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Mineralogy Class of Calcareous Zeolitised Vertisols

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Abstract *: There is an incompatibility between marked shrink-swell characteristics and mineralogical classification of Vertisols in U.S. Soil Taxonomy. It was stated that it is the smectite mineral alone which governs the vertic characteristics of soils and therefore mineralogy class of Vertisols should only be smectitic to the tune of minimum 20% in the clay (<2 µm) fractions. Besides smectitic mineralogy class, U.S. Soil Taxonomy provides a carbonatic mineralogy class for Vertisols, if the content of* $CaCO_3$ *plus gypsum exceeds 40% in the <20 µm size fraction. Soil Taxonomy, however, does not offer explanations to justify this (carbonatic) mineralogy class except a mention of* $CaCO_3$ *by weight. The present study provides pedo-edaphic justification of retaining smectitic mineralogy class in the light of natural soil degradation in terms of formation of* $CaCO_3$ *in these soils vis-à-vis crop performance, ensured by the presence of natural soil modifiers like zeolites.*

Smectite minerals in the clay fractions (<2 µm) of the Vertisols result in an appreciable shrink-swell potential which induces formation of cracks and slickensides. Earlier, Soil Taxonomy (Soil Survey Staff, 1975) proposed kaolinite and mica as the dominant mineral alongwith smectites to manifest shrink-swell properties. Later it was established through facts and figures that vertic characteristics can be a function of smectites only (Bhattacharyya *et al*., 1997). The provision of mixed mineralogy class was unexplained at that point of time which necessitated fixing a minimum threshold value of smectites to manifest vertic properties (Bhattacharyya *et al*., 1997). Shirsath *et al*. (2000) showed that minimum 20% smectites in clay fraction can manifest vertic properties in soils to group them as Vertisols and/or vertic intergrades. This was later validated by Bhuse *et al*. (2001) who found a fairly good correlation between vertic properties (linear extensibility, LE, Soil Survey Staff, 2003) and the smectite content.

It is interesting to note that, other than smectitic mineralogy class, Soil Taxonomy (Soil Survey Staff, 2003) also provides carbonatic mineralogy class for Vertisols and their intergrades. The conditions are that in the mineralogy control section if carbonate (expressed as $CaCO_3$) plus gypsum, either in the fine-earth fraction (<2 µm) or in the fraction less than 20 mm in size is >40%, then the mineralogy class should be carbonatic.

By and large, the Vertisols in India are calcareous (Pal *et al.*, 2000; Srivastava *et al.*, 2002) with some exceptions (Bhattaharyya *et al.*, 1993). In general, the Vertisols have been grouped in smectitic mineralogy class in spite of the fact that in many semi-arid and aridic bioclimatic systems, the proportion of $CaCO_3$ has been high in these soils. Moreover, Soil Taxonomy does not offer explanations to justify carbonatic mineralogy class except a mention of $CaCO_3$ by weight. This requires an adequate pedogenic explanations since it indicates a natural soil degradation in terms of secondary carbonates in soils (Pal *et al.*, 2000) particularly in arid and semi-arid climate.

In India, we have nearly 228.8 mha area covered by calcareous soils which include calcareous Vertisols and their intergrades. These soils occur mainly in arid and semi-arid bioclimate (Pal *et al.*, 2000). However, many of these soils do not have $CaCO_3$ > 40% in their soil control section (Bhattacharyya *et al.*, 2006a; Ray *et al.*, 2006; Srivastava *et al.*, 2002; Pal *et al.*, 2003, 2004). It is in view of this, the present

Table 1. *$CaCO_3$ content in the selected Vertisols in different bioclimatic systems*

Bioclimatic System*	Rain-fall (mm)	Soil Series	Soil Classifi-cation	$CaCO_3$ (<20 mm) (%)	Clay CEC cmol(p+) kg^{-1}	BS** (%)	Soil mineralogy	
							Soil Taxo nomy***	Proposed
Semi-arid (dry)	660	Kovilpatti	Gypsic Haplusterts	12	91	100	Smectitic	Smectitic
Semi-arid (dry)	635	Semla	Typic Haplusterts	18	98	108	Smectitic	Smectitic
Arid	533	Sokhda	Typic Haplusterts	33	73	115	Smectitic	Smectitic
Arid	520	Nimone	Sodic Haplusterts	42	63	110	Carbonatic	Smectitic

* Bhattacharyya et al. (2006); ** BS = Base Saturation; *** Soil Survey Staff (2003)

study was undertaken to address the formation of $CaCO_3$ vis-à-vis natural degradation of smectite-dominant Vertisols and to infer on rationale of carbonatic mineralogy class for these soils.

