The Mineralogical Characteristics of Volcanic Soils from North-Lampung, Sumatra Indonesia

Karakteristik Mineralogi Tanah-tanah Volkan dari Lampung Utara, Sumatera Indonesia

Alkasuma[1] and R.B. Badayos[2]

ABSTRACT

The study took place in the volcanic soils of Mt. Hulu Sabuk in North Lampung Regency, Lampung Province. The research had been conducted from June to October 2000. The objective of study was to reveal the mineralogical characteristics of volcanic soils, especially in the study area. The methodology used was transect/landscape analysis by studying of six soil profiles that supported by mineralogical analyses of optical, X-ray diffraction and differential thermal of soil samples. The results of the study showed that opaque minerals and quartz dominate the soil mineralogy of the study area. While the weatherable minerals like volcanic glass, feldspars, amphiboles, and pyroxenes were encountered in small amounts. The secondary minerals of clay fraction were occupied by kaolinite and gibbsite. The characteristics of soil minerals indicated that the volcanic soils in the study area are highly weathered and already developed.

Key words : Volcanic soils, Mineralogy, Highly weathered, Lampung

ABSTRAK

Penelitian tanah-tanah volkan ini berasal dari daerah Gunung Hulu Sabuk, Kabupaten Lampung Utara, Provinsi Lampung. Penelitian dilaksanakan pada bulan Juni sampai Oktober 2000. Tujuan dari penelitian ini adalah untuk mengungkapkan karateristik mineralogy tanah-tanah volkan, khususnya di daerah penelitian. Metodologi yang digunakan adalah survey dengan analisa transek/bentang alam melalui pembuatan enam buah profil tanah dan dilengkapi dengan analisa mineralogy melalui mikroskop polarisasi, X-RD, dan DTA dari sejumlah sampel tanah. Hasil penelitian menunjukkan, bahwa jenis mineral yang mendominasi daerah ini adalah mineral-mineral opak dan kuarsa. Sedangkan mineral mudah lapuk seperti gelas volkan, feldpar, amfibol, dan piroksin dijumpai dalam jumlah kecil. Mineral-mineral sekunder dari fraksi liat didominasi oleh kaolinit dan gibsit. Berdasarkan sifat-sifat mineraloginya, tanah-tanah di daerah penelitian telah mengalami pelapukan kuat dan telah berkembang.

Kata Kunci : Tanah-tanah volkan, Mineralogi, Pelapukan kuat, Lampung

INTRODUCTION

As a tropical country Indonesia has many islands, which have been built up and influenced by the activity of volcanoes. Sumatra is one of the islands, which is rich in volcanic systems, lying from northwest to the southeast of the island. Lampung Province, located in the south end of the island, is also occupied by soils derived from volcanic ash, tuff, and lava parent materials mainly consisting of dacitic and andesitic rocks. Due to warm and humid climate condition, these parent materials have been rapidly weathered to form primary and secondary minerals.

Minerals are inorganic substances occurring naturally with more or less definite chemical composition and specific chemical properties. Mineral weathering releases plant nutrients that are retained by other minerals through adsorption, cation exchange, and precipitation. Minerals are indicators of the amount of weathering that has taken place and the presence or absence of particular minerals provides clues as to how soils formed.

Soil minerals are also referred to as either primary minerals or secondary minerals. Primary minerals are formed at high temperatures and usually derived from igneous and metamorphic rocks, while secondary minerals are formed by low temperature reaction and either inherited from sedimentary rocks or formed in soils by weathering (Schulze, 1989). Sand and silt grains tend to be composed mostly of inherited primary minerals. Conversely, clay particles are composed mostly of secondary minerals (Allen and Hajek, 1989).

