



Amorphous materials in soils under different pedogenic development stages of sub-tropical humid region of Assam

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Abstract: Amorphous material was studied in soils of different pedogenic development stages under sub humid environment of Assam, India. Soil profiles collected from four soil orders namely Entisols, Inceptisols, Alfisols and Ultisols representing different pedogenic development stages were taken for the purpose. The amorphous material in the clay fraction (<0.002mm) varied from 10.8 to 28.77 %. The highest average amount was observed in Ultisols (25.63%) and lowest was recorded in Entisols (13.15%). The amorphous materials were siliceous in nature with molar ratio ranging from 1.33 to 3.77 for $\text{SiO}_2/\text{Al}_2\text{O}_3$ and 1.16 to 2.95 for $\text{SiO}_2/\text{R}_2\text{O}_3$. The highest content of SiO_2 , Al_2O_3 and Fe_2O_3 was observed in Ultisols (10.9, 8.03 and 2.02%, Weighted mean, respectively) followed by Alfisols, Inceptisols and Entisols. The major portion of the amorphous material was composed of tetrahedral $\text{Si}_3\text{AlO}_6(\text{OH})_4$ component (47.49 to 78.23 %). The octahedral $\text{Al}(\text{OH})_{2.5}$ and neutral FeOOH components constituted 15.38 to 42.18% and 6.00 to 13.24% respectively. The calculated hydroxyl water content of amorphous materials was found to increase with the advancement of soil development and enhanced by deposition organic matter and acidification of soil.

Key words: Amorphous Material, Pedogenic Development Stages, Entisols, Inceptisols, Alfisols and Ultisols

Introduction

The amorphous materials in clay refers to a class of materials that are non crystalline and do not have a regular or the repeating order, internal atomic structure that is detectable by X-ray diffraction analysis. The principal forms of amorphous materials in soils are oxides and hydroxides of iron, aluminium and silica and silicates of iron and aluminium, all in various combination of water (Wada and Harward 1974). These materials commonly occur as coatings or gel-hulls on larger mineral grains and as aggregates of discrete particles in the clay fraction. These materials though often regarded as minor soil constituents, may contribute significantly to the physical and chemical properties of soils as they may have high pH dependent cation and anion exchange capacity, large specific surface area and high reactivity with anion like phosphorus (Hodges and Zelazny 1980).

The mineralogy of weathering is dominated by three elements Si, Fe, and Al and at the stage of weathering of igneous rocks represented by loss of primary struc-

ture, these three elements constitute 85% of the residual metals. The consequent crystallization of these elements present in noncrystalline state may lead to the formation of crystalline clay minerals and therefore amorphous materials are long been recognized as the precursors of crystalline clay minerals (Eggleton 1987). Amorphous or non-crystalline materials thus assume significance in pedogenic development of soils. Amorphous materials in soils derived from volcanic ash have been extensively studied, but comparatively little is known about the amorphous materials in soils derived from other parent materials. The presence of appreciable amount of amorphous materials in Indian soil under tropical and sub tropical environment was reported by few researchers (Krishna Murthy *et al.* 1976; Gupta and Tripathi 1983; Choudhury and Dhir 1983; Seshagirirao *et al.* 1992; Mishra and Ghosh 1994; Karmakar and Borah 1996; Karmakar 2012). The characterization of amorphous material in India (Karmakar and Borah 1996; Karmakar 2012; Krishna Murthy *et al.* 1976) and in abroad (Shoji and

Masui 1969; Smith and Mitchell 1984) soils reported higher content of SiO_2 than Al_2O_3 and Fe_2O_3 . Most of these works were however confined to characterization of the components of amorphous constituents in different types of soils like laterite soils, black soils, alluvial soils, soils rich in micas, *etc.* and their relation with soil properties. The present investigation is therefore undertaken to study the distribution of amorphous materials and its genesis in soils of different pedogenic development stages under Sub Tropical Humid Region of Assam, India.

