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Soil mineralogy in relation to physiography in Jumar sub-watershed, Jharkhand

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Abstract : The mineralogical compositions of three pedons occurring on three different physiographic areas in Jumar sub-watershed of Jharkhand, India, were studied alongwith some soil properties. Though these soils are from same area under similar climate, but their mineralogy vary widely. Mineralogical composition based on calculated weathering mean and relative abundance of clay minerals is indicative of high weathering intensity of all soils. However, soil occurring on pediment is at comparatively higher stage of weathering than the soils of monadnock and undulating plateau.

Additional key words : *Soil minerals, weathering index, chemical composition*

Introduction

Soil mineralogy is important for proper understanding of the soil development as well as for information about the soil fertility and crop management. The amount of different clay minerals present in soil controls the nutrient availability to crops. Previously, Baxla *et al.* (2001) studied the infiltration characteristics of soils of Jumar sub-watershed. The resource information of the sub-watershed has been generated by using remote sensing (Puspanjali 2006). The present work is aimed to study the soil mineralogy and their variations in relation to physiography in Jumar sub-watershed.

Materials and Methods

Site description

Jumar sub-watershed is a part of Subarnarekha watershed in Ranchi district, Jharkhand, India. It is situated at an altitude of 598 to 793 m above mean sea level (MSL) between 23° 22'15" to 23°32'00" N and 85° 10'30" to 85° 26'30" E. The area is dominated by granite, granite-gneiss and schist rocks. The area is a part of an undulating and rolling upland of Ranchi plateau sloping gradually from North-West to South-East direction. The area can be divided into five major physiographic units *viz.* pediment, monadnock, plateau top, undulating plateau and valley. Undulating plateau is most dominant physiography in the study area. The region belongs to hot sub-humid climate. Annual rainfall ranges from 1400 to 1500 mm, mean summer temperature is 22.9 °C and mean winter temperature is 11.7 °C. The soil moisture and temperature regime of this area are 'ustic' and 'hyperthermic' respectively although 'aquic' moisture regime is also present in some low-lying areas of undulating plateau (Puspanjali 2006).

Soil sampling, processing and analysis

Soil samples were collected from three pedons

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representing monadnock (Bharamdih series), pediment (Khakhra series) and undulating plateau (Kathartoli series) of Jumar sub-watershed. For mineralogical analysis, soils were collected from upper two horizons (Ap and Bt) of Khakhra and Kathartoli series; and one A horizon of Bharamdih series. Basic data of these pedons are given in table 1. The pH, cation exchange capacity, sand, silt and clay of the soils were determined following standard methods. For X-ray diffraction (XRD), Ca and K saturated parallel oriented clay samples were prepared. X-ray diffractograms of sand, silt and clay samples were recorded by Pananalytical XRD machine using Ni filtered Cu K-α radiation, following six treatments for clay samples: Ca saturated clays at room temperature, Ca saturated clays glycolated, K saturated clays at 25 °C, K saturated clays heated to 110 °C, K saturated clays heated to 300 °C and K saturated clays heated to 550 °C. Total elemental chemical analysis of clay by Na_2CO_3 fusion method and CEC were measured following the methods described by Jackson (1969). Frequency distribution diagrams of clay-sized particles of different horizons were made following Jackson *et al.* (1948). Semi- quantitative estimation of the clay minerals were done following the method outlined by Gjems (1967). Amount of amorphous portions of clay fractions was determined by selective dissolution analysis (SDA) following Hashimoto and Jackson (1960). Weathering mean of pedons were determined following stage of weathering of minerals as described by Jackson *et al.* (1948).

Results and Discussion

The clay fractions (crystalline part) of the soils were analyzed by XRD. For amorphous part by SDA, CEC and elemental chemical constitution were used. The silt fractions were also analysed by XRD.

