–9	A1	5YR 4/4	558	330	0·59	0·04	5·7	15	680	50	270	n.d.	n.d.	—
9–31	B21	5YR 3/3	564	358	0·63	0·05	5·3	17	600	50	350	n.d.	n.d.	—
31–60	B22t	5YR 3/3	502	371	0·74	0·05	5·3	21	610	100	290	n.d.	n.d.	—
60–107	B23t	2·5YR 3/4	666	452	0·68	0·07	5·6	23	600	100	300	n.d.	n.d.	—
107–155	B24	5YR 4/4	692	318	0·46	0·08	5·6	21	760	50	190	n.d.	n.d.	—
Control						0·057 (5·7)		21						
						Pedon 2: Typic Hapludalf								
0 16	Ap	10YR 4/4	476	340	0·71	0 06	6·4	19	900	Nil	100	n.d.	n.d.	-
16–36	B2	10YR 4/3	624	431	0·69	0·06	6·4	14	950	Nil	50	n.d.	n.d.	
36 55	C		608	417	0·68	0·07	6·5	15	950	Nil	50	n.d.	n.d.	
Control						0·035 (3·5)		15						
						Pedon 3: Vertic Eutropept								
0 16	Ap	10YR 3/3	607	330	0·54	0·06	6·6	50	760	240	Tr	250	510	490
16 40	B21ss	10YR 3/3	601	481	0·80	0·06	6·4	47	660	340	Tr	480	180	820
40 79	B22ss	10YR 3/3	614	444	0·72	0·07	6·8	47	700	300	Tr	490	210	790
79 123	B23ss	10YR 3/2	663	461	0·69	0·07	6·7	45	570	430	Tr	420	150	850
123 165	B24ss	10YR 3/2	613	505	0·82	0·08	6·5	63	450	550	Tr	330	120	880
Control						0·066 (6·6)		46						813

n.d., not determined.
Tr, traces (<50 g/kg).
^{A} Total smectite = smectite+smectite in Sm/Ka.

ys of these soils are dominated by interstratified smectite–kaolin (Sm/Ka) inor amounts of chloritised smectite and mica (Fig. 1*a*). However, the ackground at the low-angle side of the mica peak on both glycolation and g indicates a probable presence of chloritised smectite interstratified with The proportion of smectite and kaolin in Sm/Ka could not be calculated k shift analysis (Wilson 1987) because of the restricted shifting of the m peak towards lower angles on glycolation due to a partial chloritisation smectite interlayers (Fig. 2*a*).