Materials and Methods

The study area lies between $24^{\circ}07'$ and 28° N latitudes and $89^{\circ}43'$ and $95^{\circ}58'$ longitude and located in the North Eastern region of India. The area is characterized by sub tropical humid environment with mean annual rainfall of 1900 mm and average temperature of 24.5°C with hot and wet summer and dry and cool winter. The soil moisture and temperature regimes of the area are *udic* and *hyperthermic*, respectively. The clay mineralogy is dominated by kaolinite, micas and chlorite (Karmakar and Rao 1998; Dutta and Shanwal 2006).

All together four soil profiles, one each from Entisols, Inceptisols, Alfisols and Ultisols representing the soils under different pedogenic development stages were selected and exposed in four different locations. The site characteristics of the selected profiles along with their taxonomy are presented in Table 1. Soil samples were air dried and processed ($< 2\text{mm}$) and analyzed for pH (1:2.5 soil water suspension), organic carbon (Wakley and Black, 1942) and exchangeable acidity (Peech 1965). Soil was extracted with 1N NH_4OAc to determine the total exchangeable cations Na, K, Ca and Mg were estimated in Atomic Absorption Spectrometer. CEC of the soil was determined following distillation method (Jackson 1973). The different particle size groups *i.e.* sand (2-0.05), silt (0.05-0.002) and clay (< 0.002) were quantitatively separated by gravity sedimentation technique (Jackson 1956). The clay obtained by sedimentation technique was saturated with Na using normal solution of the salt containing the electrolyte. The excess electrolyte was removed as per procedure described by Jackson (1956). The clay concentration was determined by taking a suitable aliquot of the clay suspension.

Table 1: Site characteristics of the selected soil profiles

Pedon no.	Physiographic position	Latitude	Longitude	Order	Soil Classification
P ₁	Natural Levee	$26^{\circ}20.052$ N	$92^{\circ}44.122$ E	Entisols	Typic Udifluvents
P ₂	Foot hill slopes	$26^{\circ}00.0549$ N	$92^{\circ}35.742$ E	Inceptisols	Typic Dystrudepts
P ₃	Alluvial Plain	$25^{\circ}54.309$ N	$92^{\circ}58.759$ E	Alfisols	Aeric Endoaqualfs
P ₄	Undulating upland	$26^{\circ}19.945$ N	$93^{\circ}50.259$ E	Ultisols	Typic Hapludults

Weathering Index in each horizon of a profile was calculated from total elemental analysis. The total elemental analysis was carried out as per the procedure outlined by Lim and Jackson (1982). The elements Ca, Mg, K, Na, Al, Fe and Si were determined by Atomic

Absorption Spectrometer. The content of the elements is converted to their respective oxide forms and subsequently used for calculation of weathering Index using formula developed by Evans and Cameron (1979) as follows:

$$\text{Weathering Index} = \frac{\% \text{CaO} + \% \text{MgO} + \% \text{K}_2\text{O} + \% \text{Na}_2\text{O}}{\% \text{CaO} + \% \text{MgO} + \% \text{K}_2\text{O} + \% \text{Na}_2\text{O} + \% \text{SiO}_2 + \% \text{Al}_2\text{O}_3 + \% \text{Fe}_2\text{O}_3} \times 100$$

The amorphous material in clay fraction was extracted by selective dissolution method as outlined by Hashimoto and Jackson (1960). A suitable amount of Na saturated clay suspension containing 100 mg of clay was boiled with 50 ml of 0.5 N NaOH for 2.5 minutes. It was then centrifuged and in the extract Si, Al was determined by Atomic Absorption Spectrometry. Then Fe in the residue clay was extracted by dithionite citrate bicarbonate method (Mehra and Jackson 1960) and later determined

by Atomic Absorption Spectrometer. The amorphous Si, Al and Fe were then converted to their respective oxides.

