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Research Article

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Clay mineralogy and geochemistry of some black, red and red laterite soils in semi arid tropical region of Tamil Nadu

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Summary

The X-ray diffraction pattern of soil clay fraction of one red soil pedon from Maize Research Station, Vagarai of Dindigul district, one black soil pedon from Cotton Research Station, Veppanthatai (Perambalur district) and one red laterite soil from Dryland Agricultural Research Station, Chettinad of Sivaganga district of Tamil Nadu was carried out to distinguish the distribution of clay minerals by using X-ray diffraction method and the mineral composition was assessed semiquantitatively. The black soil pedon revealed the dominance of smectite in association with small quantities of illite and kaolinite. The red soil pedon clay faction was "mixed" with smectite, illite and kaolinite type of clay minerals. The dominant clay mineral was kaolinite with small quantities of illite in red laterite soils pedon. The chemical composition of soils exhibited the siliceous nature with broad and large silica/sesquioxides and silica/alumina ratios. The wider ratios of SiO_2/R_2O_3 and SiO_2/Al_2O_3 (4.64 to 5.61 and 5.75 to 6.94) were found in the black soils pedon followed by red soils pedon (4.55 to 5.01 and 7.78 to 9.64), respectively where smectite and illite were the dominant clay minerals. The narrow silica/sesquioxides and silica/alumina ratios (2.23 to 2.56 and 4.13 to 5.37) were found in red laterite soils where Kaolinite was dominant clay mineral in semi arid tropical region of Tamil Nadu.

Key words : Black soils, Red soils, Red laterite soils, Clay mineral, X-ray diffraction, Elemental composition

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Introduction

The black soils, red soils and red laterite soils are the most common tropically pedogenic surface deposits in India. Their geotechnical characteristics and field performance are influenced considerably by their pedogenesis, degree of weathering, morphological characteristics, chemical and mineral compositions as well as prevailing environmental conditions.Tamil Nadu being under a semi-arid tropical monsoon climate has a number of soil types which are found in all types of climates, occupying for 4.0 per cent (12.99 m ha) of the country's geographical area. The clay fraction of Alfisols of Sivagiri micro-watershed of Andhra Pradesh was constituted by smectite (21 to 56%), kaolinite (40 to 64%), mica (4 to 15%) and traces of quartz (identified by 0.42 nm diffraction peak) (Thangasamy *et al.*, 2004).

They attributed that genesis of smectite due to retention during Pliopleistocene transition period; kaolinite might have been formed from montmorillonite and mica from alteration of minerals. Based on X-ray diffraction pattern, Singh and Agarwal (2005) found illite as the dominant mineral in the clay fraction of Alfisols followed by kaolinite. Direct conversion of mica to kaolinite might be one of the causes. The X - ray diffraction analysis showed that the fine clay fractions of Vertisols of different locations of India were dominantly smectitic (62 to 85 %) with small amount of illite and kaolinite except in Salusterts (Nayak *et al.*, 2006). Based on CEC /clay ratio of black soils of Krishna district, Babu *et al.* (2002) identified the presence of smectite, illite and kaolintie.

The CEC / clay ratios of different horizons of Alfisols of Chotanagpur plateau were in between 0.13 and 0.43 and Sarkar *et al.* (2001) had grouped the clay under mineralogical class 'mixed'. The CEC / clay per cent varied from 44 to 54 indicating mixed mineralogy in Ultic Haplustalfs of Bhubaneswar (Nayak *et al.*, 2002). According to Manjulatha *et al.* (2001), the silica-alumina and silica – sesquioxides ratios showed decreasing trend with depth in Alfisols and Vertisols, in general. Molar ratios of silica / alumina, silica / iron oxides, silica / sesquioxides were broad in the red and black soils of Andhra Pradesh and these ratios indicated the siliceous nature of the soils (Ramesh *et al.*, 2004). Singh and Agarwal (2005) reported silica, alumina, iron oxides and sequioxides content of different horizons of Alfisols of eastern region of Uttar Pradesh which varied from 66.5 to 80.0, 4.5 to 16.8, 1.3 to 5.2 and 5.8 to 22.0 per cent, respectively, while the SiO_2/R_2O_3 and SiO_2/Al_2O_3 ratios were in between 5.62 and 25.51; 6.73 and 30.22, respectively. Illuviation of clay, alumina and iron oxides had lead to fairly high silica, silica alumina ratio and silica sequioxides ratio in surface soils than in sub-surface soils. Alumina content was negatively correlated with silica and sand content. Silica content was decreased in Bw and Bt horizons due to illuviation, which reflected in decreased molar ratios of silica alumina, and silica sesquioxides ratios down the depth.

Information on the clay mineral distribution in the soils of semi arid tropical region of Tamil Nadu was meagre. Distribution of various minerals in three groups of soil pedon state has been worked out in this paper.

Resource and Research Methods

Location, climate and brief discussion of the study area :

The Maize Research Station (MRS) at Vagarai village is extending over an area of 22.94 acres and boundary is surrounded between 10^0.570' N latitude and 77^0.56' E longitudes and is situated at an altitude of 254.45 m above mean sea level. The physiography of study area was nearly level to gently sloppy in nature. The Cotton Research Station (CRS), Veppanthattai of Perambalur district extending over an area of 55.4 acres bounded in between 11^0.326' N latitude and 78^0.832'E longitudes and situated at an altitude of 147 m above mean sea level. Physiographically the land is characterized by flat terrain level to nearly level. The soils of the research station are very deep, calcareous, clayey, moderately well drained with slow permeability and low hydraulic conductivity.

