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CLAY MINERALOGY OF SUGARCANE SOILS FORMED ON GRANITE-GNEISS PARENT MATERIAL OF CHITTOOR DISTRICT, ANDHRA PRADESH

P.A. VISALAKSHI DEVI[1] AND M.V.S NAIDU[2]*

Department of Soil Science and Agricultural Chemistry, S.V. Agricultural College, ANGRAU, Tirupati- 517502, Andhra Pradesh

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ABSTRACT

Mineralogy of clay fractions using X-ray diffraction technique and characteristics of sugarcane growing soils developed from granite-gneiss parent material in Chittoor district of Andhra Pradesh under semi-arid climate were studied during 2012. The clay fraction of these soils exhibited the characteristic peaks of smectite, illite and kaolinite. Semi-quantification of clay fractions based on relative areas under corresponding peaks indicated that the pedon 1 was dominated by kaolinite followed by illite, feldspars and smectite. Pedons 2 and 6 were dominated by smectite followed by illite, kaolinite and feldspars. Pedons 3 and 4 were dominated by smectite followed by kaolinte, feldspars and illite whereas pedon 5 was dominated by smectite followed by kaolinite, illite and quartz and pedon 7 dominated by illite followed by kaolinite, smectite and feldspars. The formation of smectite suggests that these soils were formed through a progressive landscape reduction process and appears to be under basic environment. Chemical composition showed that soils were neutral to strongly alkaline in reaction, non-saline with CEC ranging from 1.30 to 28.80 cmol (p+) kg^{-1} soil.

Key words: *Clay mineralogy, illite, kaolinite, smectite, sugarcane soils*

INTRODUCTION

Clay is an important soil constituent that controls its properties and also influences its management and productivity (Davies *et al.,* 1972). Clay with cementing agents contributes structural stability that helps in resisting the destructive effects of rain and wind. Moreover, clays have a large specific surface area that is mostly negatively charged and these sites retain nutrients like K^+ and NH^+ ions and also adsorb many toxic elements. The mineralogy of soil clays is the result of several factors interacting with the parent material. In certain combination of circumstances soil forming processes exhibit their effects on the clay mineralogy viz., Oxisols, Vertisols and Andisols (Newman, 1984). Soil mineralogy, which is closely linked to soil texture, is a major determinant of physical and chemical properties of soils (Sumner, 2000). Soil mineralogy defines the capacity of soil minerals to adsorb and protect organic carbon, which depends on the specific surface area and surface charge characteristics of the mineral (Krull *et al.,* 2001, Zinn, 2005). Knowledge of clay minerals in soils is thus critical to our understanding and use of soil. However, there is no information available on the clay mineralogy of sugarcane growing soils of Chittoor district. Hence, the present investigation was carried out to identify the clay minerals in these soils for their sustainable management.

MATERIALS AND METHODS

Study Area

The study area lies in between 12^o 37" and 14^o 80" N latitude and 78^o 33" and 79^o 55" E longitude. The climate of the area is semi-arid monsoonic with distinct summer, winter and rainy seasons. The annual precipitation was 893.63 mm of which 94.31 per cent was received during May to December. The mean annual soil temperature was 27.70^{o}C with a mean summer and winter temperatures of 31.77^{o}C and 26.99^{o}C, respectively. The area qualifies for isohyperthermic temperature regime. The soil moisture control section remains dry for more than 90 cumulative days or 45 consecutive days in four months following summer solistice and qualifies for ustic soil moisture regime. The soils of the study area are developed from granite-gneiss parent material. The natural vegetation of the study area was *Parthenium hysterophorus, Calotropis gigantia, Tridax procumbens, Pongamia pinnata, Azardirachta*

[1]*Research Associate and* [2] *Professor* (venkata_naidu8888@yahoo.com)*

indica, Lantana camera, Cyperus rotundus and *Cynodon dactylon*.

