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Pedogenesis in high altitude soils of Meghalaya plateau

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Abstract : The study was to investigate the pedogenesis and taxonomy of some of the high altitude soils at two sites in Meghalaya plateau, one at Myllieum (site A) and the other at Pynursala (site B), differing in elevation, vegetation and rainfall. The morphological, physical and chemical characteristics of three pedons in each site were studied on different topographic positions. The Myllieum site has summits, side-slopes and valleys under different land uses including forest and cultivation. The pine forest soils on the summits have argillic horizon and low base saturation. The soils on the side-slopes are eroded and shallow with little pedogenic development. The soils in the valleys are deep and coarse textured with high water table. The Pynursala site has summits and convex plateau tops and supports grasses only. The soils have dark brown umbric epipedon and redder cambic or kandic horizons. The redness increased with depth. The soils are strongly to moderately acid with high organic carbon, low base status, high exchangeable aluminum and low effective cation exchange capacity (<3 cmol(p+)kg^{-1}). The soils developed in summits and convex plateau tops are Dystrudepts, weakly expressed Hapludults and Kanhapludults. The application of pathways relating to slope processes to pedogenesis of sub-surface horizons revealed that the argillic horizon forms quickly in fresh re-golith summit soils than in convex plateau tops where colluvium interrupts the orderly progression of soil development. The pathways are helpful to characterize and monitor the state of soil quality in high altitude regions of Meghalaya. These soils are best understood when studied in landscape contexts rather than individual pedons or classification units.

Additional key words : *Pedogenesis, high altitude soils, topography, land use*

Introduction

The high altitude region in Meghalaya extends from the border of Bangladesh to Mawphlong in upper Shillong plateau. The Kernel of Shillong plateau is the exposed Archean gneiss and schists covered in central and eastern parts by Precambrian quartzites and phyllites, intruded later by young granites and basic/ultra-basic suites. The ancient peneplain surface of the plateau is still preserved with the marks of different cycles of denudation in the central and northern part. It is hidden beneath the Mesozoic traps along the central southern fringe and cretaceous, tertiary and post tertiary sediments over the southern, south eastern and western parts. The drainage pattern is a spectacular feature revealing the extraordinary straight courses of the rivers and streams evidently along joints and faults. The magnificient gorges scooped out by rivers in the southern Khasi hills are the result of massive headward erosion by antecedent streams along the joints of the sedimentary rocks over gneissic rocks and granites.

The high lands of Meghalaya comprise large area (≈ 30% of total geographical area) but information on their soils is meagre. The pedogenic characteristics of some subgroups of Inceptisols in the highlands of the Darjeeling Himalayan region (Pal *et al.*1984), Alfisols and Ultisols in Sikkim forest division (Gangopadhyay *et al.*1986) and in Mizoram (Singh *et al.*1991) have been reported. The distribution and characteristics of moderately acid to strongly acid subgroups of Oxisols, Inceptisols and Entisols were reported in the high altitude region of Meghalaya (Nair and Chamuah 1988). These Oxisols were reclassified later on in the subgroups of *Ultisols* by defining subsurface horizons as kandic taking into consideration the values of apparent ECEC and CEC (Bhattacharyya *et al.* 1994). The same criteria was used to identify kandic horizons in soils of Manipur by Sen *et al.* (1994). The objective of this study is to investigate pedogenic characteristics of high altitude soils of Meghalaya Plateau and classify them for various uses.

Materials and Methods

Study area

The two sites referred as site A at Myllieum (around 25°29'N and 91°48'E) and site B at Pynursala (around 25°19' N and 91°53') are situated south of Shillong city (Fig.1). The two sites differ in aspect, vegetation, elevation, rainfall and temperature. However, sandstone capping over granite is common in both sites. On some shoulder slopes, granite boulders are observed. Site A is on eastern aspect at the altitude of 1660-1760 m above MSL and is dominated by pine (*Pinus insularis*) with oak, rhododendron, mongolia and other temperate forest trees. It receives an annual rainfall of 2026 mm in 128 days and experiences maximum temperature of 24.1°C in July and a minimum temparature of 3.6 °C in January (Table 1). The transect of Myllieum covers summits with pine vegetation (slopes of < 8 per cent), side-slopes

(8-15 per cent) and narrow valleys (<8 per cent). The side–slopes are presently under potato and radish cultivation whereas valleys are cultivated to rice in the rainy season and peas in winter. The site-B (Pynursala) is covered with grasses and has two land units *viz* summits and convex plateau tops. The elevation ranges from 1280 m to 1631 m . This site is near Cherrapunji and receives mean annual rainfall of 11000 mm. The maximum temperature is 22.9 °C in June and the minimum is 7.6°C in January. Myllieum is cooler by 4°C than Pynursala in the winter. (Table 1). The soil moisture regime is *udic* in the hill slopes and in the valleys with *thermic* soil temperature regime.

Soil studies

Three pedons (P1,P2 and P3) were studied in site A and three (P4, P5 and P6) in site B. The soils at both sites were described in the field (Soil Survey Division Staff 2000) and classified (Soil Survey Staff 1999). At every profile site, longitude, latitude and altitude were recorded with the help of hand held GPS (Global map100, Lawrence). Horizon-wise soil samples were collected and passed through 2 mm sieve for laboratory analysis. The particle- size analysis was carried out by pipette method after removing organic matter. The pH in 1:2.5 soil : water ratio, organic carbon by wet oxidation method and CEC by1*N* NH_4OAc at pH 7.0 were determined (Jackson 1973). The exchangeable Al^{3+} and H^+ in 1*N* KCl extract were determined using standard method (Black *et al.* 1965). The effective cation exchange capacity (ECEC) is the sum of exchangeable bases plus extractable Al in 1*N* KCl. The triacid (Jackson 1973) and the CBD (Mehra and Jackson 1960) extractable iron and manganese contents were determined by atomic absorption spectrophotometer (Perkin Elmer Model, 3100).

