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Clay Minerals in two Ferruginous Soils of Southern India

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Abstract : *Two Benchmark ferruginous soils namely Jamkhandi and Palathurai have been taken for this study. In contrast to the general understanding, these ferruginous soils are calcareous and alkaline in nature. Layer silicates present in silt, coarse clay and fine clay fractions of these soils are also in sharp contrast to those of ferruginous soils reported earlier. Dominant presence of smectite in all the size fractions is very common alongwith mica. Kaolinite is present in Jamkhandi soils. Under the prevailing semi-arid environment neither such a huge amount of smectite nor kaolinite can be formed. These soils have suffered truncation as evident from their thin Ap horizon followed by Bt horizon of >30 per cent clay, exposing a relatively unweathered soil formed in pre-Pliocene tropical humid climate. Smectite in fine clay fractions of Jamkhandi soils have both high and low charge density, whereas smectite in silt and coarse clay fractions have high charge. Mica present in silt and coarse clay fractions consists of more biotite than muscovite and it survived tropical weathering. In the present semi-arid climate biotite has weathered to high charge smectite. Aridity also induced the precipitation of calcium carbonate. Therefore, high amount of weatherable minerals in ferruginous soils of southern India has distinct relevance in their water and K-management. It appears that detailed clay mineralogical information should form one of the criteria for soil-site evaluation for better management of ferruginous soils of semi-arid tropical regions of Southern India.*

In India, ferruginous soils (Rengasamy *et al.*, 1978) occupy about 72 m ha and occur in varied ecosystems ranging from arid to subhumid region with an average annual rainfall varying from 300 to 4000 mm. Due to their occurrence in such varied ecosystems, relationship between their spatial distribution as different categories differentiated by soil classification system and the soil forming factors (Jenny, 1941, 1961, 1980) is extremely difficult to establish. Some scientist consider that these soils are developed under present day climate (Govinda Rajan and Gopala Rao, 1978) but others (Mohr *et al.*, 1972; Murali *et al.*, 1974; Rengasamy *et al.*, 1978;

Bronger and Bruhn, 1989 ; Pal and Deshpande, 1987; Pal *et al.*, 1989) suggests that these are relict soils formed in a more tropical environment of the pre-Pliocene period. Since then the active soil forming factors must have changed considerably. Presently, climate in major part of the Peninsular India changed into semi-arid tropics, thereby making the soils relict or polygenetic in nature (Pal *et al.*, 1989; 1999).

The present study was undertaken to gain information on the clay mineralogical composition that may have some relevance in the management of these soils for better agricultural productivity.

Materials and Methods

Two Benchmark ferruginous soils, Jamkhandi series of Bijapur district, Karnataka and Palathurai series from Coimbatore district, Tamil Nadu, described by Murthy *et al.* (1982) were selected for this study. Both areas experience semi-arid subtropical climate with an average annual rainfall of 575 to 600 mm. Jamkhandi soils are developed in mixed alluvium derived from sandstone and quartzite on gently sloping filled in valleys at an altitude of 550 to 600 m above MSL. They are classified as *Typic Paleustalfs* (Soil Survey Staff, 1999). The soils are extensive in Bijapur and Belgaum districts of Karnataka. Palathurai soils are developed on calcic gneiss and occur on gently sloping and undulating pediments at 400 m above MSL. The annual rainfall is less than 600 mm but distributed equally both in kharif and *rabi* seasons. These soils are classified as *Typic Haplustalfs* (Soil Survey Staff, 1999).

Physical and chemical properties were determined as per standard procedures (Jackson, 1973). For mineralogical analysis, particle size fractions were separated as per size segregation procedure of Jackson (1979) after removal of $CaCO_3$, organic matter and free iron oxides. Silt and clay fractions were subjected to X-ray examination of the parallel oriented Ca/K saturated samples with a Philips diffractometer using a Ni-filtered Cu-Kα radiation and a scanning speed of $2^{0}2\theta$ /minute. Semi-quantitative estimation of the clay minerals was based on the principles outlined by Gjems (1967).

