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Mineralogy of some Floodplain Soils under Lower Mahanadi Delta of Odisha

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Abstract The mineral assemblage of fine sand and clay fractions of floodplain soils (*Entisols* and *Inceptisols*) in lower Mahanadi delta was investigated using petrographic study, elemental chemical analysis, CEC, molar ratio and X-ray diffraction. The finesand mineralogy is dominated with quartz, orthoclase, plagioclase, micas and opaque, with traces of calcite, garnet and hornblende. Higher orthoclase contents presence of plagioclase indicates that these deposited soils are relatively young. The molar ratio of SiO_2/Al_2O_3 of clays varies from 3.58 to 3.92 indicating the dominance of illite. The clay CEC of 50.6 to 52.7 c mol (p^+) kg^{-1} reflects mixed mineralogy in these soils. The X-ray diffraction of clays with semi-quantitative estimation show varying proportions of kaolinite, illite and smectite group of clay minerals and the relative order of dominance is illite > smectite > kaolinite. The relative similarities in mineralogy of these deposited soils suggest that the clay minerals are mostly inherited from the parent materials with little in situ transformation under prevailing conditions.

Keywords Floodplain soils, Fine sand mineralogy, Clay mineralogy, Molar ratio, X-ray diffraction.

Introduction

Alluvial soils of floodplains exhibit characteristics of both sediment transport and deposition and soil formation and the floodplain geometry is governed by the flow characteristics of the river and the nature and amount of material available for transportation deposition process [1]. The minerals present in these soils, being relatively unaltered may also indicate the nature and course of rocks in the catchment areas of the river. The type and amount of clay in a soil has very important bearing on the genesis, characteristics, physical and chemical properties of soils [2].

In Mahanadi delta, sediments are deposited partly under the influence of river water in a subaerial environment and partly under the influence of marine agents of Bay of Bengal giving rise to different types of deposits in river channels, point bars, natural levees and flood plains [3]. Information on mineralogy of such deposited soils is scanty. Hence an attempt has been made in the present study to characterize the minerals in fine sand and clay fractions of soils to

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Table 1. Major soil characteristics of surface layers and control section.

Pedous	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Sand/Silt	pH (1:2.5)	OC g kg^{-1}	$CaCO_2$ equiva-lent g kg^{-1}	CEC c mol (p^+) kg^-	BS (%)	CEC /clay
Fine loamy over coarse loamy, mixed, hyperthermic, *Typic Ustorthent* (upland)												
P_1	0–10	17.5	35.4	47.1	c	0.49	5.6	6.1	–	27.3	80	0.58
	10–110	48.0	28.1	23.9	l	2.01	6.6	2.8	8.6	12.3	87	0.51
Fine loamy, mixed, hyperthermic *Aquict Ustifluvents* (medium land)												
P_2	0–13	12.9	32.4	54.7	l	0.40	5.9	9.2	–	31.4	82	0.57
	13–95	28.8	40.6	30.6	l	9.71	7.0	6.4	9.0	18.3	91	0.60
Fine, mixed, hyperthermic, *Vertic Haplustepts* (lowland)												
P_3	0–13	6.8	47.1	46.1	sic	0.14	5.6	10.5	–	26.9	71	0.60
	13–93	12.2	42.4	45.4	sic	0.29	6.5	4.8	–	24.2	76	0.53

understand their genesis.

(The authors are grateful to Indian Mineral and Material Institute, Bhubaneswar for facilitating X-ray analysis of clay samples).

Materials and Methods

The study area Kanchinala micro-watershed (85°48´05´´ E, 20°16´20´´ N and 4.8 above MSL) is located in the floodplains of lower Mahanadi deltaic tract in Puri district, Odisha. The climate is hot, moist sub-humid with mean annual rainfall of 1473 mm. The soils of the region are developed from the recent tertiary deposits of alluvium formed through the sedimentation by Mahanadi river systems. The entire area of the micro-watershed is drained by the stream Kanchinala, a distributary branch of river Mahanadi systems. Based on field observations, geomorphology and soil differences, three locations were selected for the study. Soil samples were collected from representative pedons of three identified soil series, one each in gently sloping upland with 3–5% slope (P_1 : *Typic Ustorthents*), very gently sloping medium land with 1–3% slope (P_2 : *Aquic Ustifluvents*) and nearly level lowland with 0–1% slope (*Vertic Haplustepts*).