The formula for computing redness rating is $Rr = (K\text{-}H)CV^{-1}$. The value of K (constant) is 30 as proposed by Alexander (1985). H is assigned number to the hue as per scheme of Hurst (1977), C is chroma and V is value. H is assigned by adding zero to the number preceding R, 10 to the number preceding YR or 20 to the number preceding Y in Munsell colour notation. Simple correlation coefficients were worked out to establish relationships among soil properties.

Results and discussion

Soil morphology

The soils on summit (P1) have dark brown (10YR4/3) A horizons and reddish brown (5YR4/4) to yellowish red (5YR4/6) argillic B horizons (Table 2). The soils on side–slopes (P2) are shallow and dark brown (10YR3/3) or brown (10YR 4/4) in A horizons over weathered sandstone observed below 52 cm. The soils in the valley (P3) are deep, moderately well drained and saturated with water throughout the year. It has dark grey (10YR 3/1) Ap horizon and yellow (10YR 7/6) C horizons. The ground water is within 50 cm. The soils on convex plateau tops at site B are moderately deep to deep show-

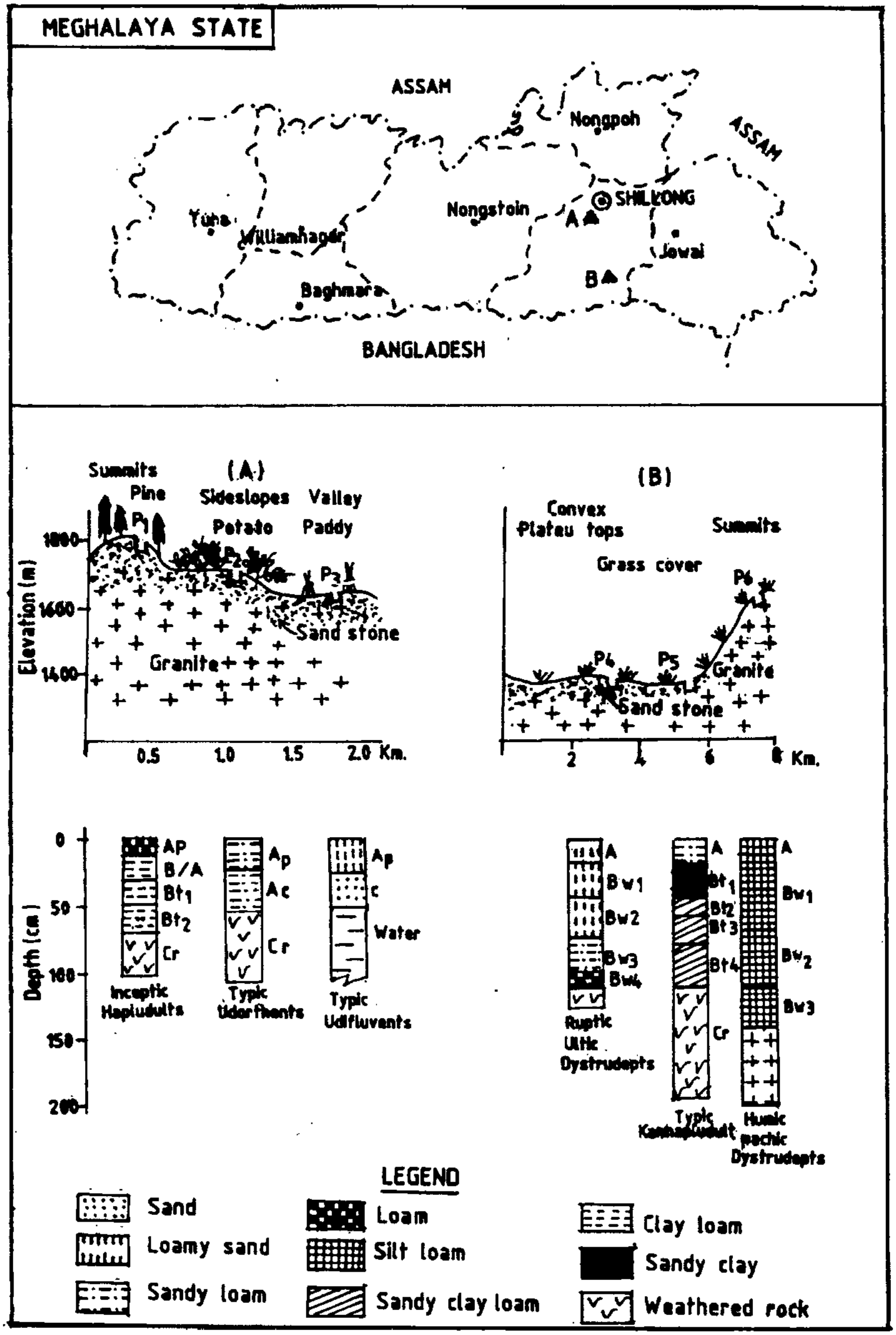

Fig. 1. Land characteristics at Myllieum (A) and Pynursala (B)

Table 1. Climatic data of two sites in high altitude areas of Meghalaya

Climatic parameters	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Site A													
Rainfall (mm)	18.3	23.4	51.9	131.2	299.5	419.0	348.2	298.8	252.5	155.2	23.2	5.7	2026.0
PET (mm)	38.6	56.1	100.1	110.6	106.1	84.9	82.2	82.8	73.2	65.5	45.5	35.7	889.9
Temp. (⁰C)													
Maximum	15.5	17.1	21.5	23.8	23.7	23.7	24.1	24.1	23.6	21.8	18.9	16.4	
Minimum	3.6	6.4	10.5	14.1	15.5	17.4	16.1	17.8	16.6	12.9	7.7	7.7	
Site B													
Rainfall(mm)	19.8	37.3	178.9	605.2	1705.2	2921.5	2456.7	1827.5	1162.7	447.4	46.7	4.9	11418.7
PET (mm)	49.6	76.5	107.6	105.5	103.0	88.0	85.3	85.8	82.0	80.1	58.1	45.9	961.8
Temp. (⁰C)													
Maximum	15.8	16.9	20.5	22.0	22.1	22.9	22.2	22.5	22.9	22.4	19.7	17.0	
Minimum	7.6	10.5	12.9	15.1	16.3	17.3	18.4	18.4	18.1	15.9	11.9	8.8	