The Dryland Agricultural Research Station, Chettinad extending over an area of 317 acre and boundary is surrounded between 10^0.166 to 10^0.179 N latitude and 78^0.785 to 78^0.805 E longitudes and is situated at an altitude of 108 m above mean sea level. Nearly three fourth of the land is under *Pedi plains* and characterized by flat terrain nearly level to gently slope (1-3%) in nature. The climate of the study area is hot and dry in summer and temperature is low during the month of January and the lowest mean daily temperature is 19.8 to 21.0^{o}C. The temperature begins to rise after March and the hottest month is July during which period the maximum temperature is 36.0 to 40^{o}C. Mean humidity varies from 65 per cent in July to 80 per cent in December. The mean annual rainfall of the study area is 700-1080 mm**.** The North East monsoon contributes 45 per cent of the annual rainfall from October to December. South West monsoon also contribute 37 per cent of rainfall from July to October. The soil moisture control section is dry for more than 90 cumulative days or 45 consecutive days in the months of summer solstice. The soil moisture and soil temperature regimes of the study area are Ustic and Iso-hyperthermic, respectively.

The natural vegetation existing in the study area are grasses, shrubs, thorny bushes such as *Cynodon dactylon, Cyprus rotundus, Butea frondosa, Dalbergia latifolia, Azadirachta indica, Tectona grandis, Terminalia tomertose and Acacia* spp. *Prosopis juliflora, Cacia* sp., broad leaf weeds such as *Selotia, Parthenium, Eucalyptus, Euforbia* spp., etc. The principal crops cultivated and research focused in this station is on maize, cotton, groundnut, redgram, horsegram, greengram, blackgram, pearlmillet and onion.

Collection and processing of soil samples :

One representative soil pedon from each research station are selected for X-ray diffraction analysis based on the morphological characteristics and physiography *viz.*, Maize Research Station (10^0.570193 N, 77^0.560816 E and 329.0 m above the MSL), Vagarai, Cotton Research Station,Veppanthattai (11^0.35023 N, 78^0.80133 E and 146.0 m above the MSL) and Dryland Agricultural Research Station, Chettinad (10^0.16965 N, 78^0.79045 E and 112.0 m above the MSL).

X-ray diffraction analysis :

The Ca and K saturated clays were used for X-ray diffraction analysis in Phillips X-ray diffractometer (PW 1390 with C_0 K_α radiation obtained at a scanning speed of 2^o 2θ/minute) using Ni-filtered Cu-K_a radiation obtained at 35 kv and 15 mA, at scanning speed of 1 degree 20 per min and a time constant of 4. Parallel oriented specimens were used in the X-ray diffraction studies. Chemical analysis of the H-clays was carried out according to the method described by Jackson (1956).

Preparation of Ca and K saturated clay :

Suitable quantity of sodium clay suspension was transferred to a centrifuge tube and 30 mL of 1 N $CaCl_2$ solution was added. These contents were centrifuged for 5 minutes at 1500 rpm. This treatment was repeated twice and the Ca saturated clay was washed with methanol to remove excess calcium. Then the clay was transferred into a bottle using required quantity of distilled water to make two per cent clay suspension. The K saturated clay was prepared in the same way as Ca saturated clay by using 1 N KCl solution.

Preparation of Ca and K saturated clay slides:

The Ca and K saturated clay slides were prepared separately by spreading 1 ml of 2 per cent clay suspension on clear microscopic slides and allowed to dry at room temperature. Thus, the clay oriented parallel slides were prepared as Ca saturated at room temperature, Ca saturated and glycerol solvated at room temperature, K saturated at room temperature, K saturated and heated to 110^0C, K saturated and heated to 300^0C and K saturated and heated to 550^0C. This slide was placed on the sample holder and the angle were set to rotate between 0°-40° because the clay peaks appear within this range of angles. The process from scanning to the plotting of the diffractograph was repeated. In this case, the graph plotted was not compared directly with the database but inferences from the usual behaviour of the main clay groups (kaolinites, smectites, micas and chlorites) were used to determine the clay groups present.

Confirmatory tests :

The next stage was glycolation of the samples. This was done by exposure of the clay fractions to ethylene fumes. The samples were again scanned at angles between 0 - 15^o as the common clay minerals appear around this range. The results obtained were then checked by inference, from usual behaviour of minerals. ii) After this, the samples were heated in a furnace for upto 550ºC and then scanned again at angles between 0-15°. This test is to check for kaolinites. Kaolinites cannot sustain high heat, therefore, their lattice structures disintegrate, becoming mullite (non-crystalline structures or minerals with destroyed structures). On scanning after heating, kaolinite' peaks disappeared.

The Loss on Ignition was estimated by igniting the soil of known weight at 900^oC and the loss in weight was expressed as loss on ignition (Piper, 1966). The acid extract for sesequioxides was prepared as per the procedure described by Hesse (1971). For estimation of silica, the residue on the filter paper obtained during the preparation of acid extract was washed with warm double distilled water to make acid free. Then the residue along with filter paper was ignited in a muffle furnace and weighed to a constant weight. From the weight of the residue the percentage of silica was calculated. The sesquioxides content was determined by using silica free acid extract as per the procedure given by Hesse (1971) and the results were expressed as per cent sesquioxides. The concentration of iron was estimated by aspirating the silica free acid extract to atomic absorption spectrophotometer and the results were expressed as per cent Fe_2O_3.Al_2O_3 content was calculated by deducting the Fe_2O_3 content from the total sesquioxides content.