Results and Discussion

Physico-chemical properties of the studied soils are presented in **Table 2**. The soils varied considerably in mechanical composition. The amount of sand, silt and clay ranged from 23.6-70.0%, 13.5-53.5%, 8.6-56.2% respectively. The particle size distribution data of the soils exhibited a decreasing trend of the sand fraction of all

the soils with depth of the profile except in P₁ (Entisols) where it was irregular (Table 2). However, a reverse trend was observed in the clay fraction of the soils. It indicates that clay has been formed due to *in situ* weathering of sand, which was also supported by highly significant and negative correlation between clay and sand ($r = -0.816^{**}$). The pH values revealed strongly acidic condition of the soils under order Ultisols (P₄, 4.7-4.8) while in other soils it was mostly moderate to slightly acidic (5.0-5.9). Surface horizons of all the pedons recorded the highest amount of organic carbon (0.76-0.91%) which decreased regularly with the soil depth except in 2C3 horizon of P₁. Similarly, exchangeable acidity was also high in the sur-

face horizons (0.79-1.68 cmol(p⁺)kg⁻¹) as compared to the subsurface horizons (0.12 - 1.39 cmol(p⁺)kg⁻¹) and showed a decreasing trend with depth except in few horizons of P₂ and P₄. The total exchangeable bases (Ca²⁺, Mg²⁺, Na⁺, K⁺) of the soils ranged from 1.94 to 4.81 cmol (p⁺) kg⁻¹. The highest total exchangeable bases (weighted mean of the profile) was recorded in Alfisols (4.25 cmol (p⁺) kg⁻¹) followed by Inceptisols (4.17 cmol (p⁺) kg⁻¹), Entisols (3.06 cmol (p⁺) kg⁻¹) and Ultisols (3.01 cmol (p⁺) kg⁻¹). The CEC of the soils was low (4.0-11.7 cmol (p⁺) kg⁻¹) and it was found to be mainly governed by the amount of clay as indicated by a highly significant and positive relation ($r = 0.867^{**}$) between these two parameters

Table 2: Physico-chemical properties of the soils

Horizon	Depth(cm)	Sand	Silt	Clay	pH	OC	Exch. acidity	Total exch. cations	CEC
		-----%-----							
P ₁ : Typic Udifluvents									
Ap	0-10	70.0	16.9	12.9	5.3	0.81	1.15	3.66	6.2
2AC	10-45	24.3	53.5	22.1	5.7	0.57	0.81	3.30	5.1
2C1	45-95	53.1	36.0	10.7	5.9	0.33	0.64	3.30	4.5
2C2	95-115	58.7	32.6	8.6	5.9	0.21	0.47	3.03	4.0
2C3	115-135	49.7	40.9	9.3	5.9	0.29	0.26	2.63	4.0
2C4	135-150	55.3	35.6	9.0	5.7	0.18	0.12	1.94	5.2
P ₂ : Typic Dystrudepts									
Ap	0-20	47.0	21.6	31.3	5.7	0.82	1.27	3.85	10.8
Bw1	20-75	46.3	17.4	36.1	5.6	0.32	0.92	3.60	9.3
Bw2	75-140	30.0	19.7	50.3	5.6	0.24	1.08	4.68	11.7
Bw3	140-180	25.2	23.2	51.4	5.6	0.24	1.13	4.32	10.5
P ₃ : Aeric Endoaqualfs									
Ap	0-20	61.7	13.5	24.7	5.0	0.76	0.79	4.15	7.1
B	20-45	35.5	19.2	45.3	5.3	0.45	0.58	4.81	8.4
Btg1	45-110	31.4	21.2	47.2	5.2	0.33	0.43	4.35	9.8
Btg2	110-220	27.7	22.9	49.2	5.1	0.27	0.22	4.09	9.2
P ₄ : Typic Hapludults									
Ap	0-15	52.0	22.3	25.6	4.8	0.91	1.68	2.41	8.5
B	15-65	33.4	25.4	41.1	4.8	0.48	1.39	3.72	8.9
Bt1	65-100	23.6	27.2	49.1	4.7	0.39	0.76	2.88	9.3
Bt2	100-145	24.6	23.0	52.3	4.7	0.30	0.91	3.08	10.7
Bt3	145-200	28.0	15.7	56.2	4.7	0.22	0.84	2.58	8.7