(Source: Nair *et al.* 1983)

ing well expressed cambic B horizons (P4) and kandic horizons (P5). The Pedon 5 has redder (5YR/ 2.5YR) B horizons than Pedon 4 (7.5YR) with value of 4 or 6 and chroma of 6 or 8. The soils on summits (P6) have umbric epipedon of 20 cm thick and colours in the hue of 10YR, value of 3 and chroma of 2. The redness increases with depth in P5 and P6 and its values are as high as 26 in P5.

The particle-size distribution

Most of the soils *i.e.* P2 and P3 at site A and P4 and P5 at site B have 60 per cent or more sand (Table 2). Only two pedons, P1 and P6 have higher silt content of 35 to 60 per cent. The clay content is 25 per cent or more in soils on summits (P1) and convex plateau tops (P4 & P5). The clay content increases in the B horizons of P1 and P5 showing the formation of argillic or kandic horizons. Argillic horizon in the soils of high altitude areas of Meghalaya has been reported by several workers (Nair and Chamuah 1988 and Bhattacharyya *et al.* 1994).

P^H *and organic carbon*

The soils on the summit (P1) and the side–slopes (P2) are strongly acid (pH of 5.1 to 5.3) whereas in the valleys (P3), the soils are moderately acid (pH of 5.0 to 5.7) (Table 2). The soils at site B are more acidic. The soils P4 and P6 are extremely acid (3.9 to 5.0) as they undergo intense leaching leading to H^+ concentration in this high rainfall region (Jenny 1980). The organic carbon is high in the grassland soils at site-B compared to the soils at site A which are mostly under cultivation. The soil (P6) at site B has higher organic carbon content (11-38 gkg^{-1}) than the other grassland soils (P4 and P5) as disturbance is least from grazing of animals and coal mining. The elevation has a significant positive correlation (r = 0.48*) with organic carbon (Table 5) content through distinct pattern of vegetation (Sims and Nielsen 1986).

Exchangeable cations

The summit soils at site A contain exchangeable aluminum of 2.03 to 2.94 cmol (p+) kg^{-1} but its content decreases in soils on side–slopes (P2) and valleys (P3). At site B, the exchangeable Al increases with depth in soils on convex slopes (P4) and decreases in soils on summits (P6), the values varying from 0.81 to 4.16 cmol(p+)kg^{-1}. The Al saturation is high in the soils of summits (>50 per cent of effective cation exchange capacity) where leaching is severe followed by convex plateau tops (35-50 per cent). In the soils of side–slopes and valleys the Al saturation is low (<30 per cent) as they experience limited leaching. Similar results were reported by Prasad *et al.* (1985) for the high land soils of East Khasi Hills in Meghalaya. The exchangeable aluminum per cent of 60 or more in the soil solution is reported to contain toxic levels of aluminum (Evans 1968 and Nye *et al.*1961). The pedon 1, 5 and 6 have exchangeable aluminum in such critical limits that the aluminum remain chelated with organic matter and may get released at pH values of 6-7 (Hargrove 1986) as these soils are rich in organic matter. The depth- wise distribution of exchangeable Al in pedon 4 shows higher amount (16.5 cmol(p^+)kg^{-1}) at the depth of 190 cm which is lying over hard granitic rocks. This higher amount of exchangeable Al can be attributed to release of Al by weathering of primary minerals (Graham *et al.* 1989) which is frequently observed at the weathering front very near to hard rock. The exchangeable H^+ ranges from 0.1 to 0.5 cmol(p^+)kg^{-1} soil as the pH of the soils is higher than 4.5. The exchangeable Ca and Mg are low (1.1 cmol(p^+)kg^{-1} soil) except in pedon 6 where exchangeable Ca is 3.6 cmol(p^+)kg^{-1} soil in the surface and decreases with depth. The higher amount of exchangeable Ca is attributed to grass vegetation and higher organic carbon content throughout the profile.

Cation exchange capacity

The ECEC is extremely low (less than 5 cmol(p^+)kg^{-1}) in majority of horizons (Table 2). All the soils have base saturation less than 50 per cent in the sub surface horizons and some soils qualify for subgroups of Ultisols . The soils on convex plateau tops (P6) has apparent CEC less than 16 cmol(p^+)kg^{-1} and apparent ECEC less than 12 cmol(p^+)kg^{-1} to support the presence of kandic horizons. These values were used to define kandic horizons in soils of Meghalaya by Bhattacharyya *et al.*(1994) and in soils of Manipur by Sen *et al.* (1994). The other soils has higher CEC (20 to 64 cmol (p^+)kg^{-1} clay) and ECEC (14 to 26 cmol(p^+)kg^{-1} clay). The effective CEC has a linear relationship with organic matter (r =0.48*). Similar kind of relation was reported in soils of Southern Applachian mountains by Daniels *et al.* (1987) indicating the ability of these soils to hold nutrients in the organically enriched surface horizons.