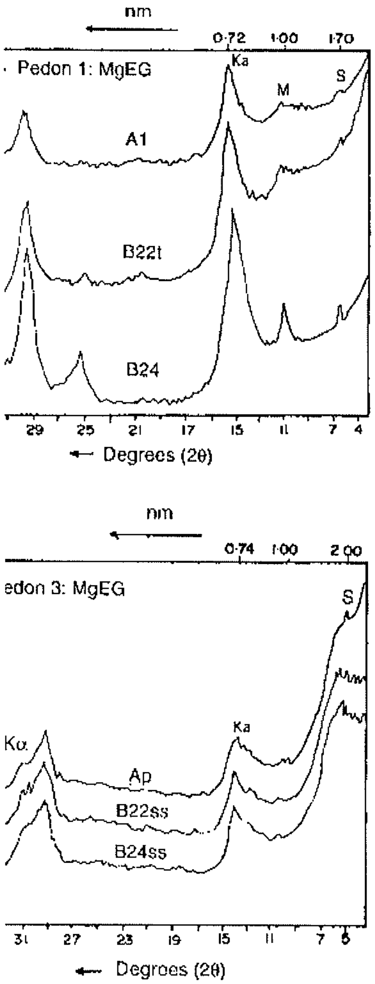
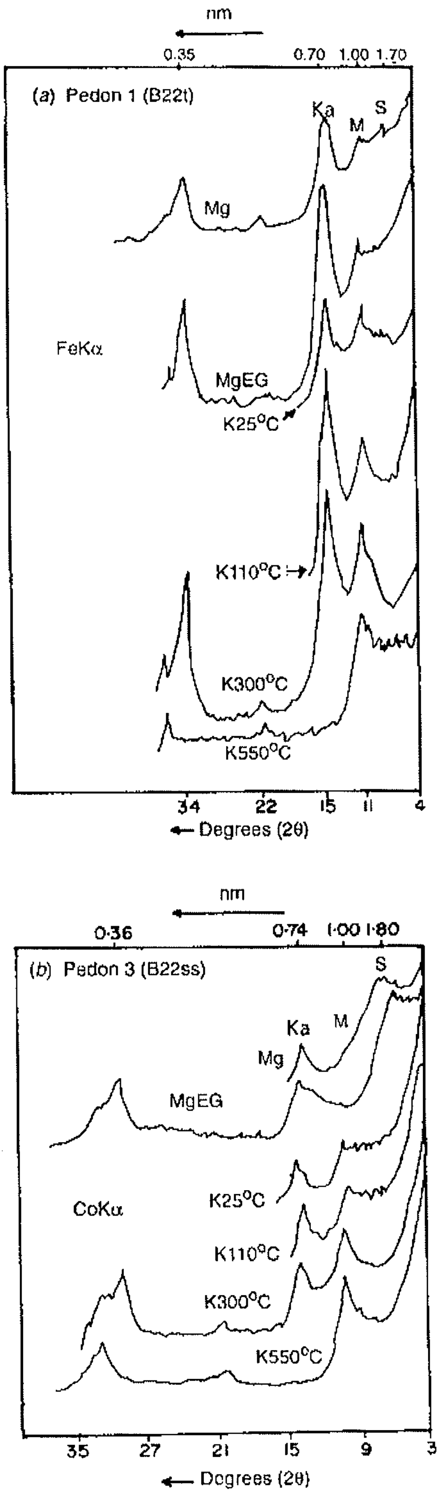


Fig. 1. Representative XRD patterns of the fine clay fractions of (*a*) red soils and (*b*) black soils (MgEg, Mg-saturated plus glycol vapour; S, smectite; M, mica; Ka, kaolin).



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Taxonomy (Soil Survey Staff 1992) proposes a kaolinitic mineralogy r soils with vertic properties in which the kaolinite content should 50% along with <10% smectite. The red soils under study have Sm/Ka and 10% smectite in the control section, according to the semi-ative mineralogical analysis of the clay fractions. On this basis, these not appear to qualify for a kaolinitic mineralogy class. However, the f the clay of pedon 1 ranges from 15 to 23 cmol(+)/kg and measures l(+)/kg in the control section; for pedon 2 it is 14–19 cmol(+)/kg, with

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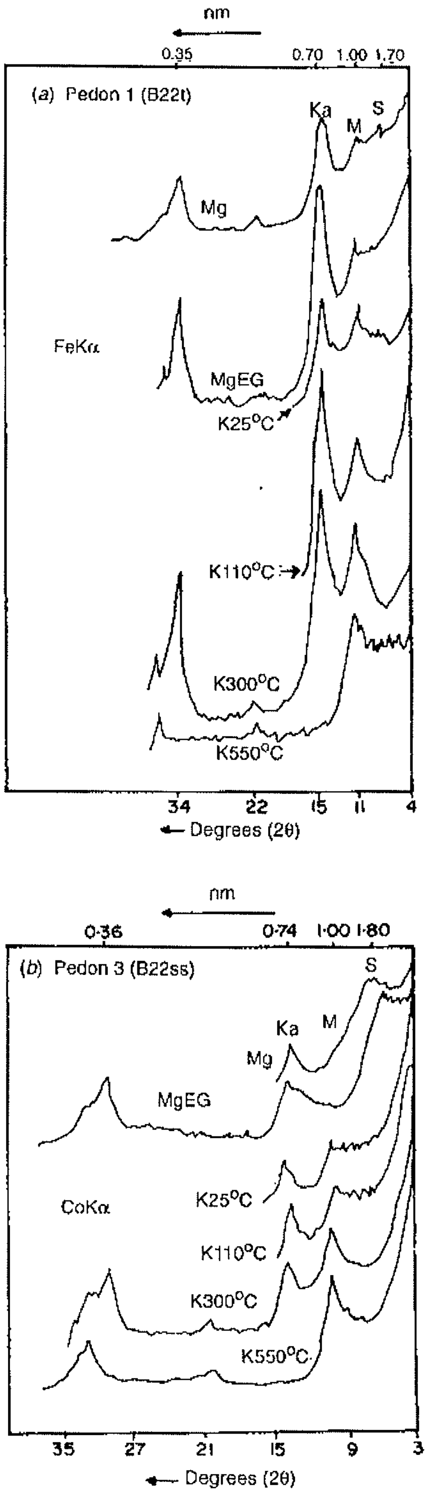