Total elemental analysis of the studied soils was carried out and data were utilized for calculating the weathering index according to the formula proposed by Evans and Cameron (1979). The weathering index in Entisols (P₁), Inceptisols (P₂), Alfisols (P₃) and Ultisols (P₄) varied from 6.24 to 4.19, 5.63 to 3.82, 5.40 to 3.22 and 5.69 to 3.03 % respectively (Fig. 1). The highest value of weathering index (based on weighted mean of the profile) was observed in Entisols (5.55 %) followed by Inceptisols (4.57 %), Alfisols (3.92 %) and Ultisols (3.77

%). The findings are in conformity with that of Evans and Cameron (1979) who reported that this index decreased with the pedogenic development of the soils. Weathering index showed a decreasing trend with the depth in all the soils. The formation of higher amount of clay resulted in lowering of weathering index because of accumulation of Si, Al and Fe and loss of base materials. This is well supported by highly significant negative relationship weathering index and clay ($r = -0.66^*$) and positive relationship with sand ($r = 0.586^*$).

Distribution of amorphous materials

The constituents of amorphous materials in the deferred clay fraction expressed as oxides of Si, Al and Fe are presented in **Table 3**. The amorphous SiO₂ was found to be the dominant constituent and it ranged from 3.50 % in 2C4 horizon of Entisols (P₁) to 12.27 % in Bt2 horizon of Ultisols (P₄). The Al₂O₃ was next in abundance (3.72 to 9.01 %) followed by Fe₂O₃ (0.91 to 2.34%). The constituents of amorphous material did not exhibit any definite pattern of distribution with soil depth. However, a decreasing trend of SiO₂ in Inceptisols (P₂) and somewhat increasing trend of all the constituents with soil depth

were observed in Ultisols (P₄). Similar findings were also reported earlier for some soils of Assam (Das and Sharma 1980; Karmakar and Borah 1996). The well developed Ultisols (P₄) contained the highest average amount (weighted mean of the profile) of SiO₂ (10.90%), Al₂O₃ (8.03%) and Fe₂O₃ (2.02 %) as compared to other soils. This finding clearly indicates that more amounts of amorphous SiO₂, Al₂O₃ and Fe₂O₃ were formed with the advance stage of soil development in acidic soil environment under humid-subtropical climatic condition. This was also corroborated by a negative correlation of SiO₂, Al₂O₃ and Fe₂O₃ with pH and weathering index (**Table 4**).

Table 3: Constituents of amorphous materials in clay fraction

Horizon	Depth (cm)	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Molar Ratio	
		------%-----			SiO ₂ /Al ₂ O ₃	SiO ₂ /R ₂ O ₃
P ₁ : Typic Udifluvents						
Ap	0-10	8.15	4.10	0.91	3.37	2.95
2AC	10-45	6.46	3.72	1.24	2.94	2.43
2C1	45-95	5.71	3.98	1.31	2.43	2.01
2C2	95-115	4.87	3.72	1.45	2.22	1.78
2C3	115-135	6.22	5.67	1.38	1.86	1.61
2C4	135-150	3.50	3.96	1.24	1.50	1.25
P ₂ : Typic Dystrudepts						
Ap	0-20	8.27	5.87	1.21	2.39	2.11
Bw1	20-75	6.75	7.90	1.13	1.45	1.33
Bw2	75-140	6.61	8.44	1.97	1.33	1.16
Bw3	140-180	6.18	6.52	1.18	1.61	1.44
P ₃ : Aeric Endoaqualfs						
Ap	0-20	9.81	5.63	1.64	2.96	2.49
B	20-45	8.81	4.99	1.84	3.00	2.42
Btg1	45-110	7.87	4.82	1.11	2.77	2.41
Btg2	110-220	8.08	5.12	0.93	2.68	2.40
P ₄ : Typic Hapludults						
Ap	0-15	8.44	4.53	1.73	3.16	2.54
B	15-65	8.70	6.52	1.64	2.27	1.95
Bt1	65-100	11.72	8.95	1.91	2.22	1.95
Bt2	100-145	12.27	9.01	2.21	2.31	2.00
Bt3	145-200	11.91	8.95	2.34	2.26	1.93