Analysis of clay fractions

Mineralogy of crystalline components by XRD

The X-ray diffractograms of Ca and K saturated soil clays with different treatments depict the presence and relative abundance of different minerals. Presence of kaolinite, mica/ illite, vermiculite, smectite and chlorite are well depicted from peaks at 0.7 nm (Ca saturated clays), 1 nm (Ca saturated clays), 1.4 nm (glycolated Ca-clays), 1.75 to 1.8 nm (glycolated Ca-clays) and 1.4 nm (K saturated clays heated at 550 °C) respectively in diffractograms. Peak heights and areas under 0.7 nm peaks indicate that Khakhra soil clay had more amount of kaolinite with higher crystallinity than other pedons. In the diffractogram, Bharamdih soil clay shows maximum broadening of the basal spacing of 0.7 nm peak at lower angle followed by Kathartoli and Khakhra soil clays indicating interstratification of kaolinite with 2:1 minerals (Bhattacharyya *et al.* 2000; Chandran *et al.* 2004). On the other hand, broadening and tailing of 1 nm peak in diffractograms towards lower angle indicates decomposition and weathering of mica (Walker 1949). In glycolated Ca-clay curves of these soils, relative intensity of first and second order mica/ illite peak (M001/M002) indicates dominance of biotite type of mica in all soil clays (Kapoor 1972; Pal et al. 2001). Peaks at 2.4 nm in all soil clay diffractograms glycolated Ca clay diffractograms and the same after subsequent K-saturation followed by heating clearly indicate occurrence of regularly interstratified minerals of mica and vermiculite. In sub-surface soil clay of Khakhra pedon and both surface and subsurface soil clay diffractograms of Kathartoli soil pedon, 2.8 nm peaks are indicative of presence of interstratified minerals of mica and smectite. There may be some irregular interstratification also.

Mineralogy of amorphous ferrialuminosilicates by SDA

Amorphous materials are formed by dissolving and precipitation of silica and sesquioxides without any definite proportion from the primary minerals of the parent rocks or from crystalline minerals by means of weathering or during the transformation processes. The total amount of amorphous material content of clay fraction has been calculated by adding 18 % weight with the total amount of amorphous silica, alumina and iron oxides according to Hashimoto and (Jackson 1960). Bharamdih pedon had relatively higher amount of amorphous materials. This is

Table 1. Relevant properties of the soils

Soil Series	Hori-zons	Depth (cm)	Sand	Silt	Clay	Matrix colour (moist)	pH (1:2.5)	CEC (NH_4OAC) cmol(p^+) kg^{-1}	Taxonomy
			%						
Bharamdih	A	0-16	61.5	22.1	16.4	7.5YR 5/4	5.6	6.4	Loamy-skeletal, hyperthermic Lithic Ustorthent
Khakhra	Ap	0-14	48.1	36.9	15.0	5YR4/6	5.5	6.2	Fine-loamy, hyperthermic Typic Paleustalfs
	Bt	14-34	26.4	41.9	31.7	5YR4/4	5.7	8.0	
Kathartoli	Ap	0-16	11.7	58.2	30.1	10YR5/4	5.3	10.1	Fine-loamy, hyperthermic Typic Endoaqualfs
	Bt	16-31	9.5	58.5	32.0	10YR4/4	5.5	12.2	

Table 2. Semi quantitative estimation of crystalline fractions of clays (percentage by weight)

Soil Series	Depth	Mica/ Illite (%)	Kaolinite (%)	Chlorite (%)	Vermi-culite (%)	Smectite (%)	Mixed layered (%)	Amorphous material (%)	Weathering mean
Bharamdih	0-16	21.27	23.02	1.21	7.40	15.30	8.16	23.64	8.89
Khakhra	0-14	16.51	44.56	1.98	2.67	5.87	10.44	17.97	9.16
	14-34	11.92	49.85	1.61	1.44	2.73	11.21	21.24	9.35
Kathartoli	0-16	7.45	8.94	Neg	13.01	20.53	32.61	17.46	8.66
	16-31	16.85	8.64	0.77	4.72	15.48	31.78	21.76	8.60

probably a step of formation of amorphous aluminosilicates before cryatallization. For amorphous aluminosilicates, weathering stage was considered as 10 for weathering mean calculation as kaolinite is the dominant clay mineral in all these soil clays (Jackson, 1969).

The amount and distribution of crystalline and amorphous clay fractions along with their weathering means is presented in table 2. The structural constituents of amorphous materials of pedons is shown in table 3. The XRD graph of Bharamdih soil clay is depicted in Fig 1.

Frequency distribution diagrams

Based upon the amount of the crystalline and amorphous minerals present in the soil clays and their respective stage of weathering, a combined frequency distribution diagram of all soil clays have been drawn (Fig. 2) following Jackson *et al.* (1948). These curves clearly indicate relatively high weathering status of pediment soil clays followed by monadnock and plateau soil clays.