Research Findings and Discussion

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

X-ray diffraction of soil clay fraction :

The X-ray diffraction pattern of soil clay fraction of selected pedons was depicted in Fig. 1 to 3. Diffraction peaks (d-spacings) recorded in different treatments of soil clay fraction is presented in the Table 1. Based on the lower and higher order peaks and their nature in the diffractograms, pedon wise clay minerals were identified. The clay minerals identified were secondary minerals present in clay fraction are belonging to the phyllosilicates (Si_2O_5 group).

X-ray diffraction pattern of red soils pedon :

The diffraction pattern of clay fraction of red soils pedon of MRS, Vagarai (pedon 1) had shown broad lower

Table 1: d-spacings (A^0) of X-ray diffractograms of soil clay fraction

Pedon	Calcium saturated		Potassium saturated (Temperature ^{0}C)				Clay mineral
	Glycerol solvated	Room temperature	25^0C	110^0C	300^0C	550^0C	
MRS, Vagarai (Red soils)							
Pedon 1: Loamy-Skeletal, Mixed, Isohyperthermic, Non-calcareous, Lithic Haplustalfs							
	16.33	14.69	--	--	--	--	Smectite
	12.76	11.74	--	--	--	--	
	5.03	4.98	9.13	10.11	9.40	9.77	Illite
	3.36	3.30	3.35	9.87	6.85	3.31	
	--	--	--	4.97	4.98	--	
	--	--	--	3.31	3.35	--	
	3.21	-	3.18	--	3.12	3.11	Feldspar
	7.01	7.10	7.07	7.09	7.08	--	Kaolinite
	3.58	3.56	3.55	3.57	3.56	--	
CRS, Veppanthattai (Black soils)							
Pedon 5: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert							
	17.71	14.88	12.39	12.00	18.3	--	Smectite
	16.89	--	11.60	---	--	--	
	9.74	5.66	4.98	3.33	10.03	9.65	
	9.80	4.95	3.26	--	4.88	9.31	
	5.52	3.30	--	--	4.23	4.98	
	3.35	--	--	--	3.35	3.34	Illite
	--	--	--	--	--	3.18	
	--	--	--	--			
	7.01	7.04	7.08	7.08	7.06	--	Kaolinite
	3.50	3.51	3.56	3.56	3.53	--	
DARS, Chettinad (Red laterite soils)							
Pedon 8: Fine Loamy, Kaolinitic, Isohyperthermic, Non calcareous Typic Rhodustalfs							
	7.07	7.14	7.10	7.04	7.08	--	Kaolinite
	3.50	3.57	3.50	3.57	3.56	--	
	9.72	9.85	9.88	9.99	9.85	9.63	Illite
	3.28	4.91	4.85	5.05	3.41	5.82	
	--	3.34	3.27	4.92	3.32	4.87	
	--	--	--	3.34	--	3.35	
	4.16	4.26	4.27	4.17	--	--	Quartz
	--	--	4.08	--	--	--	
	--	--	3.15	3.14	--	3.17	Feldspar
	3.19	--	309	--	3.20	3.13	