Seven representative pedons (P1 to P7) in sugarcane growing soils of Chittoor district in Andhra Pradesh were selected after surveying the area in the year 2011. The horizon-wise soil samples were collected for analysis of chemical parameters whereas the samples collected from control section (25-100cm) of the pedons were analysed for clay minerals. The samples were air-dried at room temperature and stored in polyethylene bags. The air-dried samples were crushed, passed through a 2 mm sieve, mixed and stored for analysis. The chemical parameters were determined by following standard procedures. The clay fractions were separated by sedimentation technique (Jackson, 1979). The clays (< 2μm) were isolated by removing organic matter, sesquioxides and allophones. Basically oriented clay samples (Mg-25^{O}C, Mg-glycerol, K-25^{O}C and K-550^{O}C heated) were subjected to X-ray diffraction studies. The X-ray diffractograms were recorded in Philips diffractometer (Model 1140) using Ni-filtered Cu-Kα radiation at a scanning speed of 2^{O} 2θ per min. Identification and semi-quantitative estimation of clay minerals was also carried out based on peak intensities (Gjems, 1967).

RESULTS AND DISCUSSION

The general characteristics of the study area have been represented in Table 1. The soils were developed on granite-gneiss parent material. P1, P2 and P5 were located on plains while P3, P4, P6 and P7 were developed on uplands. Moderate erosion was observed in pedons 3, 4, 6 and 7 while others did not show any erosion. The drainage was moderately well drained.

Table 1: Salient site characteristics of the profiles in the study area

Features	Pedon 1 (Neruvoi*)	Pedon 2 (Palamangalam*)	Pedon 3 (Gollapalle*)	Pedon 4 (Vonaruvaripalli*)	Pedon 5 (Digavapokalavaripalli*)	Pedon 6 (Gattivaripalli*)	Pedon 7 (KMV Palli*)
Physiography	Plain	Plain	Upland	Upland	Plain	Upland	Upland
Slope (%)	0-1	0-1	3-8	3-8	0-1	3-8	3-8
Elevation (msl)	120m	120m	120m	120m	120m	120m	120m
Drainage	Moderately well drained	Moderately well drained	Moderately well drained	Moderately well drained	Moderately well drained	Moderately well drained	Moderately well drained
Parent material	Weathered gneiss	Weathered gneiss	Weathered gneiss	Weathered gneiss	Weathered gneiss	Weathered gneiss	Weathered gneiss
Erosion	Very slight	Very slight	Moderate	Moderate	Very slight	Moderate	Moderate
Land use	Sugarcane crop	Sugarcane crop	Sugarcane crop	Sugarcane crop	Sugarcane crop	Sugarcane crop	Sugarcane crop

**Name of the village*

Chemical composition

The data on chemical composition (Table 2) revealed that, the pH of the soils ranged from 7.35 (neutral) to 8.21 (strongly alkaline). Cation exchange capacity of the soils varied between 1.30 and 28.80 cmol (p^+) kg^{-1} in different horizons and was positively and significantly correlated with clay (r = +0.756**) and negatively and significantly with sand (r = -0.669**). The base saturation ranged from 53.19 to 94.05 per cent. The higher base saturation in some pedons might be due to higher amount of Ca^{+2} occupying exchange sites on the colloidal complex and also may be due to recycling of basic cations through vegetation. Higher values (8.21) of loss on ignition (LOI) may be due to the presence of expanding type of clay minerals. The values of SiO_2 and Al_2O_3 indicated the occurrence of appreciable amounts of 2:1 type of clay minerals. The Fe_2O_3 content of clays in these soils suggested the presence of iron-bearing minerals. Values of MgO and CaO indicate the presence of minerals rich in magnesium and calcium. The K_2O content in all the pedons indicates the presence of K-bearing clay minerals (Raina *et al.,* 2006). Relatively higher values of P_2O_5 in the soil might be due to the presence of P-bearing minerals such as calcium apatite and also due to use of higher doses of phosphatic fertilizers (Table 2).