Forms of iron

The soils at both sites (A and B) have total iron of 8.2 gkg^{-1}(P4) to 84.2 gkg^{-1}(P2)

Table 2. Selected morphological, physical and chemical characteristics of soil

Depth (cm)	Horizon	Matrix colour	Redness rating	Sand (2.0-0.05mm)	Silt (0.05-0.002mm)	Clay (<0.002mm)	pH	OC gkg^{-1}
				(%)				
Site1 : Myllieum								
Pedon 1: Inceptic Hapludults — (1755 m above msl) —(25°29'40" N Lat; 91°48'26"E Long.)— pine								
0-13	A	10YR4/3	7.5	33.8	40.2	26.0	4.53	3.07
13-30	B/A	10YR4/4	10	26.8	46.7	26.5	4.60	2.62
30-48	B t1	5YR4/4	15	22.3	37.7	40.0	4.61	0.12
48-70	B t2	5YR4/6	22.5	20.8	34.7	44.5	4.88	0.67
70-100	Cr	2.5YR4/6	26.3	48.0	23.0	29.0	5.60	0.20
Pedon 2 : Typic Udorthents — (1735 m above msl)—(25°29'39" N Lat; 91°48'31" E Long.)— pine								
0-23	A	10YR4/3	7.5	67.0	12.9	23.5	4.58	2.46
23-52	AC	5YR5/6	18	63.6	11.0	16.0	4.56	1.26
52-105	Cr	10YR7/4	5.7	73.0	9.0	15.5	5.01	0.18
Pedon 3 : Typic Udifluvents — (1662m above msl)— (25°29'42"N Lat; 91°48'48" E Long.)— Paddy								
0-25	Ap	10YR3/1	3.3	75.5	12.9	15.5	5.22	2.93
25-50	C	10YR7/6	8.6	84.5	11.0	10.0	5.26	1.06
Site 2 : Pynursala								
Pedon 4: Ruptic -Ultic Dystrudepts — (1390.3 above msl)— (25°19'30"N Lat; 91°53'51"E long.)—grass cover								
0-18	A	7.5YR4/6	18.8	81.7	10.3	8.0	4.35	8.3
18-41	BA	7.5YR6/6	12.5	79.0	12.5	8.5	4.71	3.1
41-72	Bw1	7.5YR5/6	15.0	79.0	11.5	9.5	5.05	1.8
72-98	Bw2	7.5YR6/6	12.5	70.2	16.3	13.5	4.78	1.0
98-110	Bw3	7.5YR5/6	15.0	47.0	30.5	22.5	4.92	3.3
Pedon 5 : Typic Kanhapludults — (1386.7 above msl)—(25°19'09"N Lat; 91°53'20"E Long.)—grass cover								
0-19	A	10YR3/3	10.0	78.2	9.3	12.5	4.60	22.0
19-43	Bt1	5YR5/8	24.0	46.2	15.8	38.0	4.63	5.5
43-56	Bt2	5YR5/8	24.0	59.6	11.4	29.0	5.09	2.4
56-76	Bt3	7.5YR5/8	20.0	61.6	13.9	24.5	5.35	1.2
76-109	Bt4	2.5YR4/6	26.3	69.3	7.2	23.5	4.95	0.4
109-196	Cr	2.5YR7/6	15.0	65.3	15.7	19.0	4.98	0.2
Pedon 6 : Humic Pachic Dystrudepts — (1631.52 above msl)—(25°19'30"N Lat; 91°52'23" E long.)—grass cover								
0-20	A	10YR3/2	6.6	18.1	61.4	20.5	4.38	38.2
20-69	A/B	7.5YR4/4	12.5	31.3	51.7	17.0	4.51	17.1
69-110	Bw2	7.5YR4/4	12.5	19.8	57.2	23.0	4.77	12.7
110-140	Bw3	7.5YR4/4	12.5	21.8	54.7	23.5	5.05	11.7

and dithionite iron of 3.3 gkg^{-1}(P2) to 54.7 gkg^{-1}(P5). The depth-wise distribution of total (Fe_t) and dithionite iron (Fe_d) contents shows an increasing trend in pedon 1, 4 and 6 while decreases with depth in pedon 2 and 3 and irregular with depth in pedon 6 (Table 4). The Fe_d to clay ratio vary from 2.1(P2) to 16.3 (P5) per cent with irregular trends with depth in pedon 1. The pedon 5 and 6 have Fe_d to clay ratio of 13.3 to 15.9 per cent in B horizons. The distribution of Fe_d to clay ratio shows that the dithionite iron is positively related with clay distribution (r = 0.72*, significant at 1 per cent level, Table 5). The movement of dithionite iron with clay were reported in hill lands soils of Tripura by Gangopadhyay *et al.* (2001) and in the developmental sequence of Dystrudepts and Hapludults by Rebertus and Boul (1985). The Fe_d is positively related but not significant with ECEC values indicating that the surface reactions and exchange properties in these soils are influenced by amorphous iron oxides present as surface coatings on clays (Agbenin and Tiessen 1995). The relation of Fe_d contents with redness rating (r = 0.56**, Significant at 1 per cent level) shows the importance of iron in inducing redder colours in the solum. The relation of redness rating with hematite content were reported in various soils by Torrent *et al.* (1983). The summit soils at site A (P1) and convex plateau top soils at site B (P6) have Fe_d/Fe_t ratio more than 0.75 in the subsurface B horizons indicating intensive weathering and morphological development with depth. This ratio as proposed by Rebertus and Boul (1985) is used to differentiate less weathered Dystrudepts (P4 & P6) from highly weathered Hapludults (P1 & P6). It is further confirmed that the changes in the forms of iron are good indicators of age of soils (Arduino *et al.* 1986) and continue to change as soils become older .

Forms of manganese

The manganese contents are more variable than iron contents and in general, slightly increases with depth (Table 4). The total manganese (Mn_t) is in between 22 $mgkg^{-1}$ and 1061 $mgkg^{-1}$ with increasing trends with depth in pedon 1, 2, 4 and 6. The dithionite manganese(Mn_d) varies from 4.5 $mgkg^{-1}$ to 425 $mgkg^{-1}$ in soils but its distribution is similar to that of total manganese in pedon 1, 2, 4 and 6. The Mn_d is positively correlated with clay content (r = 0.39*, significant at 5 per cent level). This relationship is in agreement with the findings of Aubert and Pinta (1977). The Mn_d to Mn_t ratio is 0.2 to 0.6 in B horizons of pedon 1, 4, 5 and 6 with an increasing trend with depth. The soils on side slopes (P2) and valleys (P3) at site A have low Mn_d to Mn_t ratio with the values of 0.06 to 0.14. The Mn_d to Fe_d ratio has a general tendency to increase with depth indicating accumulation of Mn_d in B and C horizons which also provide evidence to water flow through the pedons (Hall 1983). The Mn seems to be highly mobile than Fe with in the landscapes (Biswas and Gawande 1964) and exert strong influence on Mn_d to Fe_d ratio in these soils.