Table 4: Components of Amorphous materials in clay fraction of soils

Horizon	Depth (cm)	FeOOH(%)	Si ₃ AlO ₆ (OH) ₄ (%)	Al(OH) _{2.5} (%)	Hydroxyl water (%)	Amorphous Material (%)	Tetra/Octra
P ₁ : Typic Udifluvents							
Ap	0-10	1.02 (6.40)	12.45 (78.22)	2.45(15.38)	2.74(17.25)	15.91	5.09
2AC	10-45	1.38 (10.01)	9.86 (71.32)	2.58 (18.68)	2.40(17.39)	13.83	3.82
2C1	45-95	1.46 (10.91)	8.72 (64.99)	3.23 (24.09)	2.40(17.91)	13.42	2.70
2C2	95-115	1.62 (13.24)	7.45(60.73)	3.19 (26.04)	2.20(17.98)	12.26	2.33
2C3	115-135	1.54 (9.42)	9.50 (58.04)	5.33 (32.53)	3.09(18.89)	16.37	1.78
2C4	135-150	1.38(12.82)	5.36 (49.61)	4.06 (37.57)	2.08(19.23)	10.80	1.32

P ₂ : Typic Dystrudepts							
Ap	0-20	1.35 (7.19)	12.64 (67.19)	4.82(25.62)	3.44(18.29)	18.81	2.62
Bw1	20-75	1.26 (6.37)	10.32 (52.29)	8.16(41.34)	3.95(20.01)	19.74	1.26
Bw2	75-140	2.20 (10.33)	10.09 (47.49)	8.96(42.18)	4.22(19.86)	21.25	1.13
Bw3	140-180	1.32 (7.65)	9.44 (54.68)	6.50(37.67)	3.37(19.54)	17.26	1.45
P ₃ : Aeric Endoaqualfs							
Ap	0-20	1.83 (8.84)	14.99 (72.38)	3.89(18.78)	3.62(17.47)	20.71	3.85
B	20-45	2.05(10.85)	13.46 (71.15)	3.40(17.99)	3.27(17.26)	18.91	3.95
Btg1	45-110	1.24 (7.39)	12.02 (71.57)	3.53(21.04)	2.99(17.79)	16.80	3.40
Btg2	110-220	1.03 (6.00)	12.35 (71.60)	3.86(22.40)	3.11(18.02)	17.24	3.20
P ₄ : Typic Hapludults							
Ap	0-15	1.92 (10.84)	12.90 (72.68)	2.92(16.48)	3.04(17.10)	17.75	4.41
B	15-65	1.83 (8.86)	13.29 (64.36)	5.53(26.77)	3.78(18.31)	20.65	2.40
Bt1	65-100	2.13 (7.69)	17.9(64.57)	7.69(27.74)	5.12(18.48)	27.72	2.33
Bt2	100-145	2.47 (8.57)	18.75 (65.17)	7.55(26.25)	5.26(18.27)	28.77	2.48
Bt3	145-200	2.61 (9.18)	18.19 (64.02)	7.62(26.80)	5.20(18.30)	28.42	2.39

Figures in the parentheses represent the percent constituents of amorphous ferri-aluminosilicate