1. A staff of Soil Research Institute, CSAR, Bogor
2. University of The Philippines Los Baños, The Philippines
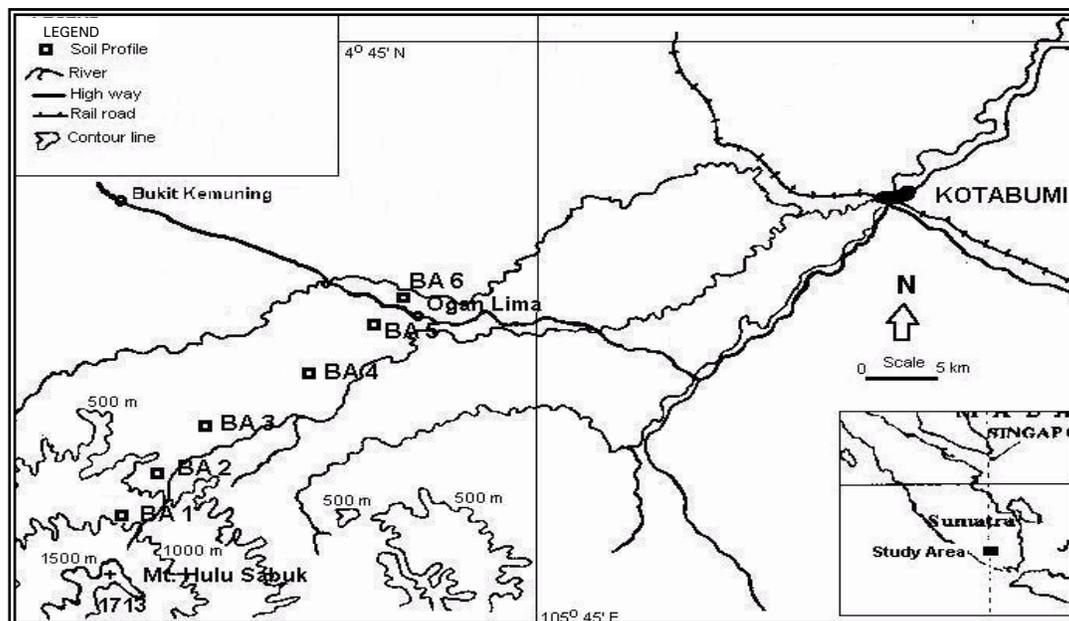
Figure 1. The location of soil pedons within landsurface units on Mt. Hulu-Sabuk

The fundamental characteristics of soils of the tropics are a consequence of their mineral composition (Prasetyo, 1993). These soils commonly consist of sesquioxides, 1:1 lattice silicate clay minerals, quartz and other minerals that are highly resistant to weathering. Less resistant silicate minerals are either absent or are present to a small extent only.

What mineral is synthesized from rock weathering, however, depends on the concentration and composition of the equilibrium solution. For a given rock, the solution concentration and composition will vary with temperature and water supply, and therefore the climate.

This study aimed to reveal the mineralogical characteristics of volcanic soils in the study area in particular and in the Sumatra Island in general.

MATERIALS AND METHODS

Materials

The study started from June to October 2000. Sites and pedons data were collected from a transect of Mt. Hulu Sabuk, Lampung Province, which lies from 1000 to 60 m asl. A number of soil samples were gathered and prepared for the laboratory analyses. The study was emphasized on six pedons representing five land surface units starting from the highest altitude in the fall face up to the lowest one in the channel bed. Location of six soil pedons is given in Figure 1 and land surface configuration is shown in Figure 2.