Results and Discussion

Morphometric properties indicate that the soils are dark reddish brown to yellowish red in colour and moderately deep to very deep. They have clay enriched Bt horizons, well developed structures and can be grouped as tropical ferruginous soils (Rengasamy *et al.*, 1978). Physical and chemical characteristics (Table 1) show that in contrast to our general understanding of tropical ferruginous soils, both the soils are mildly alkaline (pH 7.3 to 8.6) and the pH value increases with depth. CEC of the soils are medium (14 to 32 cmol(p+) kg^{-1}) and base saturation is high (88 to 99%). Calcium is the dominant cation on the exchange complex. Calcium carbonate ranges from 1 to 13.5% and it increases with depth and is found to be pedogenic in origin (Pal *et al.*, 1999). Both the soils have well developed clay enriched Bt horizon just below the plough layer, indicating the truncation of the upper horizon due to erosion (Pal *et al.*, 1989).

Total elemental composition indicates that they are siliceous as SiO_2 content ranges from 50 to 73%. It decreases, however, with depth in both the soils (Table 2). This is commonly

Table 1. *Physical and chemical characteristics of soils*

Horizon	Depth (cm)	pH	$CaCO_3$ (%)	Particle size distribution					CEC cmol(p+) kg^{-1}	Base saturation %
				Sand	Silt	Clay	C.Clay	F.Clay		
				Pedon 1 Jamkhandi Soils						
Ap	0-16	8.1	1.2	71.1	5.5	23.6	4.2	19.4	15.0	94
Bw1	16-40	8.0	1.4	56.6	5.5	35.8	7.4	28.4	21.1	89
Bt1	40-61	8.2	2.4	46.2	8.7	45.1	11.2	33.9	32.7	98
Bt2	61-89	8.3	3.3	38.6	15.6	45.8	13.2	32.6	31.1	95
Bt3	89-123	8.6	8.7	47.1	14.8	38.0	18.3	19.7	28.6	94
Bt4	123-152	8.5	8.9	49.0	27.0	24.0	9.3	14.7	27.7	93
				Pedon 2 Palathurai Soils						
Ap	0-12	8.2	2.3	71.6	7.6	20.8	1.0	19.7	14.1	88
Bt1	12-39	7.3	2.6	58.4	9.1	32.5	8.0	24.5	20.6	91
Bt2	39-57	7.5	2.5	44.3	8.5	47.2	7.9	39.3	22.8	91
Ck	57-68	8.3	13.5	65.3	12.7	22.0	10.4	11.6	16.0	99

Table 2. *Total elemental composition (% oven dry basis)*

Horizon	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI	SiO_2/Al_2O_3 (Molar)
					Pedon 1 Jamkhandi Soils					
Ap	73.3	7.4	6.9	1.0	1.1	0.9	0.3	2.5	4.6	9.3
Bw1	70.4	8.0	7.5	1.2	1.1	0.8	0.3	2.9	5.9	8.3
Bt1	59.3	12.9	10.2	1.3	1.6	1.5	0.3	2.6	8.6	4.7
Bt2	66.8	10.0	7.9	1.0	1.2	1.1	0.3	2.3	8.4	7.9
Bt3	57.8	6.4	9.7	1.3	6.8	1.8	0.3	2.4	12.5	6.8
Bt4	57.5	9.2	10.1	1.2	7.5	1.9	0.3	2.4	8.8	4.5
					Pedon 2 Palathurai Soils					
Ap	65.7	11.8	7.0	0.5	5.0	1.8	0.4	3.0	3.7	4.9
Bt1	57.1	14.9	9.0	0.7	3.7	1.8	3.1	2.5	6.2	8.0
Bt2	65.2	7.2	8.4	0.7	4.0	1.9	3.3	3.1	5.3	8.3
Ck	50.4	13.2	5.8	0.4	9.7	1.8	2.2	2.4	13.1	4.9

observed in the tropical ferruginous soils of southern India (Chandran *et al.*, 1999). R_2O_3 content varies from 14 to 25% without any specific trend with increasing depth. Similar observations were made with respect to Al_2O_3 and Fe_2O_3 content. TiO_2 content is more in the Jamkhandi soils than Palathurai soils, and its content does not vary with depth due to its immobility. Molar ratios of SiO_2 and R_2O_3 in both soils are relatively high (>4.5) and indicate apparently less weathering of the soil material. This is in contrast to observations generally made in highly weathered red and lateritic soils. Higher K_2O (2 to 3%) in the soils indicate the presence of good amount of K bearing materials.