Molar ratio of $\text{SiO}_2/\text{Al}_2\text{O}_3$ (1.33-3.37) and $\text{SiO}_2/\text{R}_2\text{O}_3$ (1.16-2.95) indicated that the amorphous material in the studied soils were siliceous in nature (Table 3). The lowest average value of $\text{SiO}_2/\text{Al}_2\text{O}_3$ was found in Inceptisols which was 1.55 (weighted mean of the profile) and almost closer to the value of 1.6 and 1.70 as reported by Karmakar and Borah (1996) and Yuan (1969) for Inceptisols. A comparatively higher $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio (weighted mean 2.77) and $\text{SiO}_2/\text{R}_2\text{O}_3$ (weighted mean 2.41) in Alfisols may be due to periodic water saturation in these soils. The findings are in well agreement with those observed by Mishra and Ghosh (1994) and Karmakar (2012). The molar ratios were found high in the surface horizons and there after it decreased down the profile in all the soils with only few exceptions. Higher molar ratio, more particularly in surface horizon might be due to presence of high organic carbon leading to more biochemical weathering. This is well supported by a highly

significant and positive correlation of organic carbon with $\text{SiO}_2/\text{Al}_2\text{O}_3$ ($r=0.693^{**}$) and $\text{SiO}_2/\text{R}_2\text{O}_3$ ($r=0.691^{**}$) in these soils (Table 5).

The Si, Al and Fe extracted by 0.5N NaOH and subsequent CBD treatment were allocated to three components as envisaged in the model of Krishna Murti *et al.* (1976). According to the model, all the iron was expressed as FeOOH. The tetrahedral component [$\text{Si}_3\text{AlO}_6(\text{OH})_4$] was calculated by using the percentage Si extracted by 0.5 N NaOH. All the Si was assigned to the tetrahedral core with sufficient Al to give the unit formula $\text{Si}_3\text{AlO}_6(\text{OH})_4$. The difference between the total extracted Al and tetrahedral Al was expressed as the octahedral component [$\text{Al}(\text{OH})_{2.5}$]. The sum of these three components *viz.* FeOOH, $\text{Si}_3\text{AlO}_6(\text{OH})_4$, $\text{Al}(\text{OH})_{2.5}$ was the amount of amorphous material. The difference between the amount of amorphous material and the sum of oxides of Si, Al and Fe gave the hydroxyl water content.

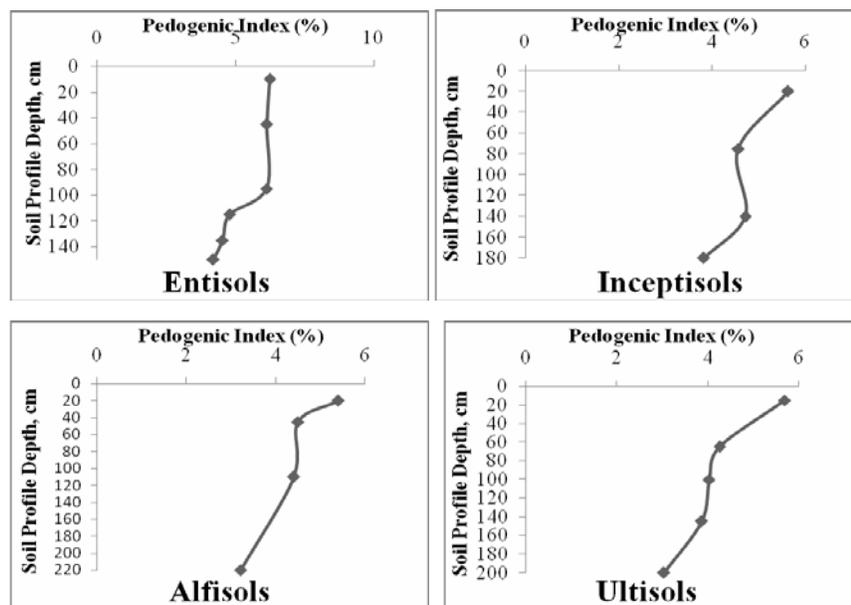


Figure 1: Depth wise variation of weathering index of different soil orders

Table 5: Relationship between the amorphous materials and its components and soil properties