The soil samples of different horizons of pedons were analyzed for pH, organic carbon, cation exchange capacity and available water capacity by standard procedures. The particle size distribution was estimated by international pipette method after removal of organic matter, calcium carbonate and free iron oxide. Sand (0.05–2 mm), silt (0.002–0.05 mm) and clay (<0.002 mm) fraction were separated from the samples after dispersion according to the size segregation procedure of Jackson [4]. For mineralogical studies, control section soils of pedons were used for fractionation. Minerals in fine sand fraction (0.25–0.1 mm) were studied through petrological microscope [5]. The elemental chemical analysis of clay samples were done by fusion with Na_2CO_3. CEC of clay samples were determined by the methods of Mackenzie [6]. X-ray diffraction analysis of Mg and K saturated clay samples were carried out by a Phillips X-ray diffractometer using Ni-filtered Cu k_α radiation with a scanning speed of 2° 20 per minute. The identification of minerals present in caly fractions were done following the criteria laid down by Jackson [4]. Semi quantitative estimates of clay minerals were based on the principles outlined by Gjems [7].

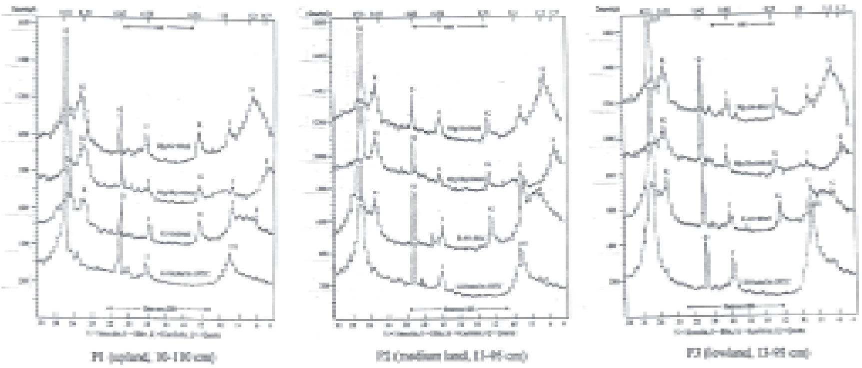

Fig. 1. X-ray differactograms of clay fractions.

Results and Discussion

Physical and chemical characteristics

Some major soil characteristics of the surface layers and control section of the pedons are presented in Table 1. The sand contents of the surface soils are very low (6.8–17.5%) as compared to silt (32.4–47.15) and 46.1–54.7%). The higher clay content in the surface layer (46.1%) and control section (45.4%) in the lowland (P_3) is related to the deposition of finer materials in lower topographic landscape farther away from the stream [8]. The wider sand to silt ratio between the surface and control section soils indicate lithological discontinuity, which might be due to the deposition in different fluvial cycles [9]. All the surface soils are slightly acidic and the pH increases down the depths. Higher organic carbon contents in the surface soils indicates surface accumulation of organic matter. Presence of $CaCO_3$ in the sub soils of upland and medium land and their absence in lowland soils indicate the deposition of the alluvium with coarser lime concretions in different erosional cycles. The CEC of the surface soils are higher, which are concurrent with the clay distribution. The soils are highly saturated with bases (71–91%). The CEC/clay ratio indicates mixed mineralogy in these soils [10].

Sand mineralogy

The mineralogy of fine sand fraction owes their origin in the rock systems through the river flows and formation due to deposition of alluvial sediments. The geology of Mahanadi basin comprises of (i) Proterozoic - limestone and shale (ii) Gondwana - sandstone, shale and conglomerate (iii) Archean - granite gneiss and charnockite (iv) Recent - laterite and alluvium [11]. The dominant minerals of these rock systems are quartz, feldspars, calcite, dolomite, ankerite, biotite, muscovite, hematite and pyroxene.

The minerals identified in the fine sand fraction of the control section of pedons are presented in Table

Table 2. Mineralogy of fine sand fraction (%).

Minerals	P_1 (upland) 10-110 cm	P_2 (medium land) 13-95 cm	P_3 (lowland) 13-93 cm
Quartz	64.2	61.4	59.3
Orthoclase	16.5	19.2	20.6
Plagioclase	4.8	5.2	5.0
Calcite	0.3	1.6	2.0
Muscovite	3.5	3.0	2.8
Biotite	2.8	2.2	2.3
Garnet	2.2	1.8	2.0
Hornblende	1.5	1.2	1.2
Opaque	3.0	3.5	4.0

Table 3. Chemical composition, molar ratios and CEC of the soil clays.

Properties	P_1 (upland) 10–110 cm	P_2 (medium land) 13–95 cm	P_3 (lowland) 13–93 cm
SiO_2 (%)	48.78	48.14	47.82
Al_2O_3 (%)	23.12	21.84	20.72
Fe_2O_3 (%)	6.86	7.08	7.22
TiO_2 (%)	0.94	1.12	1.02
K_2O (%)	2.38	2.46	2.52
CaO (%)	3.74	3.96	4.26
MgO (%)	1.63	1.69	1.79
SiO_2 / Al_2O_3	3.58	3.75	3.92
SiO_2 / R_2O_3	3.02	3.11	3.21
CEC [c mol (p^+) kg^{-1}]	50.6	51.8	52.7

Table 4. Semi-quantitative mineralogical estimation of clay fractions.