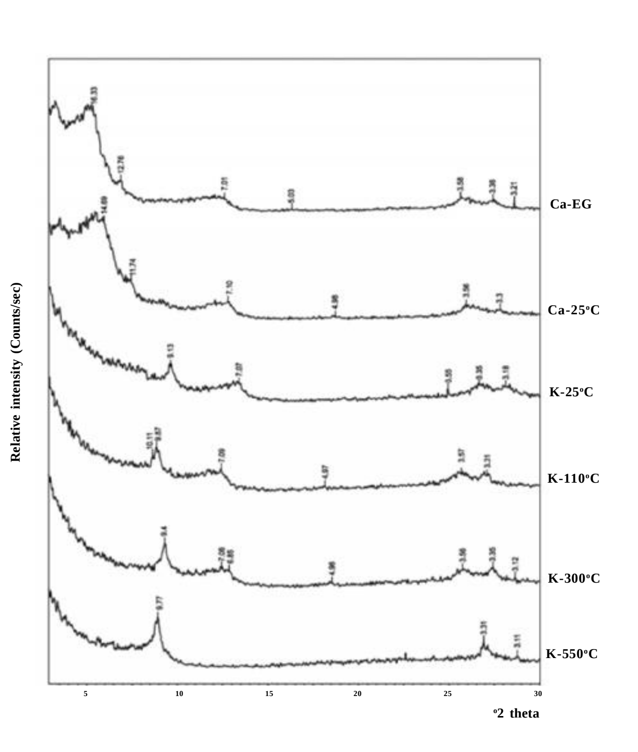

Fig. 1 : X-ray diffractograms of pedon-1(B block) MRS, Vegaral

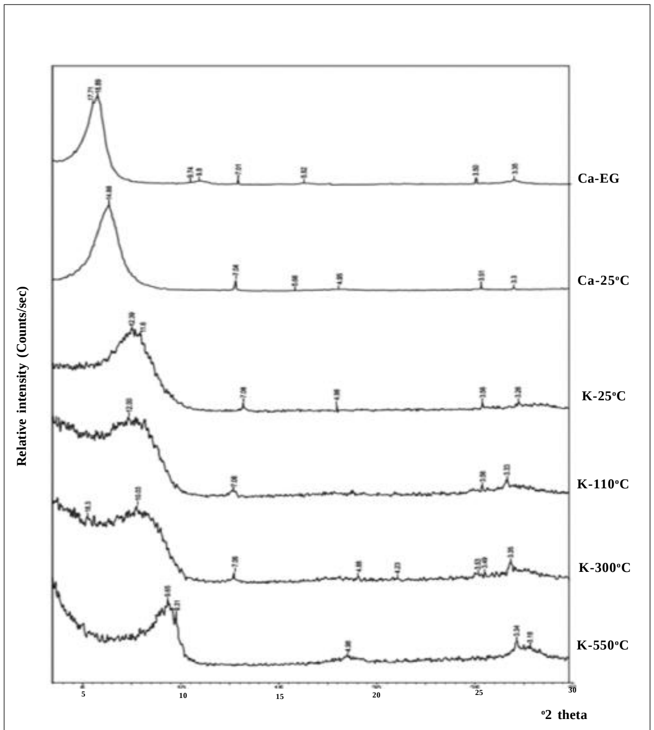

Fig. 2 : X-ray diffractograms of pedon-5 (W block) CRS, Veppanthattai (Vertisol)

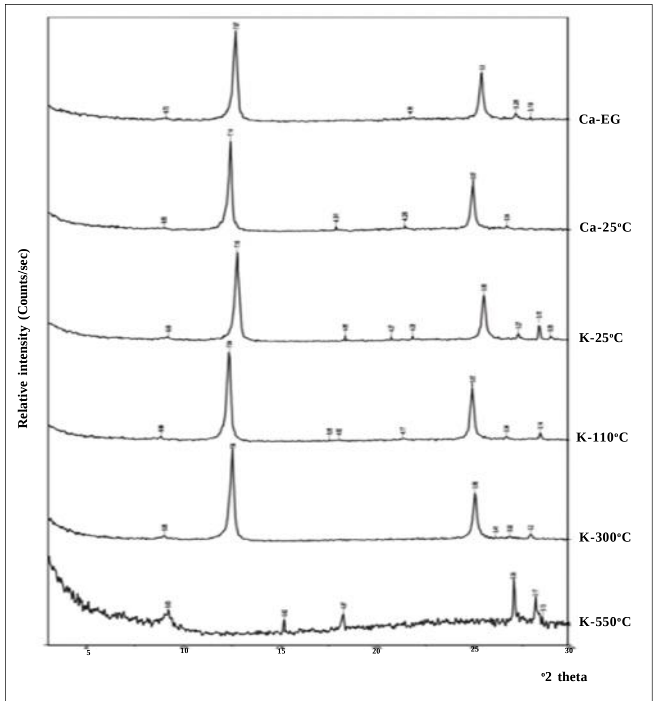

Fig. 3 : X-ray diffractograms of pedon-8 (C block) DARS, Chettinad

order peak of smectite in calcium saturated–glycerol solvated samples at 16.63 and 12.76 A^0 d-spacings. In calcium saturated treatment, the first order peaks were noticed at 14.69 and 11.74 A^0 d-spacings. Hence, these peaks indicated the presence of expanding 2:1 type of clay mineral. Their presence was further confirmed with the diffraction pattern on K treatment and heating. These peaks were shifted to 9.13 A^0 d spacing in K saturated samples followed by peaks at 10.11 and 9.87, 9.40 and 9.77A^0 on heating to 110, 300 and 550^{0}C, respectively; they were converted to illite peaks having about 10 A^0, d- spacing confirmed the presence of smectite. The corresponding peaks observed in the diffractograms of all the six treatments are mentioned in Table 1 and depicted in Fig. 1. Due to the presence of these peaks, it was identified that clay fraction have smectite type of clay minerals. Second and third order peaks corresponding of illite were recorded at d-spacing of 5.03, 4.98, 4.97, 4.98, 3.36, 3.30, 3.35, 3.31, 3.35 and 3.31 A^0 d spacing was observed in all treatments which was very small and sharp. The peaks were persisted and recognized at all most same d-spacing on glycerol solvation, K saturation and heating to 550^{0}C temperature. But the peaks had become large on K saturation and heating due to conversion of 2:1 expanding mineral to non-expanding 2:1 mineral, illite. These peaks were sharp in higher order diffraction. Due to diffraction peaks of this pattern (persistence of 10 A^0, peak in all the treatments), occurrence of illite was recognized in the clay fraction of the soil pedon.

Small, well-defined first order peaks were recorded in calcium saturation treatment at 7.01 A^0, d-spacing. The corresponding second order peaks were noticed at 3.58 A^0. In the other treatments with glycerol solvation and K– saturation, the peaks were observed almost at the same d- spacing in all the diffractograms. But the first order 7 A^0, peak or second order 3.5 A^0 peak were not recorded in the treatment heated to 550^{0}C because of the destruction or collapse of kaolinite at that temperature, these peaks might have vanished. Due to the exhibition of this type of pattern in the diffractograms, the presence of kaolinite was confirmed in the samples. However, the peaks relating to red soils were very sharp compared to peaks recorded in black soil sample.