Amorphous constituents	Sand	Silt	Clay	pH	OC	CEC	W.I (%)
SiO ₂	-0.394	-0.502*	0.628**	-0.716**	0.235	0.502*	-0.253
Al ₂ O ₃	-0.553*	-0.438*	0.727**	-0.561*	-0.290	0.670**	-0.528*
Fe ₂ O ₃	-0.364	-0.233	0.447	-0.535*	-0.135	0.291	-0.266
SiO ₂ /Al ₂ O ₃	0.215	-0.088	-0.133	-0.126	0.693**	-0.179	0.429
SiO ₂ /R ₂ O ₃	0.186	-0.140	-0.078	-0.154	0.691**	-0.113	0.386
FeOOH	-0.364	-0.236	0.449*	-0.536*	-0.135	0.294	-0.266
Si ₃ AlO ₆ (OH) ₄	-0.394	-0.502*	0.628**	-0.716**	0.234	0.502*	-0.253
Al(OH) _{2.5}	-0.495*	-0.335	0.618**	-0.423	-0.408	0.620**	-0.520*
Hydr. Water	-0.544*	-0.495*	0.753**	-0.669**	-0.130	0.662**	-0.474*
Amor. Material	-0.519*	-0.506*	0.738**	-0.708**	-0.035	0.628**	-0.424
Tetra/Octa	0.280	-0.120	-0.170	-0.101	0.729**	-0.179	0.464*

The content of amorphous material and its component in the studied soils are presented in Table 4. The data revealed a wide variation in the amorphous material content (10.81-28.77 %) of the clay fractions of the studied soils. It was observed that amorphous materials constituted 25.63% (weighted mean) of the clay fraction in Ultisols (P₄). It indicated that formation of amorphous material increases with the advancement of soil development which was further enhanced by acidification of soil profile. This was supported by the negative relationship between amorphous materials and weathering index and pH (Table 5). The higher amount of amorphous material in Ultisols also suggested that the rate of recombination of hydrolytic products is slower than the rate of hydrolysis of primary minerals with the advancement of weathering stages of soil. The apparent increase of amorphous

materials with depth in this soil was closely related to the amount of clay as indicated by a highly significant positive relationship between them (Table 5).

Among the different components, tetrahedral component [Si₃AlO₆(OH)₄] and the octahedral component [Al(OH)_{2.5}] constituted 5.36 to 18.75% and 2.45 to 8.96% of the clay fraction respectively. The FeOOH component varied from 1.02 to 2.20%. The composition of amorphous material suggest that major portion of the amorphous material in the studied soils were composed of tetrahedral Si₃AlO₆(OH)₄ (47.49 to 78.22%) followed by octahedral Al(OH)_{2.5} (15.38 to 42.18 %) and neutral FeOOH (6.00-13.24 %) components. The results are in good agreement with the findings of Karmakar and Borah (1996) and Das and Sarma (1980).

An apparent decreasing trend of the percent con-

tribution of tetrahedral component $[\text{Si}_3\text{AlO}_6(\text{OH})_4]$ towards amorphous materials down the profiles was observed almost in all the soils. The ratio of tetrahedral to octahedral components also showed the similar trend whereas a reverse trend was observed in octahedral component $[\text{Al}(\text{OH})_{2,5}]$. Higher amount of tetrahedral component and greater tetrahedral/octahedral ratio in the surface horizons, both of which decreased with soil depth might be due to more biochemical weathering in the surface horizons in presence of high organic carbon. This is corroborated by a highly significant and positive correlation co-efficient between tetrahedral/octahedral ratio and organic carbon ($r = 0.729^{**}$). Though not significant, positive relationship was also observed between tetrahedral component and organic carbon. A negative and highly significant correlation coefficient ($r = -0.716^{**}$) with pH indicated that more amount of tetrahedral $\text{Si}_3\text{AlO}_6(\text{OH})_4$ is formed with increasing soil acidity and this might be attributed to presence of higher amount of this component in Ultisols (P_4) leading to acid weathering. The FeOOH component did not show any definite vertical distribution pattern in these soils. Karmakar (2012) reported that the irregular distribution of FeOOH component was related to the redox condition of the soils which regulate the precipitation of iron and ultimately is affected by drainage and fluctuating ground water table. The amount of iron found in the amorphous material of CBD pre treated clay fraction suggested that iron is a structural component in the amorphous material and hence the amorphous material can best be regarded as amorphous ferri-aluminosilicates (AFAS). The iron in the AFAS was protected by a phase soluble in NaOH and it is therefore not believed to be a part of the outer layer comprising only tetrahedral and octahedral components. Appreciable amount of iron in the amorphous materials of Assam soils was also reported by Das and Sarma (1980), Karmakar and Borah (1996).