Physical and chemical properties mentioned above are in contrast to the general understanding of the tropical soils reported elsewhere in the world. It is well known that humid climate induces the removal of alkali and alkaline earth cation and releases iron from minerals and sets acidic soil environment. Iron is being stabilized in the upper soil horizons as oxides and hydroxides and gives red colour to the soil matrix. Once iron oxides coat the clay minerals, they produce a permeable soil in which leaching can occur to a great depth (Ferguson, 1954) and thereby produces a deep weathered soil. But the present day aridic environment is not severe enough to develop such deeply weathered profile with a well developed argillic horizon of more than 30 per cent clay. This suggests that these soils were formed in more humid environment during pre-Pliocene period. The thin Ap horizon followed by a thick argillic horizon and well developed structures also suggest that upper layers of ferruginous soils formed during earlier climate were removed by multiple arid erosional cycles (Rengasamy *et al.*, 1978; Murali *et al.*, 1978). This has resulted in a truncated profile with high amount of weatherable minerals exposed for the present agricultural use. During the later part of the Pleistocene period the climate becomes drier inducing the precipitation of $CaCO_3$ (Pal *et al.*, 1999). The presence of white glaebules of $CaCO_3$ in Bijapur soils (Mermut and Dasog, 1986), a series associate of Jamkhandi soils, indicate their pedogenic origin under semi-arid climate. The Alfisols described above are therefore relict paleosols but polygenetic in nature (Pal *et al.*, 1989).

Mineralogy of the silt fractions

In Jamkhandi soils smectite, mica and kaolinite are the dominant minerals with subordinate amount of feldspars and quartz. Smectite and kaolinite increase with depth. Smectite expands to 1.7 nm on solvation but on K-saturation and heating the peak collapses to 1.0 nm (Fig. 1). This suggests that silt smectite has a relatively high charge. This peak disappears on HCl treatment indicating its richness in iron.

In Palathurai soils mica is the dominant mineral followed by smectite, vermiculite and feldspar. Quartz and kaolinite are found in trace amount. The contraction behaviour of smectite towards K-saturation and subsequent heating to 110^{0}C indicates that smectite has high charge density.

Mineralogy of the coarse clay fractions

Smectite is the dominant clay mineral in the coarse clay fraction of both the soils. In addition, mica and kaolinite are also present in Jamkhandi and Palathurai soils. Smectite collapses to 1.0 nm on K-saturation and heating to 110^{0}C, indicating that it has high charge density (Fig. 2).