Feldspar was not the secondary mineral. It is primary in origin. Due to physical weathering, the size of the mineral might have been reduced and occurring in clay fraction of size less than 2 mm. The presence of feldspar in the clay fraction was revealed due to occurrence of small sharp peaks at 3.18, 3.12 and 3.11 A^0 d-spacing in different treatments and it was present only in traces in soil clay fraction. In the clay fraction of red soil pedon, illite (32%), smectite (43%) and kaolinite (21%) were present (Table 2). The CEC / clay ratios of these red soils also indicated the mixed mineralogy. Presence of these three types secondary clay minerals were reported by Sarkar *et al.* (2001); Thangasamy *et al.* (2004) and Singh and Agarwal (2005) in the clay fraction of red soils / Alfisols. The illite might have been inherited from the parent material (Mall and Mishra, 2000; Singh and Sawhney, 2006). The geology of the study area was granitic gneiss complex (Rao *et al.,* 1995). Granitic gneiss was an acid rock containing some mica as essential mineral. Transformation/alteration of mica (primary mineral) of parent rock into illite (secondary mineral) was possible (Sehgal *et al.,* 1974).

X-ray diffraction pattern of black soils pedon :

The diffraction pattern of clay fraction of black soils pedon of CRS, Veppanthattai (pedon 5) had shown typical broad large peak of smectite in calcium saturated – glycerol solvated samples at 17.71 A^0 d-spacing. In calcium saturated treatment, the first order peaks were noticed at 14.88 A^0 d-spacing. These peaks were expanded to higher d-spacing due to glycerol salvation indicated the presence of large quantities of expanding 2:1 type of clay mineral. Their presence was further confirmed with the diffraction pattern on K treatment and heating. These peaks were shifted to 12.39 A^0d spacing in K saturated samples followed by peaks at 12.0, 18.3, 10.03 and 9.65 A^0 on heating to 25,110, 300 and 550 ^{0}C, they were converted to illite peaks having about 10 A^0 and d- spacing confirmed the presence of smectite. The corresponding peaks observed in the diffractograms of all the six treatments are mentioned in the Table 1 and depicted in Fig. 2. Due to the presence of these peaks, it was identified that clay fraction of black soils were dominated by smectite type of clay minerals. The presence of 16.89 and 11.60 A^0 peak in the on glycerol solvation and heated sample is indicative of the occurrence of a small amount of vermiculite mineral in the sample.

Second and third order peaks corresponding of illite were recorded at d-spacing of at 5.52, 4.95, 4.98, 4.88, 4.88, 3.35, 3.30, 3.26, 3.33, 4.23, 3.35, 3.34 and 3.18 A^0 d spacing was observed in all treatments which was very small and sharp. The peaks were persisted and recognized at all most same d-spacing on glycerol solvation, K saturation and heating to 550 ^{0}C temperature. But the peaks had become large on K saturation and heating due to conversion of 2:1 expanding mineral (Smectite) to non-expanding 2:1 mineral, illite. These peaks were sharp in higher order diffraction. Due to diffraction peaks of this pattern (persistence of 10 A^0, peak in all the treatments), occurrence of illite was recognized in the clay fraction of the soil pedon.

Small, well-defined first order peaks were recorded in calcium saturation treatment at 7.01 A^0, d-spacing.

Table 2 : Relative proportion of clay minerals (from X-ray diffractograms of clay fraction)

Pedon	Location	Mineral composition (%)				
		Smectite	Illite	Kaolinite	Quartz	Feldspar
Pedon 1	MRS, Vagarai (Red soils)	43.0	32.0	21.0	--	Traces
Pedon 5	CRS, Veppanthattai (Black soils)	91.0	4.0	2.0	--	--
Pedon 8	DARS, Chettinad (Red laterite soils)	--	7.0	90.0	Traces	Traces

The corresponding second order peaks were noticed at 3.50 A^0. In the other treatments with glycerol solvation and K– saturation, the peaks were observed almost at the same d- spacing in all the diffractograms. But either the first order 7 A^0 peak or second order 3.5 A^0 peak were not recorded in the treatment heated to 550^0C because of the destruction or collapse of kaolinite at that temperature and these peaks were vanished. Due to the exhibition of this type of pattern in the diffractograms, the presence of kaolinite was confirmed in the samples. However, the peaks relating to black soils were very small compared to peaks recorded in red soil samples.

Based on the pattern of X-ray diffraction, it was found that clay fraction of black soils of CRS, Veppanthattai were dominated by smectite type of clay minerals (91.0%) which was the 2:1 expanding (under moist conditions) type of phyllosilicates (Table 2). The dominance of smectite type clay was also confirmed by the CEC / clay ratio. The CEC /clay ratios of these black soils were also higher (more than 0.7). Similar type of clay mineralogy in black soils was reported by Ratnam *et al.* (2001) and Balapande *et al.* (2007).

The black soils were formed at lower topographic positions (nearly level plains to gently sloping). The soluble weathering products including finer soil constituents, calcium carbonate and basic cations and eroded products from surrounding slopes had moved laterally and vertically down the slope and accumulated at the plain topography. Because of the slow permeability, low hydraulic conductivity and restricted drainage of the black soils formed at lower topography these constituents were accumulating in the pedon and not leached / removed out of the pedon. Because of the semi-arid type of climate, the ionic environment was concentrated by basic cations and the base saturation was very high (83.2 to 92.1%). At the same time, there was precipitation and deposition of calcium carbonate resulted either pedogenically or lithogenically. The texture of these soils was very heavy (clay textural class). Because of these conditions, the soil reaction was moderately to strongly alkaline. Thus, the soil environment had created a favourable pathway for the synthesis of smectite type of clay minerals. Formation of smectite took place under such congenial conditions in black soils of Karanataka (Rudramurthy *et al.,* 1997).