Table 2: Chemical composition of the sugarcane growing soils

Pedon no. & horizon	Depth (m)	pH (1:2.5)	EC (dS m^{-1})	CEC [cmol (p^+) kg^{-1}]	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	P_2O_5 (%)	K_2O (%)	Na_2O (%)	CaO (%)	MgO (%)	LOI (%)
Pedon 1	Neruvoi (Fine -loamy, kaolinitic, isohyperthermic Ultic Haplustalfs)												
Ap	0.00-0.20	7.64	0.01	8.52	79.60	3.16	8.52	0.13	0.15	1.22	2.73	2.09	4.80
Bw	0.20-0.47	7.63	0.03	8.05	82.04	3.68	6.68	0.08	0.27	1.45	2.45	1.39	4.60
Bt	0.47-0.65	7.37	0.08	9.50	74.80	5.22	12.10	0.10	0.38	1.88	2.03	1.29	6.62
BC1	0.65-0.87	7.39	0.24	4.54	80.75	4.03	7.64	0.09	0.23	1.27	2.66	1.08	4.84
BC2	0.87-1.06	7.43	0.06	4.67	81.40	4.78	5.12	0.09	0.28	1.42	3.36	0.95	5.24
BC3	1.06-1.30	7.40	0.06	5.60	77.20	4.83	9.11	0.08	0.29	1.58	3.36	0.75	5.35
BC4	1.30-1.60 +	8.21	0.05	5.38	75.20	5.96	7.98	0.11	0.28	1.43	3.92	2.32	7.11
Pedon 2	Palamangalam (Sandy, smectitic, isohyperthermic Typic Dystrustepts)												
Ap	0.00-0.22	8.19	0.14	10.41	86.75	2.55	5.15	0.14	0.15	1.17	2.24	0.60	3.85
Bw	0.22-0.40	8.12	0.17	15.52	82.70	3.22	7.26	0.09	0.22	1.10	3.01	0.10	3.69
BC	0.40-0.52	8.12	0.03	11.82	85.85	3.26	4.95	0.10	0.20	0.98	2.31	0.20	3.69
2C1	0.52-0.71	8.04	0.13	1.36	90.04	1.22	2.46	0.12	0.07	1.16	2.52	0.45	1.14
2C2	0.71-1.00	7.92	0.08	1.30	89.24	1.19	4.88	0.09	0.05	1.10	1.54	0.15	0.99
3C3	1.00-1.30 +	8.03	0.13	14.10	80.58	4.45	8.19	0.09	0.25	1.31	1.96	0.75	4.05
Pedon 3	Gollapalle (Fine-loamy, smectitic, isohyperthermic Typic Ustorthents)												
Ap	0.00-0.23	8.05	0.06	28.12	77.35	4.70	11.92	0.09	0.34	1.17	1.68	1.10	5.81
2A1	0.23-0.38	7.80	0.10	6.52	88.15	2.20	3.91	0.12	0.14	1.27	1.22	1.14	2.29
3A2	0.38-0.59	7.64	0.07	28.80	84.28	4.22	7.14	0.13	0.19	1.16	0.91	0.25	3.80
Pedon 4	Vonaruvaripalle (Fine-loamy, smectitic, isohyperthermic Typic Ustorthents)												
Ap	0.00-0.15	7.51	0.14	6.95	90.31	1.80	3.02	0.09	0.09	1.27	0.98	0.25	2.75
A1	0.15-0.28	7.58	0.02	3.04	87.26	1.82	6.04	0.09	0.18	1.23	0.91	0.73	0.65
A2	0.28-0.48	7.55	0.13	17.46	85.70	3.09	5.16	0.10	0.20	1.25	1.61	1.59	6.69
Cr	0.48	Weathered gneiss											
Pedon 5	Digavapokalavaripalli (Fine-loamy, smectitic, isohyperthermic Typic Haplustepts)												
Ap	0.00-0.20	7.88	0.08	31.71	83.48	3.50	7.54	0.15	0.20	1.25	1.61	0.65	8.21
Bw1	0.20-0.41	8.08	0.10	14.32	85.64	3.45	5.55	0.11	0.20	1.23	1.96	0.10	4.30
Bw2	0.41-0.60	7.91	0.03	16.64	85.20	3.53	5.64	0.09	0.15	1.12	1.47	0.20	3.85
Bw3	0.60-0.83	7.94	0.16	6.25	87.28	2.45	5.29	0.08	0.11	1.19	1.33	0.25	5.15
Bw4	0.83-1.10	7.81	0.20	19.65	87.01	2.69	5.80	0.07	0.11	1.11	1.47	0.15	3.20
Cr	1.10	Weathered gneiss											
Pedon 6	Gattivaripalli (Fine-loamy, smectitic, isohyperthermic Typic Haplustepts)												
Ap	0.00-0.22	7.67	0.03	16.83	84.86	3.36	7.57	0.14	0.16	1.23	1.19	0.15	3.45
Bw1	0.22-0.48	7.43	0.24	13.75	83.26	3.68	7.53	0.12	0.15	1.09	1.54	0.79	2.84
Bw2	0.48-0.73	7.35	0.02	11.62	85.20	4.90	6.45	0.14	0.21	1.26	0.84	0.20	4.00
Bw3	0.73-1.00	7.42	0.18	12.38	80.65	5.75	8.58	0.12	0.16	1.23	1.26	0.30	4.20
Cr	1.00	Weathered gneiss											
Pedon 7	KMV Palli (Sandy, mixed, isohyperthermic Typic Ustorthents)												
Ap	0.00-0.23	7.80	0.03	13.35	87.15	2.36	4.76	0.14	0.18	1.22	1.19	0.25	3.90
A2	0.23-0.52	7.98	0.41	5.71	90.75	1.52	3.42	0.14	0.12	1.10	0.70	0.20	2.60
Cr	0.52	Weathered gneiss											