Analysis of total clay fractions by CEC and chemical composition

The CEC of the clays varies widely. The CEC along with the silica-alumina molar ratios of the H-clays isolated and prepared from three soils indicate the presence of 1:1 and 2:1 non-expanding as well as expanding lattice clay minerals in Bharamdih soil clay. In both the horizons of Khakhra soil, 1:1 type clay

Table 3. Composition of amorphous ferrialuminosilicate of the clay fractions (percentage by weight)

Soil Series	Depth (cm)	SiO_2	Al_2O_3	Fe_2O_3	SiO_2/Al_2O_3 (M.R.)	$Al_2O_3/SiO_2+Al_2O_3$ (%)
		%				
Bharamdih	0-16	11.00	8.49	0.55	2.20	43.56
Khakhra	0-14	7.35	6.95	0.93	1.80	48.60
	14-34	10.20	7.07	0.73	2.45	40.94
Kathartoli	0-16	7.93	6.14	0.73	2.19	43.64
	16-31	11.42	6.11	0.90	3.17	34.85

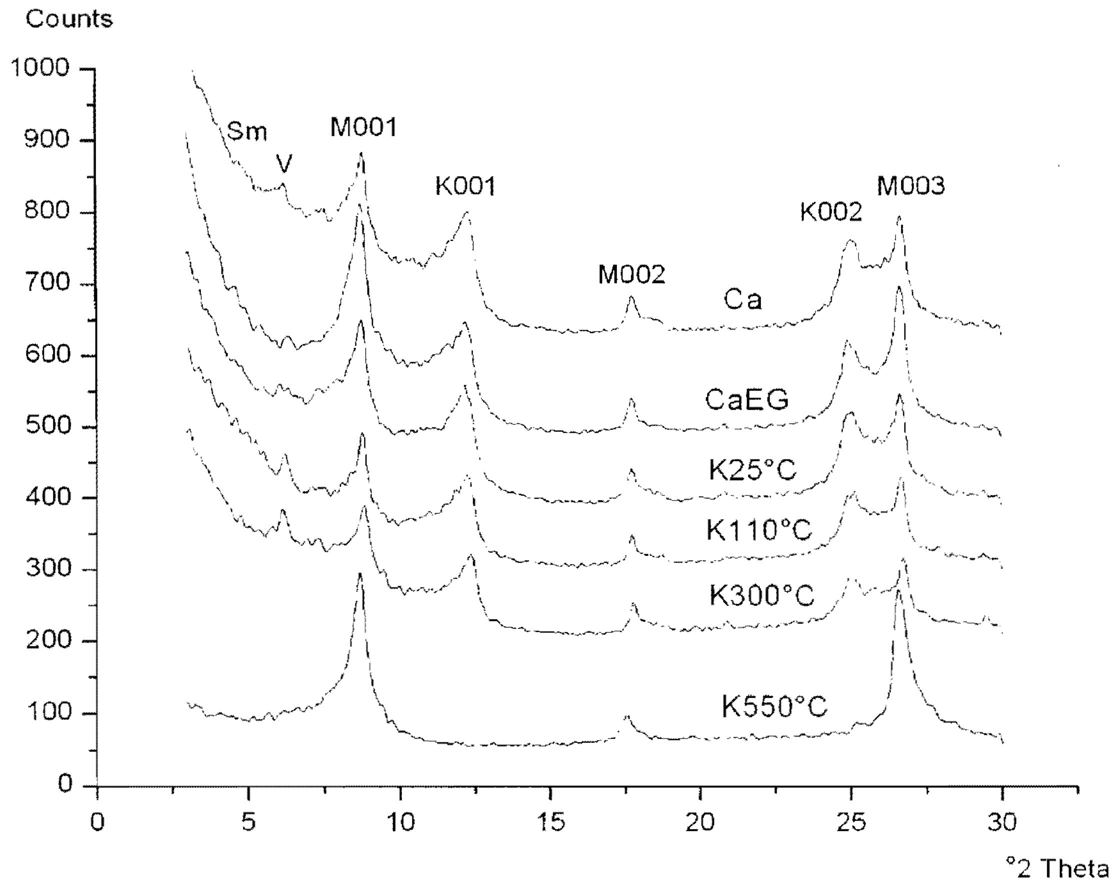

Fig 1. XRD Curve of Bharamdih soil clay

minerals dominate with comparatively less amount of 2:1 minerals. Kathartoli soil horizons are dominated by 2:1 non-expanding and expanding clay minerals with less 1:1 lattice clay minerals.