Minerals (%)	P_1 (upland) 10–110 cm	P_2 (medium land) 13–95 cm	P_3 (lowland) 13–93 cm
Illite	37	34	35
Smectites	22	24	26
Kaolinite	21	18	17
Quartz	10	9	9

2. Quartz is the dominant mineral (59.3–64.2%) in all the pedons. The higher contents of orthoclase (16.5–20.6%) and presence of plagioclase (4.8–5.2%) indicate that the soil formation has not reached maturity [12]. The presence of muscovite, biotite and calcite in these soils is related to the source of parent material. The lower content of biotite (2.2–2.8%) might be due to its destruction and resynthesis to other minerals. The presence of opaque (iron bearing minerals like hematite, limonite, magnetite and ilmenite) might be due to disintegration of basic igneous rocks [13]. Existence of unstable minerals like hornblends and biotite also suggests low intensity of weathering in these soils. The ultrabasic mineral garnet has also been identified in the fine sand fraction of these soils.

Clay mineralogy

Elemental composition

The elemental composition of clays in control section of pedons, SiO_2/Al_2O_3, SiO_2/R_2O_3 molar ratios and CEC of clays are presented in Table 3. Silicon is the most abundant element (59.3–64.2%) of the clay fraction constituting more than half of the chemical composition. Other dominant elements in the decreasing order of abundance are aluminium > iron > calcium > potassium > magnesium > titanium. The contents of Fe_2O_3 (6.9–7.2%) and MgO (1.6–1.8%) indicate the possible presence of smectite group of minerals [14]. Assuming 6% K_2O in illite, the contents of illite in clays would be ranged between 39.7 to 42.0%. The variation in TiO_2 content (0.94–1.12%) in clay fractions indicates nonconformity and stratification of parent materials in these deposited soils [15]. The molar ratio of SiO_2/Al_2O_3 of clays varies from 3.58 to 3.92. As per the criteria of Grim [16]. SiO_2/Al_2O_3 ratio for illite to be 3 and above and for smectite to be 4 and above, the clay mineralogy of the soils may be considered dominantly illitic. The SiO_2/R_2O_3 ratio of 3.02 to 3.21 indicated the dominance smectites in these soils [17]. The clay CEC of 50.6 to 52.7 c mol (p^+) kg^{-1} reflects mixed mineralogy [12].

X-ray diffraction

The X-ray diffractograms of control section clay fractions of pedons are presented in Fig. 1. Presence of strong peaks around 1.48 nm in Mg-air dried samples which on ethylene glycol solvation expanded to 1.7 nm and weak humps at 1.25 nm in K-air dried samples that collapsed to 1.0 nm on heating at 550°C confirmed the presence of smectites in these soils. Sharp peaks at 1.0 nm with their second order reflections at 0.5 nm and third order reflection at 0.33 nm in all the treatments suggest the presence of illite type of clay minerals. Diffraction peaks at 0.72 nm and 0.36 nm with Mg-air dried, Mg-ethylene glycol solvated and K-air dried indicate the presence of kaolinite in the clays. This is confirmed by the disappearance of these peaks at K-heated at 550°C. Irrespective of treatments, prominent peaks at 0.43 nm and 0.33 nm (superimposed with third order reflections of illite) are due to the presence of quartz.

Genesis of clay minerals

The soils have varying proportions of kaolinite, illite and smectite group of clay minerals and the relative order of dominance is illite > smectite > kaolinite (Table 4). The dominance of illite in these soils indicates the influence of micaceous parent materials and transformation of K-feldspar as there is high contents of orthoclase in fine sand [18]. Smectite in these soils is formed possibly from plagioclase during earlier humid geologic period and its retention is possible because of climate change from humid to sub humid during plio-pleistocene transition period [19] in the river basin that comes under the peninsular tract of India. Kaolinite could be formed by neosynthesis from the product of hydrolytic decomposition of feldspars and other primary minerals [20]. Studies on Mahanadi river water also revealed that kaolinite and Ca-smectite are thermodynamically stable in this water [11]. The higher smectite content in the lowland is related to impeded drainage and neutral soil reaction in the control section.

Conclusion

No definite trend was observed in distribution of minerals in different landforms of the study area. The relative similarities in mineralogy of these deposited soils suggest that the clay minerals are mostly inherited from the parent materials with little in situ transformation under prevailing conditions. The mineral assemblage of fine sand is dominated with quartz, feldspars, micas and opaque, whereas illite, smectite and kaolinite are the dominant minerals in clay fractions.

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