X-ray Diffraction

The X-ray diffraction pattern of clay fraction indicated that pedon 1 contained kaolinite (67%) (dominant), illite, feldspars and smectite (Fig. 1). The intense dominant peak at 0.724 nm and 0.358 nm d-spacing in Mg-saturated ethylene glycol solvated treatment indicated the presence of kaolinite. A sharp large peak was observed at 1.008 nm d-spacing followed by higher order peaks at 0.506 and 0.333 nm d-spacings in Mg-saturated ethylene glycol solvation treatment and in K-25^{o}C treatment and persistence of these peaks at K-550^{o}C treatment indicated the presence of illite clay mineral. The peak position at 1.342 nm d-spacing in Mg-saturated sample shifted to 1.685nm upon ethylene glycol solvation suggested the presence of smectite. Feldspars were identified by a small peak at 0.304 nm in Mg-saturated ethylene glycol solvation and Mg-saturated at room temperature treatments, respectively.

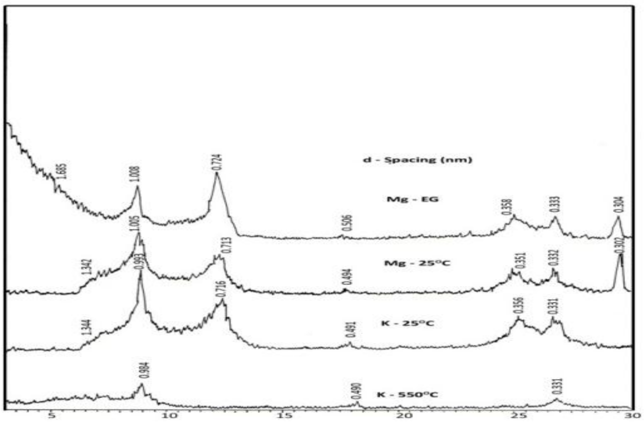

Fig. 1: Representative XRD diagrams of fine -loamy, kaolinitic, isohyperthermic Ultic Haplustalfs (0.2µm) of Pedon 1

In clay fraction of pedon 2, smectite (45%) was the dominant mineral followed by illite, kaolinite and feldspars (Fig. 2). A strong peak at 1.234 nm d-spacing in Mg-saturated sample which expanded to 1.701 nm d-spacing with Mg-saturated ethylene glycol solvated treatment indicated the presence of smectite. The presence of weak peaks at 1.003 nm, 0.500 nm and 0.335 nm is indicative of illite. Small peaks at 0.711nm and 0.355 nm d-spacings and their persistence in all the treatments except at K-550^{O}C confirmed the presence of kaolinte. A characteristic peak at 0.304 nm d-spacing indicated the presence of feldspars.