Total K_2O % of these clays supports the presence of 2:1 non-expanding lattice clays (Pal *et al.* 2009). Relatively high amount of Fe_2O_3 in all soil clays indicate the possibility of octahedral substitution of aluminium by iron. On the contrary, higher amount of MgO in the clays indicates the possible presence of 2:2 lattice types of clays (Pal *et al.* 2009). Traces of calcium may account for Ca-containing clay-sized

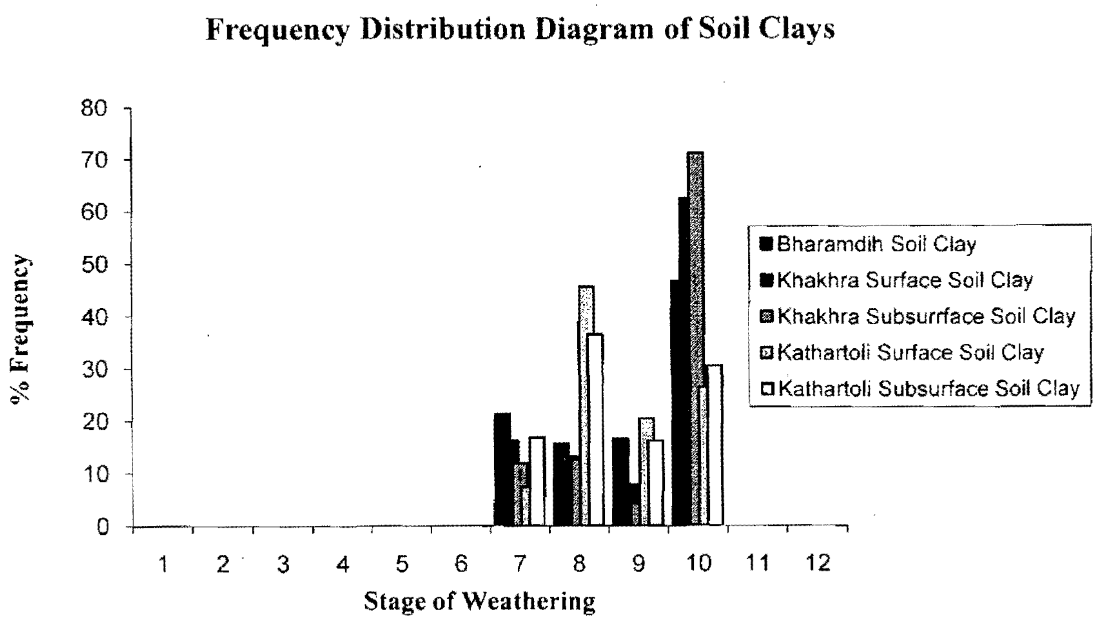

Fig 2. Combined frequency distribution diagram of soil clays

primary minerals. The chemical compositions of soil clays along with their CECs have been presented in table 4. These chemical compositions of clay fractions supplement the X-ray diffraction data to find out the types of clay minerals in soil which is considered for determining weathering intensity as suggested by Jackson (1948).

Analysis of sand and silt fractions

XRD of sand and silt fractions of the soils indicate the dominance of quartz followed by feldspar and mica. In diffractograms, a small peak at 0.22 nm indicates the presence of haematite in Bharamdih soil (silt fraction) as well as sand and silt fractions of Khakhra and Kathartoli soil, indicating a mature stage of soil formation of (Jackson *et al.* 1948). On the other hand, 0.48 nm peaks of gibbsite in the silt fractions of soils representing monadnock and undulating plateau indicate the possibility of its formation from layer silicates (Bhattacharyya *et al.* 2000). The XRD graph of Kathartoli surface (silt fraction) has been depicted in Fig. 3.