Table 3. Exchangeable cations and cation exchange capacity of soils

Depth (cm)	Exchangeable Al^{3+}	H^+	Ca^{2+}	Mg^{2+}	CEC	ECEC	Base saturation (%)	CEC	ECEC	Exchangeable Al^{3+}	***Al saturation (%)
	cmol(p+)kg^{-1}							**cmol(p+)kg^{-1}clay			
Site 1 : Myllienum											
Pedon 1 : Inceptic Hapludults — (1755 m above msl)— (25°29'40" N lat, 91°48'26"E long.)– pine											
0-13	2.44	0.15	0.9	0.56	8.8	4.46	21	33.8	17.20	9.4	54.7
13-30	2.03	0.18	0.7	0.26	9.4	4.58	25	35.5	17.30	7.7	44.3
30-48	2.94	0.13	0.9	0.32	8.6	4.60	18	21.5	11.50	7.4	63.91
48-70	2.03	0.27	1.1	0.58	7.6	4.32	27	17.1	9.70	4.6	46.99
70-100	-	0.29	1.1	0.58	3.4	3.20	-	11.7	11.00		
Pedon 2 : Typic Udorthents — (1735 m above msl)—(25°29'39" N Lat, 91°48'31" E Long.)– pine											
0-23	1.01	0.53	0.66	1.02	4.8	3.56	42	20.4	15.14	4.3	28.37
23-52	1.12	0.32	0.66	0.78	5.0	3.19	34	31.3	19.9	7.0	35.11
52-105	0.41	0.17	0.44	0.52	3.6	1.77	31	23.2	11.42	2.7	23.16
Pedon 3 : Typic Udifluvents — (1662m above msl)—(25°29'42"N Lat, 91°48'48" E Long)– paddy											
0-25	0.51	0.26	1.1	0.34	4.8	2.54	37	30.9	16.4	3.3	20.1
25-50	0.71	0.27	0.88	1.04	2.4	3.17	92	24.0	31.7	7.1	20.2
Site 2 : Pynursala											
Pedon 4 : Ruptic –Ultic **Dystrudepts** –(1390.3m above msl)— (25°19'30"N Lat,91°53'51"Elong.)–grass cover											
0-18	0.81	0.38	0.66	0.24	3.4	2.32	34	42.5	29.9	10.1	34.9
18-41	0.81	0.34	0.66	0.24	3.0	2.21	35	35.3	26.0	9.5	36.65
41-72	0.81	0.41	0.44	0.52	3.4	2.06	32	35.8	21.7	8.5	39.30
72-98	1.32	0.08	0.66	0.24	4.4	2.90	27	32.6	21.5	9.8	45.50
98-110	2.03		0.88	0.32	6.2	3.67	25	27.6	16.31	9.0	55.31
Pedon 5 : Typic Kanhapludults –(1386.7m above msl)—(25°19'09"N Lat, 91°53'20"E Long.)–grass cover											
0-19	1.22	0.32	0.44	1.0	5.2	3.22	32	41.6	25.76	9.8	37.9
19-43	2.44	0.44	0.22	0.74	6.2	4.11	20	16.3	10.81	6.4	59.4
43-56	0.81	0.44	0.44	1.0	4.2	2.87	39	14.5	9.89	2.8	28.20
56-76	1.62	0.30	0.66	0.78	4.6	3.52	35	18.8	14.4	6.6	46.02
76-109	1.52	0.21	0.66	0.30	4.8	2.87	24	20.0	12.21	6.5	52.96
109-196	3.15	0.11	0.88	0.32	5.2	4.17	30	27.4	21.9	16.5	75.54
Pedon 6 : Humic Pachic Dystrudepts– (1631.52m above msl)—(25°19'30"N Lat, 91°52'23"E long)–grass cover											
0-20	4.16	0.26	3.6	0.8	18.4	6.67	12	89.8	32.5	20.3	62.36
20-69	2.74	0.14	2.5	0.76	13.0	4.51	13	76.5	28.52	16.1	60.75
69-110	2.44	0.34	2.2	0.56	14.8	4.63	13	64.3	20.13	10.6	52.69
110-140	1.72	0.30	1.4	1.04	14.4	4.46	17	61.3	18.97	7.3	38.56

**CEC/ClayX100,ECEC/ClayX100, ExAl/clayX100, ***ExAl/ECECX100

Pedogenesis

The vegetation is dependent variable and also the function of soils and climate or *vice versa*. It is difficult in the study area to discern the pedogenesis and vegetation path ways due to dramatic shift in natural pine vegetation by fire and *jhum* cultivation (Bhaskar *et al.* 2004). The rainfall decreases from south (site B) to north (site A) and tends to lead into edaphically drier spring and summer seasons at northern parts of study area. The mean minimum temperature varies by 4°C during January and February months across the region and mean annual rainfall is 5 times more in southern parts (11000 mm) than in northern parts (2026 mm). The soils development is strongly related to climatic parameters, as deep soils with clay of 20 to 38 per cent mostly occur in hilly terrains of southern parts whereas as shallow soils with clay of 15-20 per cent in northern parts. The occurrence of deep soils belonging to Inceptisols and Ultisols on hill slopes suggest that the materials displaced from summits are not transported to long distances but deposited in nearby land units. The occurrence of cambic and argillic/kandic horizons in deep soils of Inceptisols and Ultisols on hill slopes of rubber growing areas of Tripura were reported by Bhattacharyya *et al.* (2002). Some other workers also observed Ultisols on gentle slopes of great ages (Soil Survey Staff 1999).