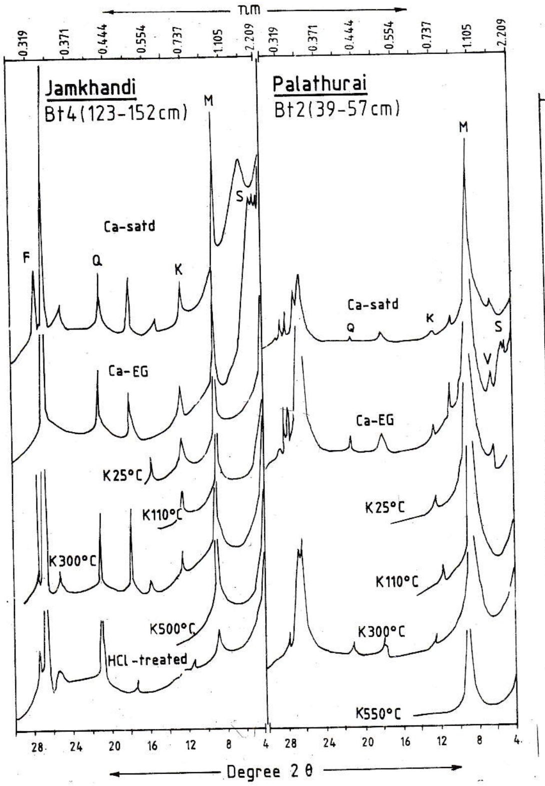

Figure 1. Representative XRD diagrams of the silt fractions : Ca-satd = Ca-saturated, Ca-EG= Ca-saturated and glycolated, K25°/110°/300°/550°C=K-saturated and heated to 25°C, 110°C, 300°C, 550°C, S=smectite, M=mica, K=kaolin, V=vermiculite, Q=quartz, F=feldspars.

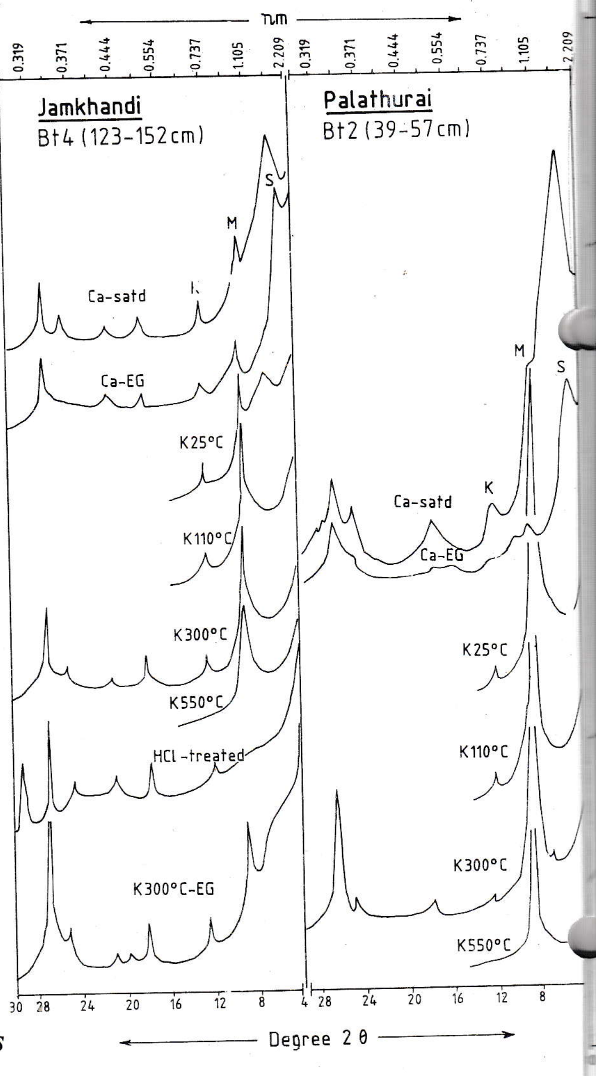

Figure 2. Representative XRD diagrams of the coarse clay fractions : Ca-satd = Ca-saturated, Ca-EG= Ca-saturated and glycolated, K25°/110°/300°/550°C=K-saturated and heated to 25°C, 110°C, 300°C, 550°C, K300°C-EG-K-saturated, heated to 300°C and glycolated, S=smectite, M=mica, K=kaolin.