X-ray diffraction pattern of red laterite soils pedon:

The diffraction pattern of clay fraction of red laterite soils (pedon 8) had shown typical very sharp large high order peaks which is having characteristic d-spacing of 7 A^0, of the lower order in all the treatments except at the temperature of 550^0C. Kaolinite mineral gets collapsed at this temperature on heating. The presence of kaolinite was identified due to the presence following peaks.

Very large sharp, well-defined first order peaks were recorded in calcium saturation treatment at 7.07 A^0 d-spacing. The corresponding second order peaks were noticed at 3.57 A^0 d-spacing. In the other treatments with glycerol solvation and K– saturation, the peaks were observed almost at the same d- spacing in all the diffractograms. But the first order 7 A^0, peak or second order 3.5 A^0 peak were not recorded in the treatment heated to 550^0C because of the destruction or collapse of kaolinite at that temperature and peaks were vanished. Due to the exhibition of this type of pattern in the diffractograms, the presence of kaolinite was confirmed in all the samples. However, the peaks relating to red laterite soils were very sharp and large compared to peaks recorded in red and black soils samples. The corresponding peaks observed in the diffractograms of all the six treatments were mentioned in the Table 1 and depicted in Fig. 3.

First, second and third order peaks corresponding of illite were recorded at d-spacing of 9.72, 9.85, 9.86, 9.99, 9.85 and 9.63, 4.91, 4.85, 5.05, 5.82 and 4.87, 3.28, 3.34, 3.27, 3.34, 3.41, 3.32, 3.35 and 3.30 A^0 d spacing was observed in all treatments which was very small and sharp. The peaks were persisted and recognized at all most same d-spacing on glycerol solvation, K saturation and heating to 550^0C temperature. But the peaks had become large on K saturation due to non-expanding nature of 2:1 mineral, illite. These peaks were sharp in higher order diffraction. Due to diffraction peaks of this pattern (persistence of 10 A^0, peak in all the treatments), occurrence of illite was recognized in the clay fraction of the soil pedon.

Quartz and feldspar are of primary in origin. Due to physical weathering, the size of the mineral might have been reduced and occurring in clay fraction of size less than 2 mm. The presence of quartz and feldspar in the clay fraction was revealed due to occurrence of small but sharp peaks at 4.16, 4.26 and 4.17 A^0 d-spacing and 3.19, 3.15 and 3.09, 3.14, 3.20, 3.17 and 3.13 A^0 d-spacing, respectively in different treatments. Quartz and feldspar were present only in traces in soil clay fraction.

Highly significant amounts of kaolinite existed in the clay fraction of red laterite soils (Pedon 8) of DARS, Chettinad and very negligible amounts in the clay fraction of black soils. Direct conversion of mica to kaolinite might be one of the causes for the synthesis of kaolinite (Singh and Agarwal, 2005). According to Verma *et al.* (1994), acid leaching and tropical climate were favourable for the formation of kaolinite.

Sehgal (1996) suggested the intensity or the stage of weathering of soils based on the clay minerals present in the soil clay fraction. According to the weathering index of clay size minerals (Jackson, 1964), montmorillonite was 9th while kaolinite was 10th stage of weathering. Black soils (dominated by montmorillonite type of minerals) were grouped under intermediate weathering stage, while, red soils because of the significant proportion of kaolinite could be grouped under advanced weathering stage. This was further confirmed by the CEC/clay ratios (Table 5). Black soils were having relatively high ratios followed by red and red laterite soils. Hence, the black soils were comparatively less weathered than red and red laterite soils. Similar conclusions were drawn by Satyavathi and Reddy (2003).

Chemical composition of soils :

Loss on ignition :

The Loss on Ignition greatly varied among the pedons and within the horizons of each pedon. The black soil pedon of CRS, Veppanthattai had shown highest loss on ignition throughout the depth and a loss of 17.85 per cent occurred for bottom layer of pedon. The high loss in weight on ignition mainly attributed due to the loss of organic matter, $CaCO_3$ content and crystal lattice water in the clay. More the $CaCO_3$ more was the loss due to conversion of $CaCO_3$ to CaO and similarly more the clay content, more was the weight loss due to loss of crystal water held by the clay (Table 3).

Silica :

In general, parent material could be the prime contributing factor for the variation in the silica content of the soils. The chemical composition of the parent material and relative abundance of coarse and fine textural fractions were found to be major contributing factors for the variation in silica content among the pedon. The silica content varied from 53.3 per cent (pedon 8) to 66.6 per cent (pedon 5) in surface horizons whereas in subsurface horizons ranged from 50.3 per cent (pedon