The hydroxyl water content of the amorphous material calculated from the structural model lies in the range of 17.10 to 20.01% with a mean value of 18.55% which is closer to the value of 18.2% as reported by Raman and Mortland (1970) and 19.00% by Das and Sharma (1980). The significant relationship with pH and weathering index (Table 5) indicated profound effect of soil acidity and weathering intensity on hydroxyl water content of amorphous materials.

Genesis of amorphous material

The soils under study have developed from diversified parent materials and acidic rocks and dominant in quartz and feldspars in the fine sand fraction (Chakravarty *et al.* 1979) and kaolinite, micas and chlorite in clay fraction (Chakravarty *et al.* 1992; Dutta and Shanwal 2006). Considering the climatic condition of the study area, hydrolysis is probably the main weathering mechanism. Hydrolysis of primary minerals particularly the feldspars which are abundant in these soils and acid

weathering of micas under hyperthermic sub tropical climate might have released the constituent elements (Si, Al and Fe) that led to formation of amorphous material. These amorphous materials can be considered as precursors of kaolinite mineral found in the clay fraction of the studied soils. The presence of considerable amount of iron domains within the gel mass of amorphous ferri-aluminosilicates of clay fraction might have enhanced the crystallization of kaolinite as crystallization takes place in the iron rich zone of the gel mass (Krishna Murti *et al.* 1976). The role of iron in formation of kaolinite in these soils was also corroborated by the positive relation between iron content of kaolinite and amorphous materials in soils of Assam (Das and Sharma 1980). Neosynthesis of kaolinite via amorphous ferri-aluminosilicates from the hydrolysis of primary minerals is possible under humid sub-tropical climate where intense leaching of bases during high rainfall has resulted in soil acidity which is conducive for the formation of kaolinite. This hypothesis holds good because the breaking of kaolinite in the high rainfall is impossible (Singer 1966). The significant negative correlation co-efficient (r) of clay with sand ($r = -0.816^{**}$) and silt ($r = -0.519^{*}$) clearly suggest neosynthesis of clay in these soils.

Organic acid played a dominant role of in the neosynthesis of kaolinite via amorphous material. Biochemical weathering due to the action of water soluble organic acids leads to the destruction of primary minerals with consequent release of Al and Si in soils (Robert *et al.* 1979). Disintegration of microcline, biotite and muscovite can effectively be carried out by organic acids like humic and fulvic acids (Potter and Kampe 1981). It was reported that fulvic acid can extract ten times more silica and six times more aluminium at pH 2.5 than at pH 7.0 (Tan 1980). Linares and Huertas (1971) observed that the presence of fulvic acid led to formation of kaolinite from solution that contained Si and Al. Considering the higher amount of organic carbon and acidic pH range in all the studied soils, organic acid might have played a significant role in the genesis of amorphous materials in these soils. This was further supported by the presence of appreciable humus consisting of very high amount of fulvic acid (47 to 90 %) compared to humic acid (10.0 to 52.4%) in some soils of Assam (Karmakar and Rao 1999).

Conclusion

The study indicated an increasing trend of amorphous material content with the advancement of pedogenic development of soils as Ultisols was recorded for the highest amount of amorphous material and its constituents were observed in Ultisols while Entisols contained the lowest amounts. The organic matter content and soil acidity played a dominant role in formation of amorphous materials in these soils. The content of amorphous material is seldom high in soils but it can significantly influence the physical and chemical behavior of the soils. Keeping in view the climatic condition of

the area, a detailed study would therefore be required to investigate the effect of the materials on soil properties particularly ion retention and fixation of nutrients.

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