Mineralogy of the fine clay fractions

The fine clay fractions of both the soils is dominated by smectite. Mica and kaolin are present in subordinate amounts. Kaolin was not detected in Palathurai soils (Fig. 3). The broad 0.7 nm peak of kaolin on glycolation indicates that it is not a discrete

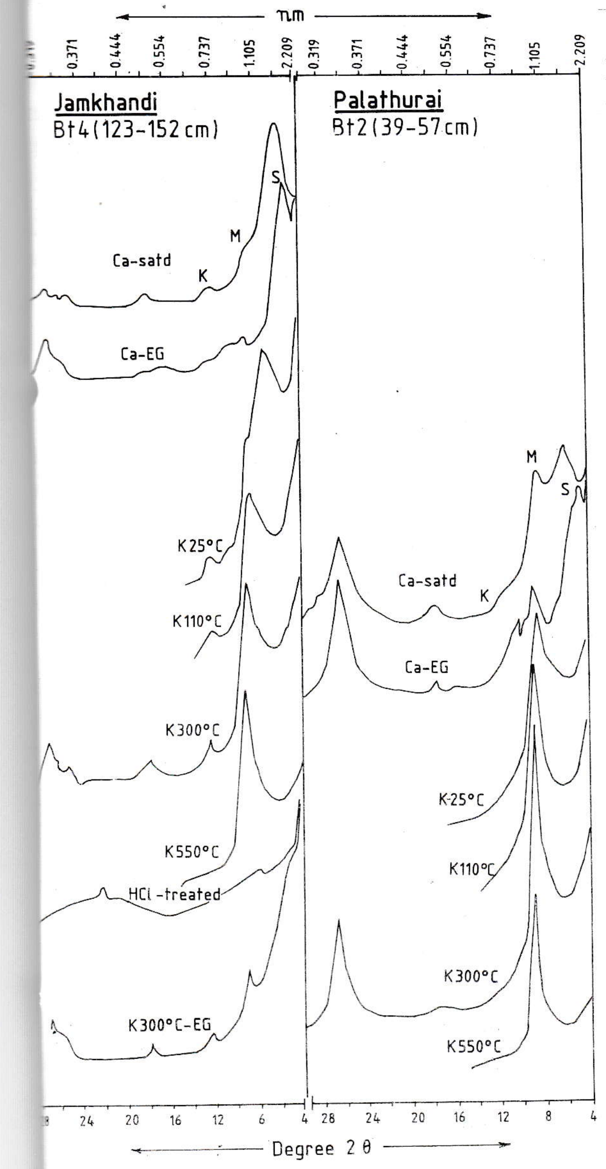

Figure 3. Representative XRD diagrams of the fine clay fractions : Ca-satd = Ca-saturated, Ca-EG= Ca-saturated and glycolated, K25°/110°/300°/550°C=K-saturated and heated to 25°C, 110°C, 300°C, 550°C, K300°C-EG-K-saturated, heated to 300°C and glycolated, S=smectite, M=mica, K=kaolin

kaolinite but appears to be interstratified with smectite (Pal *et al.*, 1989). The smectite peak in Jamkhandi soils does not readily contract to 1.0 nm at 25°C and for this, heating to 110°C is necessary. This contraction behaviour indicates occurrence of both high and low charge density smectite in this fraction. The combination of both low and high charge smectite was further confirmed by K-saturation of the fine clay and heating it to 300°C and glycolation (Ross and Kodama, 1984). This treatment indicates that all the contracted position at 1.0 nm region of K-300°C treated sample does not slide to 1.4 nm region on glycolation. The smectite of Palathurai soils, however, has high charge density as it readily contracts to 1.0 nm on K-saturation at 25°C.

Silt and coarse clay fractions of both the soils have considerable amount of mica. The ratio of 001/002 reflections of mica is much higher than unity (Pal *et al.*, 2000), indicating that mica consists of more biotite than muscovite. These micas survived the alteration during tropical weathering of pre-Pliocene period (Pal *et al.*, 2000). During the semi-arid climatic condition, however, biotite micas have been weathered to high charge smectites (Pal *et al.*, 1989).

In view of the above results, it appears very clear that the detailed clay mineralogical information is of fundamental importance for relict soils of southern India because their mineralogical make up may not be of identical nature. The mineralogical make up of the two soils under study has distinct relevance in their water and K management because of presence of biotite, mica and high charge smectite. Therefore, for site specific characterization, mineralogical information should also form a criteria for soil-site evaluation for better management of natural resources.

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