Materials and Methods

Representative benchmark soils were selected from two different bioclimatic classes namely arid and semi-arid (dry) (Fig. 1; Table 1). Detailed descriptions of these soils in terms of their morphological, physical and chemical properties are shown elsewhere (Bhattacharyya *et al*., 2006b, 2007a, b, c).

Sand (200-50 µm), silt (50-2 µm), total clay (<2 µm) and fine clay (<0.2 µm) fractions were separated from the samples

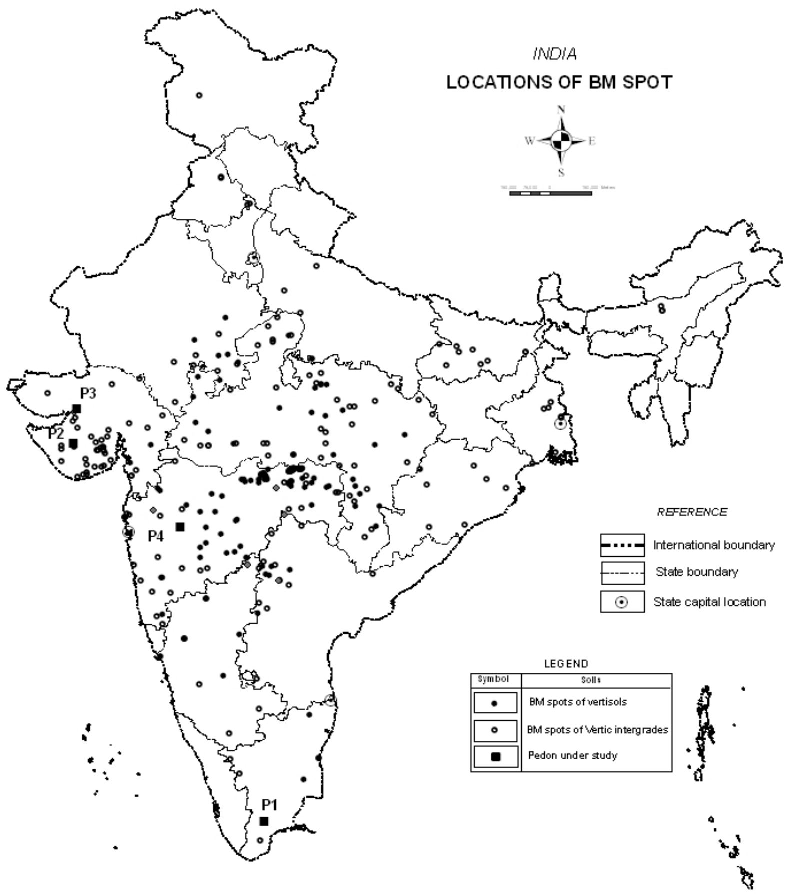

Fig. 1. Pedon location of shrink-swell soils (Vertisols and their intergrades)

after dispersion according to the size segregation procedure of Jackson (1979). Cation exchange capacity (CEC) of the soils was determined following standard method (Jackson, 1973). Oriented Ca and K saturated clay samples (<2 µm) were subjected to X-ray diffraction (XRD) analysis. After identification under the petrographic microscope the sand-sized zeolites were picked up, ground and X-rayed. A few zeolite crystals were fixed on aluminium stud with LEIT-C conductive carbon content, coated with gold and examined under scanning electron microscope (SEM).

Results and Discussion

The minerals identified in sand fractions are zeolites, quartz and feldspars (Fig. 2). The minerals in clay and silt fractions are smectites, mica and smectite-kaolin interstratified units (Figs. 3 and 4).