The soils along two slope transects (Fig.1) are strongly related to geomorphic position. The soils in summits (P1 and P6) and convex plateau tops (P4 and P5) have sub-soil horizons of Bt or Bw with 7.5YR to 2.5YR hues. The maximum redness is developed in these horizons due to weathered mafic minerals present in parent rock and its subsequent alteration to hematite. The illuviation of hematite further enhances the redness of sub-soils (Graham *et al.* 1989). The soils in summits (P1 and P6) show no losses or gains of material by mass movement and follow the genetic path way proposed for soils in residuum by Rebertus and Boul (1985). This model is applied in explaining the formation of subsurface horizons in summit soils. The pedon 1 is entirely a residual soil with an argillic horizon but no illuviation cutans. The clay content increases 1.5 to 1.7 times more in illuvial horizons. The morphology of this pedon suggests that this soil is apparently approaching the first period of minimal illuviation wherein easily weatherable minerals are depleted, biotite alters pseudomorphically and pedoturbation disrupts illuviation of cutans. The occurrence of cambic horizon in pedon 6 at site B suggests that an initial flush of clay occurs when easily weatherable minerals produce clay. This clay is translocated and formed illuviated cutans. The increase in clay is insufficient to form argillic horizon. This soil has dark coloured and thicker umbric epipedon with high organic carbon due to melanization process (Boul *et al.* 1973).

The soils on convex plateau tops (P4 and P5) often have colluvial and residual components that are not lithologically distinct. The pedogenesis in this type of soils is all together different because of mass movement and follow the genetic path way as described by Graham and Boul (1990). The pedon 4 has cambic horizon and formed in highly weathered colluvium as evident from high Fe_d/Fe_t ratio (>0.7). This pedon has low clay content in surface horizons (8 per cent). This is due to continuous eluviation process and also rain drop and splash impact in high rainfall regions. Here the illuviation is insignificant due to depletion of clay from surface horizon and colluvial cycle thereby reducing clay content in surface horizon. The pedon 5 has kandic horizon and is developed on stabilized colluvium where the rate of clay illuviation depends on *insitu* weathering and pedoturbation that disrupts illuvial cutans. This pedon is approaching period of minimal illuviation. The application of two pedogenic pathways for soils in residuum (summits) and in colluvium (convex plateau tops) are useful in identifying, differentiating and understanding the transition of cambic and argillic or kandic horizon as needed to place them in the sub-group of Inceptisols and Ultisols.

Soil classification

Based on morphology, physical and chemical properties the summit soils at site A (P1) have argillic horizon and paralithic contact at 60 cm depth. Hence these soils are classified at sub group level as Inceptic Hapludults though the argillic horizon is 40 cm thick (Soil Survey Staff 1999). The soils on eroded side–slope (P2) do not have any diagnostic horizons below A horizon. Hence this soil is classified as Typic Udorthents. The valley soils (P3) are classified as Typic Udifluvents. The soils on convex plateau tops are classified as Ruptic-Ultic Dystrudepts (P4) and Typic Kanhapludults (P5). The soils of pedon 4 have cambic horizons that include 10 to 50 per cent of illuvial parts,mostly clay and manganese and base saturation less than 35 per cent. The soils of pedon 5 have umbric epipedon, base saturation less than 39 per cent throughout depth and kandic horizon. The soils on summits (P6) have umbric epipedon of 50 cm thick and base saturation less than 39 per cent. These soils, therefore, are classified as Humic Pachic Dystrudepts.

Conclusion

Soils along two slope transects are studied to understand genetic pathways involved in soils on summits and convex plateau tops of Meghalaya plateau. These soils have maximum redness in cambic and argillic or kandic horizons with 7.5YR to 2.5YR hues. The redness is strongly related with Fe_d contents. The Fe_d/Fe_t ratio more than 0.75 is used to differenctiate Dystrudepts from highly weathered Hapludults. The organic carbon contents are strongly related with ECEC ($r = 0.52^{xx}$, significant at 1% level) and elevation ($r = 0.48^{x}$, significant at 5% level) indicating that the ability to hold nutrients in soils is primarily dependent on organically enriched surface horizons. The soil properties are used to distinguish between cambic and