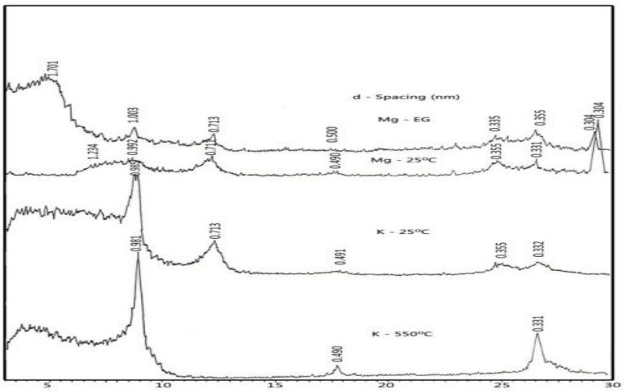

Fig. 2: Representative XRD diagrams of Sandy, smectitic, isohyperthermic Typic Dystrustepts (0.2µm) of Pedon 2

Smectite was the dominant clay mineral followed by kaolinite and illite (Fig. 3). The Mg-saturated sample in pedon 3 showed a peak at 1.228 nm d-spacing and its shift to 1.654 nm indicated the presence of smectite. The peaks at 0.717 nm d-spacing and 0.355nm in all the treatments except in K-550^{O}C treatment confirmed the presence of kaolinite. Feldspars and illite were recognized by the presence of small peaks at 0.303 nm and 1.013 nm, 0.495 nm and 0.334 nm respectively.

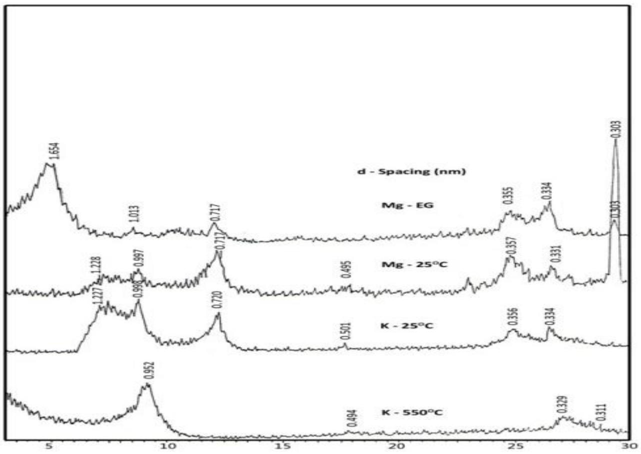

Fig. 3: Representative XRD diagrams of Fine-loamy, smectitic, isohyperthermic Typic Ustorthents (0.2µm) of Pedon 3

A peak at 1.221 nm and the other at 1.652 nm in pedon 4 on glycolation, confirmed the presence of smectite (Fig.4). The sharp peak at 0.724 nm followed by a high angle diffraction maxima at 0.355 nm in different treatments confirmed the presence of kaolinite as explained earlier. Further, a small peak at 0.301 nm d-spacing confirmed the presence of feldspars. The peaks at 1.013 nm, 0.491 nm and 0.335 nm d-spacings showed the presence of illite.

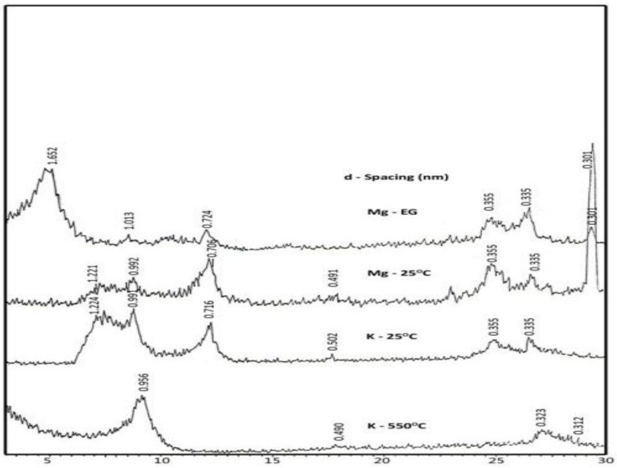

Fig. 4: Representative XRD diagrams of Fine-loamy, smectitic, isohyperthermic Typic Ustorthents (0.2µm) of Pedon 4