Table 3 : Chemical composition of pedons of the research stations

Pedon	Horizon	Depth (cm)	LOI (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	R_2O_3 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)
MRS, Vagarai (Red soil)											
Pedon 1: Loamy-Skeletal, Mixed, Isohyperthermic, Non calcareous, Lithic Haplustalfs											
	Ap	0-11	3.80	64.1	12.9	14.8	27.7	1.30	0.79	0.23	0.65
	Bt1	11- 23	1.55	60.7	13.0	15.2	28.2	1.40	0.61	0.27	0.57
	Bt2	23-40	1.61	60.0	13.1	14.4	27.5	1.55	0.63	0.27	0.48
	C	40-47	2.41	61.9	10.9	14.8	25.8	1.62	0.81	0.26	0.45
CRS, Veppanthattai (Black soils)											
Pedon 5: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert											
	Ap	0-25	14.62	66.6	16.3	6.1	22.3	6.30	3.27	0.55	0.99
	Bss1	25-71	15.44	65.4	18.8	6.9	25.7	5.89	2.95	0.63	0.88
	Bss1	71-100	14.62	64.3	19.0	7.1	26.1	5.98	3.09	0.70	0.71
	Bss2	100-125	16.05	62.9	17.5	7.2	24.7	6.15	3.56	0.75	0.76
	Ck	125-155	17.85	62.7	15.0	7.7	22.7	7.68	3.93	0.78	0.71
DARS, Chettinad (Red laterite soils)											
Pedon 8: Fine Loamy, Kaolinitic, Isohyperthermic, Non calcareous Typic Rhodustalfs											
	Ap	0-25	3.04	53.3	18.8	26.5	45.3	0.38	0.26	-	0.35
	Bt1	25-32	3.12	52.3	20.2	26.9	47.1	0.31	0.28	-	0.31
	Bt2	32-56	3.20	51.3	20.9	27.3	48.2	0.34	0.26	-	0.30
	Bt3	56-82	3.25	51.0	21.0	27.9	48.9	0.37	0.26	-	0.33
	C	82-105	2.15	53.7	17.0	29.1	46.1	0.39	0.28	-	0.29

8) to 65.4 per cent (pedon 5) (Table 3). A decreasing trend with depth was observed in pedon 5 of CRS, Veppanthattai probably due to presence of higher amount $CaCO_3$ at lower depth. In red laterite soil pedon of DARS, Chettinad the silica content decreased with depth which can be attributed to accumulation of sesequioxides. The removal of silica from the pedon may be a pre-requisite for laterite pedon development. The laterite soil pedon had shown comparatively more amount of SiO_2 might be due to higher quartz content within the landform sequence where the soils developed over young land form unit (upper pediments) as compared to lower pediments. Sidhu *et al.* (1998) also reported similar findings. The high silica content in surface and subsurface horizons due to the pedon developed on granite-gneiss weathered parent material.

The significant positive correlation with sand (r = 0.639**) and negative correlation with clay (r = -0.648**) had confirmed the relation between sand and silica (Table 6). Ramesh *et al.* (2004) obtained similar trends in red and black soils of Andhrapradesh. The mobilization of silica did not take place because it was soluble only under acid and neutral pH and solubility was very low under alkaline medium (Sehgal, 1996). Hence, accumulation had taken place in upper horizons.

Sesquioxides :

The trends of alumina, iron oxides (sesquioxides) were quite opposite to that of silica. They exhibited the trend of clay which, increased with depth. The result revealed that increase in clay content increased Al_2O_3 content and also it had registered a significant positive correlation with clay (r = 0.647**) and negative with sand (r=-0.643**). The variation was found to be dependent on the degree of replacement of Octahrdral Al^{3+}, Mg^{2+} and Fe^{2+}. Similar observations were made by Subbiah and Manickam (1992). The great variation found in Fe_2O_3 content among the pedons of red soils, black soils and red laterite soils but more or less uniformity within the horizon of each pedon. An increase of iron oxides with depth was noticed because of translocation and mobilization and /or illuviation. Higher the clay content more would be the accumulation of Fe_2O_3. These observations were in conformity with those of Manjulatha *et al.* (2001) and Singh and Agarwal (2005). Significant positive correlation (r = 0.755**) also existed

Table 4 : Molar concentrations and molar ratios of the pedons of research stations

Pedon	Horizon	Depth (cm)	Molar concentrations (%)				Molar ratios			
			SiO_2	Al_2O_3	Fe_2O_3	R_2O_3	SiO_2/R_2O_3	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3
MRS, Vagarai (Red soil)										
Pedon 1: Loamy-Skeletal, Mixed, Isohyperthermic, Non calcareous, Lithic Haplustalfs										
	Ap	0-11	1.068	0.126	0.092	0.218	4.88	8.45	11.5	1.36
	Bt1	11- 23	1.012	0.127	0.095	0.222	4.55	7.94	10.6	1.34
	Bt2	23-40	1.000	0.128	0.090	0.218	4.57	7.78	11.1	1.42
	C	40-47	1.033	0.100	0.093	0.200	5.01	9.64	11.1	1.15
CRS, Veppanthattai (Black soils)										
Pedon 5: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert										
	Ap	0-25	1.109	0.159	0.037	0.197	5.61	6.94	29.3	4.21
	Bss1	25-71	1.091	0.184	0.043	0.227	4.79	5.91	25.2	4.26
	Bss1	71-100	1.072	0.186	0.044	0.230	4.64	5.75	24.1	4.19
	Bss2	100-125	1.012	0.171	0.045	0.216	4.67	5.90	22.5	3.81
	Ck	125-155	1.002	0.147	0.048	0.195	5.13	6.81	20.8	3.05
DARS, Chettinad (Red laterite soils)										
Pedon 8: Fine Loamy, Kaolinitic, Isohyperthermic, Non calcareous Typic Rhodustalfs										
	Ap	0-25	0.888	0.184	0.166	0.350	2.53	4.82	5.35	1.11
	Bt1	25-32	0.872	0.198	0.168	0.366	2.38	4.40	5.17	1.17
	Bt2	32-56	0.855	0.204	0.171	0.375	2.27	4.17	5.00	1.19
	Bt3	56-82	0.850	0.205	0.174	0.380	2.23	4.13	4.87	1.17
	C	82-105	0.895	0.166	0.181	0.348	2.56	5.37	4.92	0.91

in between clay and Fe_2O_3 (r=0.755**) and clay and R_2O_3 and negative correlation found in between sand with Fe_2O_3 (r=-0.788**) and R_2O_3 (r= -0.762**) indicated that the sesequioxides of soil fraction existed more in clay fraction (Table 6).