Fig. 2. Representative XRD patterns of the fine clay fractions of (*a*) red soils and (*b*) black soils (Mg, Mg-saturated; MgEg, Mg-saturated plus glycol vapour; K25/110/300/550°C, K-saturated and heated to 25, 110, 300, and 550°C; S, smectite; M, mica; Ka, kaolin).

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15 cmol(+)/kg in the control section (Table 1). Soil Taxonomy (Smith 1986) advocates a limit of 16–24 cmol(+)/kg, or less, for a kaolinitic mineralogy class, and 24–45 cmol(+)/kg for soils with mixed mineralogy on the family level of soil classification. Thus, the mineralogy classes of these 2 red soils are kaolinitic, even though the clay is dominated by Sm/Ka. The COLE values of the soils and the amount of smectite and Sm/Ka in the fine clays increase with depth in pedon 1 (Table 1).

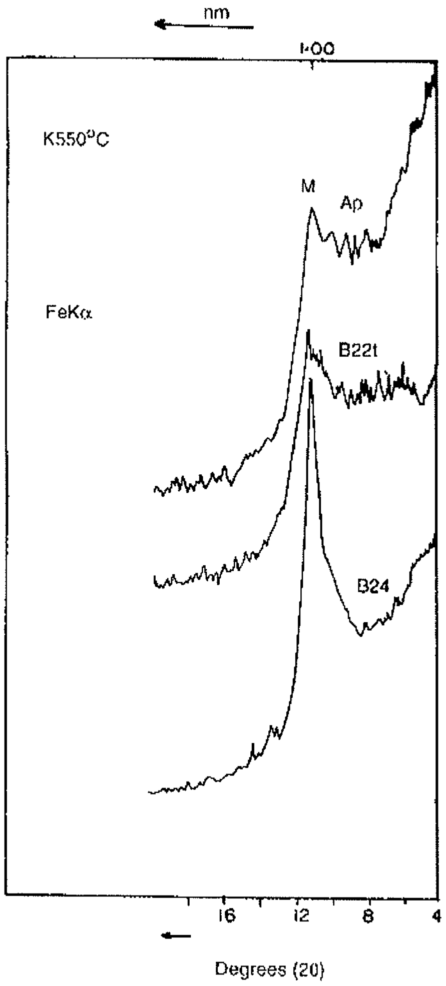

Fig. 3. Representative XRD patterns of the fine clay fractions of different horizons of red soils (pedon 1) (K550°C, K-saturated and heated to 550°C; M, mica).

Hydroxy interlayering in the smectite of Sm/Ka, as indicated by the broadening of the base of mica in K550°C samples as well as the tailings on its low-angle side, is comparatively less below the Ap and the B22t horizons in pedon 1 (Fig. 3). This indicates relatively less chloritisation of smectite in the Sm/Ka of the subsoils. Thus, the higher COLE values of the subsoils are caused by the relatively favourable expansion of smectite in Sm/Ka and a small amount of smectite in the subsoils (Fig. 1*a* and Table 1). Despite the presence of both Sm/Ka and smectite in their clay fractions, the red soils do lack vertic properties.