Table 4. Total and CBD extractable iron and manganese in soils

Depth (cm)	Horizon	Total Fe (gkg-1)	Total Mn (mgkg-1)	CBD extractable Fe (gkg-1)	CBD extractable Mn (mgkg-1)	Fe_d/clay X 100	Fe_d /Fe_t	/Mn_t Mn_d	Mn_d /Fe_d X 100
Site A : Myllieum									
Pedon 1 : Inceptic Hapludults — (1755 m above msl)— (25°29'40" N lat, 91°48'26"E long.)- pine									
0-13	A p	27.5	273	25.9	76	9.9	0.94	0.28	0.29
13-30	B/A	32.9	363	25.2	110	9.5	0.77	0.30	0.44
30-48	B t1	36.0	385	30.3	158	7.6	0.84	0.41	0.52
48-70	B t2	37.4	433	30.8	146	6.9	0.82	0.34	0.47
70-100	Cr	27.4	476	19.5	88	6.7	0.71	0.19	0.45
Pedon 2 : Typic Udorthents— (1735 m above msl)— (25°29'39" N Lat, 91°48'31" E Long.)- pine									
0-23	Ap	84.2	588	7.1	81	3.0	0.08	0.14	1.14
23-52	AC	80.2	658	6.5	36	4.1	0.08	0.06	0.55
52-105	Cr		685	3.3	76	2.1	0.04	0.11	2.30
Pedon 3 : Typic Udifluvents— (1662m above msl)— (25°29'42"N Lat, 91°48'48" E Long.)- paddy									
0-25	Ap	12.3	426	5.2	43	3.4	0.42	0.10	0.83
25-50	C	12.0	340	5.3	28	5.3	0.44	0.08	0.53
Site B : Pynursala									
Pedon 4 : Ruptic –Ultic Dystrudepts —(1390.3m above msl)— (25°19'30"N Lat,91°53'51"E Long.)- grass cover									
0-18	Ap	8.2	22	3.6	5.0	4.5	0.44	0.23	0.14
18-41	BA	9.6	31	6.7	4.5	7.9	0.70	0.15	0.07
41-72	Bw1	9.3	33	6.9	19	7.3	0.74	0.58	0.28
72-98	Bw2	11.4	41	6.4	19	4.7	0.56	0.46	0.30
98-110	Bw3	17.1	85	8.9	50	4.0	0.52	0.59	0.56
Pedon 5 : Typic Kanhapludults —(1386.7m above msl)— (25°19'09"N Lat, 91°53'20"E Long.)- grass cover									
0-19	A	62.3	925	19.9	25	15.9	0.32	0.03	0.13
19-43	Bt1	50.9	519	54.7	50	14.4	0.90	0.10	0.09
43-56	Bt2	52.6	383	46.1	99	15.9	0.88	0.26	0.22
56-76	Bt3	50.7	433	33.4	137	13.6	0.66	0.32	0.41
76-109	Bt4	47.4	801	38.3	400	16.3	0.81	0.50	1.04
109-196	Cr	47.2	1061	24.2	20	12.7	0.51	0.14	0.83
Pedon 6 : Humic Pachic Dystrudepts —(1631.52m *above msl*)—(25°19'30"N Lat, 91°52'23"E Long.)-grass cover									
0-20	Ap	41.2	333	6.0	75	2.9	0.15	0.23	1.25
20-69	A/B	44.8	516	21.4	125	12.6	0.48	0.24	0.58
69-110	Bw2	46.5	693	30.5	425	13.3	0.66	0.61	1.39
110-140	Bw3	42.7	558	9.1	305	3.9	0.21	0.55	3.35

Table 5. Correlation between variables in soils of high altitude

Y(dependent)	X(independent)	r (correlation coefficient)	Slope (b)	Intercept(a)
Redness rating	Fed (gkg^{-1})	0.56**	0.25	10.04
	Fed/Fet	0.53**	12.2	7.75
	Fed/clayX100	0.39*	0.53	10.28
Fe_d(gkg^{-1})	Clay(%)	0.72**	1.034	-2.07
Mn_d(mgkg^{-1})	Clay(%)	0.39*	4.35	7..31
	Silt(%)	0.46*	2.93	27.53
Organic carbon(gkg^{-1})	Elevation(m)	0.48*	0.037	-35.22
	ExAlcmol(p+)kg^{-1}	0.75**	8.91	-3.24
	Silt(%)	0.54**	0.26	-0.73
Base saturation(%)	pH	0.45*	9.26	-13.984
ECEC(cmol(p+)kg^{-1}	Organic carbon(gkg^{-1})	0.52**	0.072	3.099
	Clay(%)	0.59**	0.069	2.07
	Silt(%)	0.79**	0.053	2.237

*significant at 5 per cent level(Table r value= 0.388where number of observstions is 26),
** Significant at 1% level (Table r value is 0.4958 where number of observations is 26)

argillic horizon formation results from pedogenesis of soils in residuum (summits) and in colluvium (convex plateau tops) where the mass movement interrupts orderly progression of soil development. The slope processes plays an important role in finding out the routes of soil development. This study advocates the importance of mineralogical studies for further refining the observation made in three ways: (1) to quantify the stages of illuviation process in soils on summits and convex plateau tops (2) to distinguish genetic path ways involved in formation and transition of cambic and argillic or kandic horizons and (3) to justify the classification of highly weathered and intensively leached high altitude soils in sub-groups of Inceptisols.

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References

Alexander, F.B. (1985). Estimating relative ages from iron oxide /total iron ratio's of soils in the western Po valley, Italy –A discussion. *Geoderma* **85**, 257-259.

Agbenin, J.O. and Tiessen, H.(1995). Soil properties and their variations on two contiguous hill slopes in Northeast Brazil. *Catena* **24,** 147-161.

Arduino, E., Barberis, E., Ajmone Marsan, F., Zanini, E. and Franchini, M. (1986). Iron oxides and clay minerals within profiles as indicators of soil age in Northern Italy. *Geoderma* **37,** 45-55.

Aubert, H. and Pinta, M. (1977). Trace elements in soils. Dev. Soil Sci.No. **7.** Elsevier, Amsterdam.

Bhaskar, B.P., Mishra, J.P., Baruah, U., Vadivelu, S., Sen, T.K., Butte, P.S. and Dutta, D.P. (2004). Soils on Jhum cultivated hill slopes of Narang-Kongripara watershed in Meghalaya. *Journal of the Indian Society of Soil Science.* **52,** 125-133.

Bhattacharyya, T., Sen, T.K., Singh, R.S., Nayak, D.C. and Sehgal, J.L.(1994). Morphology and classification of Ultisols with kandic horizon in North Eastern region. *Journal of the Indian Society of Soil Science* **42,** 301-306.

Bhattacharyya, T., Ram Babu, Sarkar, D., Mandal, D., Mandal, C. and Nagar, A.P. (2002). Soil erosion of Tripura, a model for soil conservation and crop performance. *NBSS Publication No.* **97**. NBSS&LUP, Nagpur.

Biswas, T.D. and Gawande, S.P. (1964). Relation of manganese in genesis of catenary soils. *Journal of the Indian Society of Soil Science.* **12,** 261-267.

Black, C.A., Evans, D.D., Ensminger, L.E., White,J.L. and Clark, F.E. (1965). *Methods of Soil Analysis.* **Part-1** . American Society of Agronomy. Inc.(Pb.).Madison. Wisconsin. USA.