The Mg-saturated sample in pedon 5 showed a peak at 1.682 nm d-spacing which indicated the confirmation of smectite (Fig.5). The peaks at 0.722 nm and 0.358 nm d-spacing in all the treatments except in K-550^{O}C treatment confirmed the presence of kaolinite. Presence of a sharp peak at 0.995 nm, 0.498 nm and 0.332 nm in all the treatments suggests the presence of mica. The peaks were not affected by glycerol treatment or by heating up to 550^{O}C, thereby confirmed that the degree of hydration of mica was not much. Very small peak at 0.415 nm confirmed the presence of quartz.

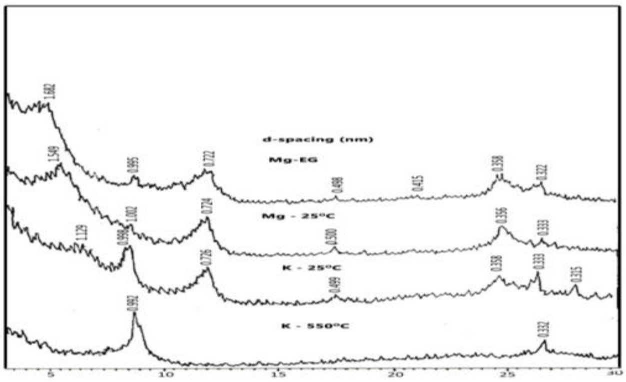

Fig. 5: Representative XRD diagrams of Fine-loamy, smectitic, isohyperthermic Typic Haplustepts (0.2µm) of Pedon 5

An intense large peak in pedon 6 at 1.232 nm in Mg-saturated sample which expanded to 1.703 nm on ethylene glycolation confirmed the presence of smectite (Fig.6). Presence of large peaks at 1.003 nm, 0.504 nm and 0.332 nm d-spacing in all the treatments suggests the presence of mica. Kaolinite was recognised by a large intense peak at 0.715 nm

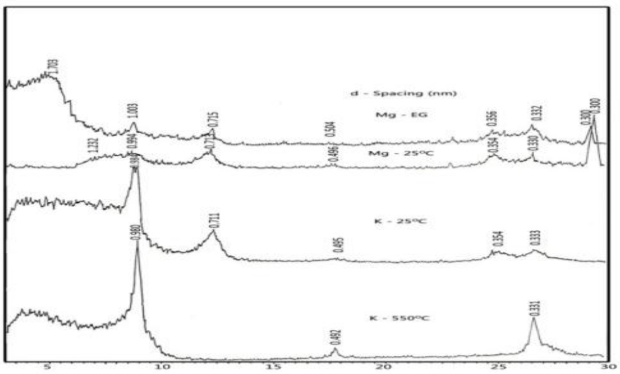

Fig. 6: Representative XRD diagrams of Fine-loamy, smectitic, isohyperthermic Typic Haplustepts (0.2µm) of Pedon 6

in all the treatments, but it disappeared in K-saturated sample heated to 550^{O}C. A characteristic peak at 0.300 nm d-spacing confirmed the presence of feldspars.

Pedon 7 showed a mixed mineralogy with no dominance of any specific mineral (Fig.7). The abundant quantity of illite in pedon 7 was detected by the presence of a sharp peak at 0.996 nm, 0.499 nm and 0.334 nm which persisted in all the treatments. The small peak at about 0.716 nm and 0.355 nm d-spacing in all the treatments except in K-saturation and heating at 550^{o}C is indicative of kaolinite. A high intensity peak at 1.415 nm in Mg-saturated sample which shifted to 1.711 nm on ethylene glycol solvation indicated the presence of smectite. Small quantities of feldspars were recognized by the presence of a sharp and low intensity peak at 0.304 nm.