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The LE value <6 (Table 1) also reflects their non-vertic character (Soil Survey Staff 1992). A close inspection of XRD diagrams of the fine clays of shrink–swell soils of El Salvador (Yerima *et al.* 1985), where shrink–swell phenomena have been correlated primarily with the fine clay kaolin content (Yerima *et al.* 1987), indicates the presence of a peak of smectite in the Atiocoyo soils in addition to the dominating presence of interstratified smectite kaolin (Sm/Ka). Thus, the combination of Sm/Ka and smectite minerals provides an explanation for the higher COLE (0·10–0·12) and clay CEC values (62–79 cmol(+)/kg) of the Atiocoyo soils, which imparted the vertic characters. It appears that the possible presence of expansible minerals might have been ignored in a few so-called kaolinitic shrink–swell soils of the USA (Hajek 1985) because the CEC of their clays is >40 (Eswaran *et al.* 1988). In view of the above results, it can be concluded that kaolinite as a dominant mineral, even with <10% smectite, is not likely to induce the shrink–swell process to such an extent that vertic properties can develop in soils. Therefore, no provision should be made for a truly kaolinitic mineralogy for shrink–swell soils.

The fine clay fractions of the black soil (pedon 3) indicate the dominant presence of Sm/Ka (Fig. 1*b*). The shift of the 0·73 nm peak of Sm/Ka to 0·80 nm on glycolation was more conspicuous in the black soil clays than in the red soils (Fig. 2*b*). The peak shift analysis (Wilson 1987) indicates that kaolin forms 67–84% of this interstratification. In addition to the dominant presence of Sm/Ka, a considerable amount of smectite and traces of mica are also present (Fig. 2*b*). These smectites are chloritised as indicated by an incomplete expansion of the 1·40 nm peak on glycolation and a broadening on the low angle side of the 1·0 nm peak of K-saturated samples heated to 550°C. The mineralogy of the control section indicates Sm/Ka as the dominant mineral (>50%) followed by smectite (<50%), thus qualifying the mineralogy class of this soil as mixed (Soil Survey Staff 1975). The clay CEC of the control section is 46 cmol(+)/kg (Table 1), which further supports the mixed mineralogy class of this soil (Smith 1986). Like COLE, the clay CEC, the amount of smectite, and the smectite component in Sm/Ka mineral, as well as the sum of the latter two, increase with depth. By contrast, the kaolin proportion in Sm/Ka decreases with depth (Table 1). The vertic character of this soil is clearly indicated by the high values of COLE, LE >6, and a high clay CEC resulting primarily from the presence of smectite, both discrete and interstratified with kaolin in Sm/Ka (>50% in the soil control section; Table 1). Kaolin, being a nonexpanding mineral, plays an insignificant role in swelling. Therefore, if the mineralogy of pedon 3 is considered as mixed, the inherent relationship between expanding minerals and shrink–swell processes that essentially reflects the genesis of vertic characters will be undermined. The influence of the smectite component in Sm/Ka has also been realised elsewhere, not only in the swelling of clays but also in their dispersion and nutrient-holding capacity (Churchman *et al.* 1994). The deviation from this basic concept may still prevail if the role of other nonexpanding minerals continues to be unduly highlighted without pinpointing their contribution to the process of swelling. The study, therefore, suggests a need to establish the minimum threshold value of smectite in the soil control section for the manifestation of vertic properties, in order to remove the existing ambiguity in the mixed mineralogy class.

Conclusions

The results indicate that vertic properties of soils can only be a function of smectite content, even when it is present in small amounts but alongside a dominating amount of interstratified smectite/kaolinite, and cannot be induced by kaolinite, despite its presence in large amounts.

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Manuscript received 6 December 1996, accepted 16 June 1997

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