Boul, S.W., Hole, F.D. and Mc Cracken, R.J.(1973). *Soil Genesis and Classification*. The Iowa state university press, Ames, Iowa.

Daniels, W.L., Everett, C.J. and Zelazny, L.W.(1987). Virgin hard wood forest soils of the Southern Applachian Mountains. I. Soil morphology and geomorphology. *Soil Science Society of America Journal* **51,** 722-729.

Evans, C.E. (1968). Ion exchange relationships of aluminum and calcium in soils as influenced by organic matter. Ph.D. Diss. North Carolina State Univ.(Order 68-14,651) Univ. Microfilms ,Ann Arbor, MI (Diss. Abstr. **29:** 1233-B).

Gangopadhyay, S.K., Debanath, N.C. and Banerjee, S.K. (1986). Characteristics of some high altitude soils of Sikkim forest division. *Journal of the Indian Society of Soil Science* **34**, 830-838.

Gangopadhyay, S.K., Bhattacharyya, T. and Sarkar, D. (2001). Rubber growing soils of Tripura- Their characteristics and classification. *Journal of the Indian Society of Soil Science* **49,** 164-170.

Graham, R.C., Weed, S.B., Bowen, L.H. and Boul, S.W. (1989). Weathering of iron-bearing minerals in soils and saprolite on the North Carolina Blue Ridge Front. I. Sand sized primary minerals. *Clays* and *Clay Minerals* **37**: 19-28.

Graham, R.C., Weed, S.B., Bower, L.H., Amarasisiwardena, D.D. and Boul, S.W. (1989). Weathering of iron bearing minerals in soils and saprolite on the North Carolina Blue Ridge Front : II. Clay mineralogy. *Clays* and *Clay Minerals* **37:** 29-40.

Graham, R.C. and Boul, S.W. (1990). Soil Geomorphic relations on the Blue Ridge Front. II. Soil characteristics and pedogenesis. *Soil Science Society of America Journal* **54:** 1367-1377.

Hargrove, W.L. (1986). The solubility of aluminum-organic matter and its implication in plant uptake of aluminum. *Soil Science* **142,** 179-181.

Hall, G.F. (1983). Pedology and Geomorphology. P.117-140. *in* L.P. Wilding *et al.* (ed.*Pedogenesis and Soil Taxonomy:*1.Concepts and Interactions. Elsevier, Amsterdam.

Hurst, V.J.(1977). Visual estimation of iron in saprolite.*Geological Society of American Bulletin* **88,** 174-176.

Jackson, M.L .(1973). *Soil Chemical Analysis*.Prentice Hall of India Private Limited, New Delhi. p 498.

Jenny, H. (1980). The Soil Resource: Origion and behavior. Spring-Verlag, NewYork.

McDaniel, P.A., Bathke, G.R., Boul, S.W., Cassel, D.K. and Falen, A.L. (1992). Secondary manganese/ iron ratios as pedochemical indicators of field-scale throughflow water movement. *Soil Science Society of America Journal* **56,** 1211-1217.

Mehra , O.P. and Jackson, M.L.(1960). Iron oxide removal from soils and clays by dithionite-citrate system buffered with sodium bicarbonate. *7th Natl.Conf. Clays and Clay Minerals* **7,** 317-327.

Nair, K.M., Baruah, U. and Chamuah, G.S. (1983). Soil Survey Report of East Khasi hills district, Meghalaya. Report No.522. NBSS & LUP, Nagpur.

Nair, K.M. and Chamuah, G.S. (1988). Characteristics and classification of some pine forest soils of Meghalaya. *Journal of the Indian society of Soil Science* **36,** 142-145.

Nye,P., Doris Craig, N., Coleman, T. and Ragland, J.L.(1961). Ion exchange equilibria involving aluminum. *Soil Science Society of America Proceedings* **25**, 14-17.

Pal, D.K., Nath,S. and Banerjee,S.K. (1984). Pedological characteristics of some soils of the Darjeeling Himalayan region . *Journal of the Indian Society of Soil Science* **32,** 716-724.

Prasad, R.N., Patiram and Munna Ram (1985). Forms of Aluminium in soils of east khasi hills,Meghalaya. *Journal of the Indian Society of Soil Science* **33,** 523-527.

Rebertus, R.A. and Boul, S.W.(1985). Iron distribution in a developmental sequence of soils from Mica Gneiss and Schist. *Soil Science Society of America Journal* **49**, 713-720.

Rebertus, R.A. and Boul, S.W. (1985). Intermittency of illuviation in Dystrochrepts and Hapludults from the Piedmont and Blue Ridge Provinces of North Carolina. *Geoderma* **36,** 277-291.

Sen, T.K., Chamuah, G.S. and Seghal, J.L.(1994). Occurrence and characteristics of some kandi soils in Manipur. *Journal of the Indian Society of Soil Science* **42,** 297-300.

Sims, Z.R. and Nielsen, G.A.(1986). Organic carbon in Montana soils as related to clay content and climate. *Soil Science Society of America Journal* **50,** 1269-1271.

Singh, O.P., Datta, B. and Rao, C.N. (1991). Pedochemical characterisation and genesis of soils in relation to altitude in Mizoram. *Journal of the Indian Society of Soil Science* **39,** 739-750.

Soil Survey Division Staff (2000). Soil Survey Manual. Agric.Handb.U.S.Dept. Agric.18. Indian print, Scientific publishers, Jodhpur, 437.

Soil Survey Staff (1999). *Soil Taxonomy: A basic system of Soil Classification for making and interpreting soil surveys.*. **Second edition**. Agricultural Handbook Number **436**. United States Department of Agriculture and National Resources Conservation Service, Washington D.C. USA.

Torrent, J., Schwertmann, U., Fechter, H. and Alferez, F. (1983). Quantitative relationships between soil colour and hematite content. *Soil Science* **136**, 354-358.

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