Table 4. Chemical compositions (percentage by weight) of the total cleaned clay (Na_2CO_3 Fusion Method)

Soil Series	Depth (cm)	SiO_2	R_2O_3	Al_2O_3	Fe_2O_3	SiO_2 /Al_2O_3 (M.R)	K_2O	MgO	CaO	CEC (NH_4OAC) cmol(p^+) kg^{-1}
		%					%			
Bharamdih	0-16	52.60	39.47	34.63	4.84	2.58	1.69	1.13	0.64	51.02
Khakhra	0-14	50.27	42.91	38.50	4.41	2.22	1.69	1.18	0.61	33.10
	14-34	49.93	42.55	37.55	5.00	2.26	1.69	1.03	0.46	29.68
Kathartoli	0-16	54.69	36.31	32.14	4.17	2.89	1.68	0.39	0.52	71.10
	16-31	55.40	37.27	32.54	4.73	2.89	1.7	0.59	0.70	63.84

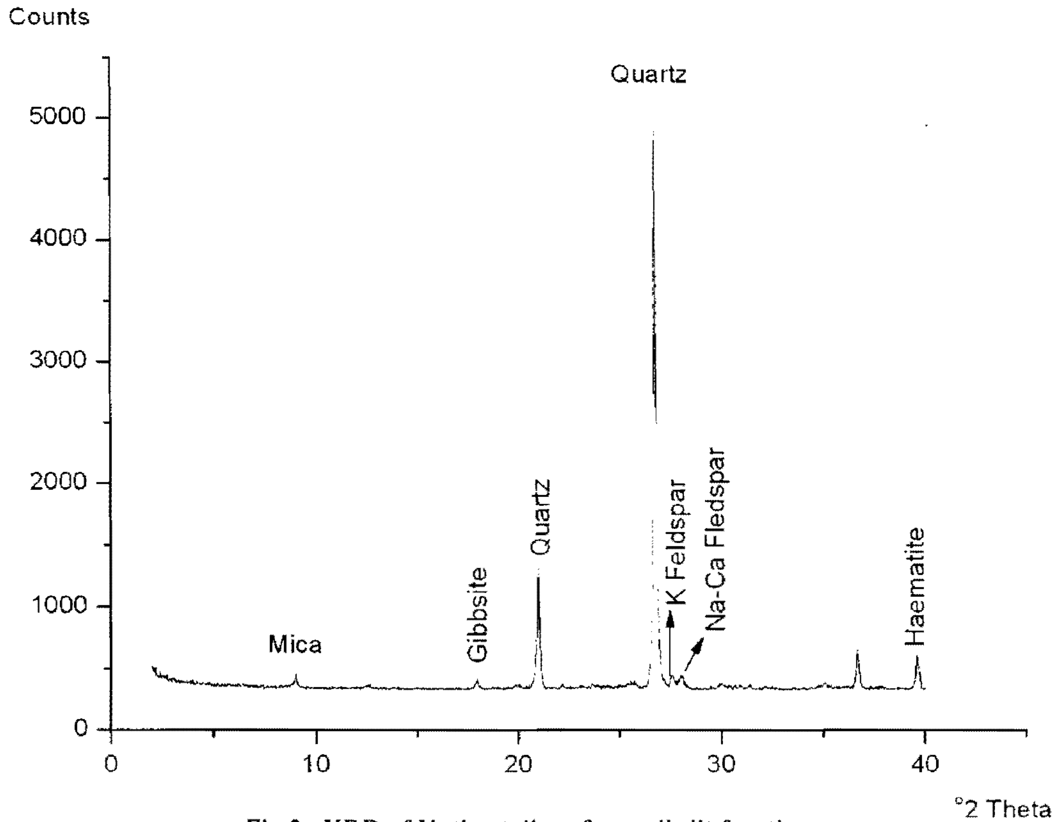

Fig 3. XRD of Kathartoli surface soil silt fraction.

Conclusion

Presence of quartz and feldspar is prominent along with mica in primary fractions of all soils (Table 2). The presence of different minerals in sand, silt and clay fractions of the soils indicates the possible weathering of K bearing minerals to 1 nm component (illite), smectite and kaolinite by continuous release of K in soil from lattice.

The soil clay fractions are dominated by kaolinite, mica/ illite and smectite type of minerals (Table 2). Kaolinite group of minerals dominate in surface and sub-surface soil clays with a good amount of mica/illite and less amount of smectite and vermiculite. In monadnock and pediment soil clays, presence of Mg results little chloritization. On the contrary, in soil clays of undulating plateau (i.e. Kathartoli series) smectite, mica/illite, vermiculite and high amount of interstratified minerals are present though their relative abundances changes horizonwise.

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