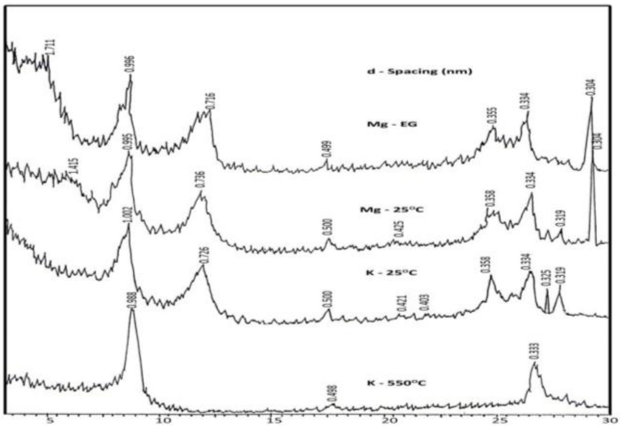

Fig. 7: Representative XRD diagrams of Sandy, mixed, isohyperthermic Typic Ustorthents (0.2µm) of Pedon 7

Genesis of clay minerals

The clay fraction of soils in the present study was found to be a mixture of three clay minerals *viz.,* smectite, illite and kaolinite. Smectite was the single most dominant mineral in pedons 2, 3, 4, 5, 6, whereas kaolinite was the dominant mineral in pedon 1. In pedon 7 no dominance of any specific mineral was observed. It is quite unlikely that such a high amount of smectite in these soils could be produced during the low rainfall period of the present semi-arid conditions (Bhattacharyya *et al.,* 1993). Smectite was also formed possibly from plagioclase during earlier geologic period and was an ephemeral in humid environment (Tardy *et al.,* 1973 and Bhattacharyya *et al.,* 1993), however its retention was possible because of climate change from humid to semi-arid during pleistocene transition period (Pal *et al.,* 1989).

Kaolinite was the dominant mineral in pedon 1. Kaolinite present in this pedon might had been formed from smectite (Bhattacharyya *et al.,* 1993). Kaolinite minerals could be formed by neosynthesis from the products of hydrolytic decomposition of feldspars and other primary minerals (Geetha Sireesha *et al.,* 2015) and by conversion of smectite or vermiculite to kaolinite following hydroxy interlayering in the expandable mineral or mixed layering between 2:1 and 1:1 layers (Pal *et al.,* 1989 and Bhattacharyya *et al.,* 2000). Further, the kaolinite was formed in an earlier geological period with more rainfall and greater fluctuations in temperature (Pal and Deshpande, 1987). The study area had also experienced the above conditions, which lead to synthesis of kaolinite mineral in pedon 1.

Table 3: semiquantitative estimats of clay minerals (%)

Pedon No.	Tentative soil series	Smectite	Kaolinite	Illite	Feldspars	Quartz
1	Neruvoi	3	67	18	12	-
2	Palamangalam	45	20	20	15	-
3	Gollapalle	54	22	10	14	-
4	Vonaruvaripalli	51	29	7	13	-
5	Digavapokalavaripalli	65	15	15	Tr	5
6	Gattivaripalli	50	15	22	13	-
7	KMV Palli	24	30	33	13	-

Illite was present in small quantities in all the pedons. Illite present in the clay might have been derived by alteration of micas from the parent material. Potassium bearing minerals of rocks under the prevailing conditions of the soil formation had led to formation of illitic type of minerals (Satyanarayana and Biswas, 1970). Quartz was present in small quantities in these soils.

Clay mineralogy investigation by X-ray diffraction technique indicated that smectite was the dominant clay mineral in almost all the pedons except pedons 1 and 7. Kaolinite was dominant mineral in pedon 1 and pedon 7 showed mixed mineralogy. The relative similarities in the mineralogy of these granite-gneiss derived soils irrespective of the degree of pedogenesis suggested that all the clay minerals were inherited from the parent material with very little *in- situ* transformation under prevailing conditions. The information regarding the relative proportion of various minerals is vital for effective management of soils.

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