Silica-sesquioxides ratios :

The molar ratio of silica-sesquioxides in different horizons of red soils pedon and red laterite soils pedon varying from 4.55 to 5.01 and 2.23 to 2.56, respectively, whereas in the black soils pedon ranges from 4.64 to 5.61. The molar ratio of silica-alumina in different horizons of red soils pedon and red laterite soils pedon varying from 7.78 to 9.64 and 4.13 to 5.37, respectively, whereas in the black soils pedon ranges from 5.75 to 6.94 (Table 3). The wider ratios of SiO_2/R_2O_3 and SiO_2/Al_2O_3 were found in the black soils followed by red soils which might be due to the smectite and illite as dominant clay minerals in soils, respectively. Similarly narrow ratio was the characteristic feature of red laterite soils where the kaolinite was found to be dominant clay mineral (Subiah and Manickam, 1992). The molar ratios of silica–

Table 5 :CEC/clay ratios of the fine earth fractions of pedons

Pedon	Horizon	Depth (cm)	Total sand (%)	Silt (%)	Clay(%)	BSP (%)	CEC [cmol (p+) kg^{-1}]	CEC/ Clay ratio
MRS, Vagarai (Red soil)								
Pedon 1: Loamy-Skeletal, Mixed, Isohyperthermic, Non calcareous, Lithic Haplustalfs								
	Ap	0-11	63.3	13.8	22.9	76.0	16.8	0.73
	Bt1	11- 23	64.6	12.0	23.4	77.0	15.6	0.66
	Bt2	23-40	59.8	12.5	27.7	78.8	15.2	0.55
	C	40-47	65.6	17	17.4	85.6	15.0	0.66
CRS, Veppanthattai (Black soils)								
Pedon 5: Fine, Montmorillonitic, Isohyperthermic, Calcareous, Typic Haplustert								
	Ap	0-25	29.2	16.0	54.8	83.2	45.5	0.83
	Bss1	25-71	26.4	18.0	55.6	86.9	46.4	0.83
	Bss1	71-100	23.8	19.0	57.2	88.8	46.7	0.81
	Bss2	100-125	20.7	15.0	64.3	89.8	48.8	0.75
	Ck	125-155	22.4	20.0	57.6	91.4	47.9	0.83
DARS, Chettinad (Red laterite soils)								
Pedon 8: Fine Loamy, Kaolinitic, Isohyperthermic, Non calcareous Typic Rhodustalfs								
	Ap	0-25	70.4	4.7	24.9	41.4	6.3	0.25
	Bt1	25-32	63.5	5.3	31.2	43.6	6.3	0.20
	Bt2	32-56	54.5	7.1	38.4	46.5	6.6	0.17
	Bt3	56-82	51.9	7.2	40.9	48.1	6.7	0.16
	C	82-105	60.6	9.0	30.4	50.0	6.6	0.21

Table 6 : Correlation co-efficient (r) values between fine earth fractions and silica-sesequioxides

	Sand	Silt	Clay	LOI	SiO_2	Al_2O_3	Fe_2O_3	R_2O_3
Sand	1							
Silt	-.740**	1						
Clay	-.972**	.561**	1					
LOI	-.726*	.250	.708*	1				
SiO_2	.639**	.184	-.648**	-.567	1			
Al_2O_3	-.643**	-.193	.647**	-.168	-.472**	1		
Fe_2O_3	-.788**	-.106	.652**	-.817**	-.884**	.487**	1	
R_2O_3	-.762**	-.166	.755**	-.737**	-.871**	.672**	.974**	1

* and ** indicate significance of values at P=0.05 and 0.01, respectively (2-tailed)

iron oxides in different horizons of red soils pedon and red laterite soils pedon varying widely from 10.6 to 11.5 and 4.87 to 5.35, respectively, whereas in the black soils pedon ranges from 20.8 to 29.3 (Table 4). The molar ratio of alumina- iron oxides in different horizons of red soils pedon and red laterite soils pedon varying from 1.15 to 1.42 and 0.91 to 1.19, respectively, whereas in the black soils pedon ranges from 3.05 to 4.26. Soils of granite origin and the soils with sand fraction recorded higher molar ratios of SiO_2/Fe_2O_3. These ratios were, in general, broader and wider indicating the siliceous nature of parent material (Ramesh *et al.*, 2004).

Conclusion :

The results indicate clearly that the black soils pedon was characterised by the content of smectite as the major mineral with low content of illite and kaolinite in the clay fraction. The clay mineral composition of the red soil was "mixed" with smectite, illite and kaolinite type of clay minerals. The red laterite soil is characterised by the dominanance of kaolinite with small quantities of illite. The chemical composition of soils exhibited the siliceous nature with broad and large silica/sesquioxides and silica/alumina ratios. The wider ratios of SiO_2/R_2O_3 and SiO_2/Al_2O_3 was found in the black soils pedon followed by red soils pedon where smectite and illite were the dominant clay minerals and narrow ratio was found in red laterite soils where Kaolinite was dominant clay mineral. The red laterite soils of Sivaganga district appeared to be more weathered than the red and black soils of Maize Research Station, Vagarai (Dindigal District) and Cotton Research Station, Veppanthattai (Perambulur district), respectively.

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