Nimone soils contain 40% $CaCO_3$ (Table 1) and thus at the family level of soil classification it is necessary to group them under carbonatic mineralogy class as per Soil Taxonomy (Soil Survey Staff, 2003). Formation of $CaCO_3$ has been reported to be a signature of dry (arid and semi-arid) climate (Pal *et al*., 2000; Raja *et al*., 2009). The increase in $CaCO_3$ content in soils has been related to the development of sodicity as reflected by high exchangeable sodium percentage (ESP) (Balpande *et al*., 1996). The depth function of $CaCO_3$ and ESP (Pal *et al*., 1994, 2000) suggests that due to formation of $CaCO_3$, sodicity develops initially in the subsoils. This subsoil sodicity impairs the hydraulic properties (sHC) of soils. The initial impairment of the percolative moisture regime in the subsoils results eventually in a soil where gain exceeds losses. This self-terminating process (Yaalon, 1983) subsequently leads to the development of sodic soils where ESP decreases with depth. Thus the formation of pedogenic $CaCO_3$ is a basic process of initiation of chemical (natural) soil degradation (Pal *et al*., 2000, 2006). Against this background, it is experienced that Nimone soils despite being calcareous and qualifying for Sodic Haplusterts have not lost their productivity as evident from successful growing of agricultural crops (Table 2).

An obvious question may be raised that how the ill effect of natural soil degradation in terms of sequestration of huge amount of inorganic carbon as $CaCO_3$ is obliterated by the Nimone soils? A closer look at the mineralogical analyses of clay and silt fractions of these soils indicate the dominance of smectites (Figs. 3, 4). The sand fractions show the presence of zeolites alongwith other minerals (Fig. 2). Changes in phases of zeolites on thermal treatments as indicated by shifting of 0.90 nm peak to 0.86 and 0.83 nm at 300^{o}C and its disappearance at 450^{o}C suggest that these zeolites belong to Si-poor heulandites type (Bhattacharyya *et al*., 1993,

Table 2. *Comparison of crop performance between carbonatic and non-carbonatic Vertisols*

Values are yield in t ha^{-1}

Crops	Carbonatic Vertisols (e.g. Nimone soil series)	Non-carbonatic Vertisols
Sugarcane	150	90
Ratoon	75 – 90	60 – 70
Cotton (irrigated)	1.8 – 2.0	1.8 – 2.0
Wheat	4.5	3.0 – 3.5
Sorghum (rainfed)	1.2	1.0 – 1.2

1997, 2006b; Pal *et al.*, 2006). These base-rich zeolites have been reported to act as saviours for the persistence of Alfisols (Bhattacharyya *et al.*, 1999) and Mollisols in the Western Ghats and the Satpura (Bhattacharyya *et al.*, 2006) and also the Vertisols in the black soil region (Bhattacharyya *et al.*, 1993; Pal *et al.*, 2006). The presence of these zeolites helps in maintaining the productivity of these soils by two ways viz. (i) supplying nutritional elements (Ca, Mg) in appropriate proportions and (ii) improving drainage for bringing right pedo-edapho environment for crop growth.

Presence of zeolites in Nimone soils modify soil characteristics. These minerals permit the expression of shrink-swell phenomena, characteristic of a smectite-rich soils. Interestingly zeolites retard the process of drainage reduction, characteristic of soils containing relatively high amount of $CaCO_3$ (viz. >40%). The identification of pedological signatures viz. presence of zeolite mineral and the calcium carbonate nodules *vis-à-vis* the information of edaphological performance of soils in terms of crop yield has been elucidated in this study. This effort could explain the process of reducing the ill effects of natural soil degradation process in the form of development of pedogenic $CaCO_3$. Mineralogy class of Nimone soils should, therefore, be considered as *smectitic* in spite of >40% $CaCO_3$ in <20 mm fraction. However, Vertisols with true carbonatic mineralogy class may exist in absence of natural modifiers which will lead to a steady process of natural degradation of shrink-swell soils in semi-arid and arid bioclimatic systems.

This indicates that in view of contemporary natural chemical degradation process in terms of sequestration of inorganic carbon (as $CaCO_3$) and geogenic presence of natural modifier (as zeolites/gypsum), mineralogy class of Soil Taxonomy should be based on pedo-edaphic datasets supporting resilience rather than any arbitrary nomenclature.

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