Methods

The profiles of selected pedons were describes according to guidelines of the Soil Survey Manual (Soil Survey Staff, 1951) and Chapter 4 of the new Soil Survey Manual (Soil Survey Staff, 1981). The soil pedons were classified according to Soil Taxonomy (Soil Survey Staff, 1998), which were called as Inceptisols, Ultisols, and Oxisols soil orders (Alkasuma, 2000).
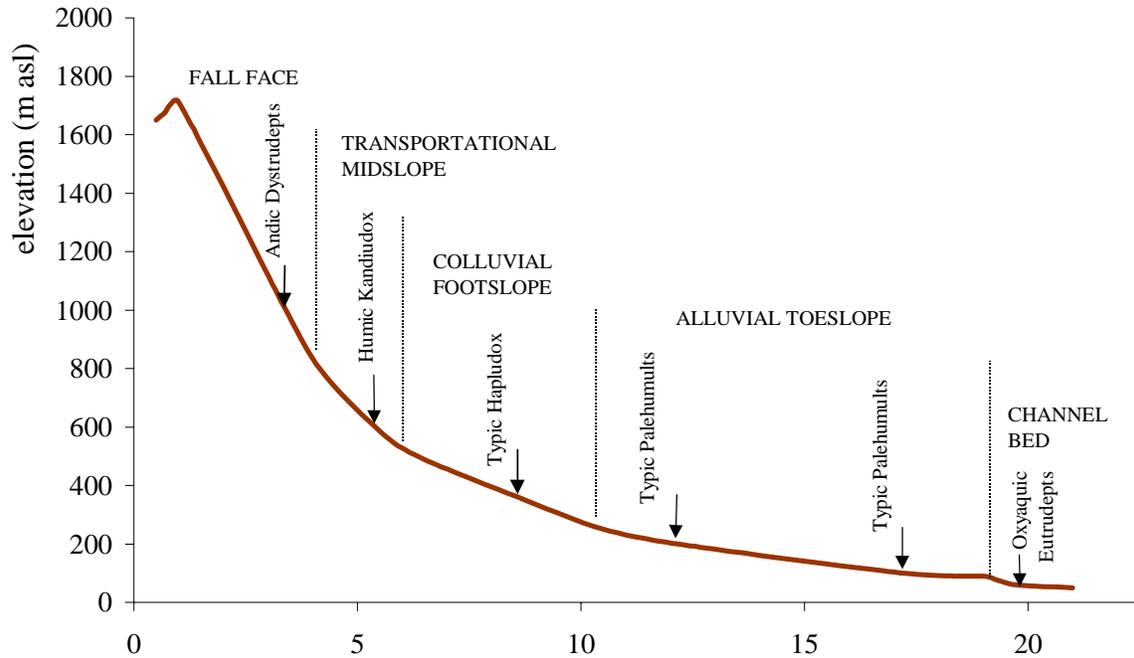
Figure 2. Land surface configuration and soils encountered in the study area

Sample fractionation for clay mineral analysis

For mineralogical study of clay, fractionation analyses were performed on selected samples representing the surface, diagnostic subsurface and bottom horizons. The procedure is outlined by Jackson (1979). Hydrogen peroxide (H_2O_2) 30% is used for removal of organic matter.

From 25 to 50 g soil samples of Inceptisols, Ultisols and Oxisols and 50 to 100 g samples of andic soil, were weighed into 250-ml centrifuge bottles. Samples were treated twice with 50 ml of a buffered pH 5 1M NaOAc solutions, and heated for 30 minutes on a waterbath. After centrifugation the solution was discarded. The sample was then dispersed in water and its pH was adjusted to 9 or 10 with 1 M NaOH. The suspension was centrifuged and the liquid discarded. The removal of organic matter then follows using hydrogen peroxide (H_2O_2) as the oxidation agent. The sample pH was adjusted to 9.5 and then treated three times with 50 ml NaOCl-solution. Each time it was heated to $80^{\circ}C$ in a waterbath, intermittently stirred, centrifuged and the liquid discarded.

The sample was saturated with 50 ml 0.1 M NaCl and washed three times with 25 ml distilled water. A silver-nitrate ($AgNO_3$) test was performed on the centrifugate to check the presence or absence of free chloride (Cl^-) clays.

Samples were transferred to 400-ml beakers using 100 ml of pH 10 dilute Na_2CO_3 solution and dispersed for 2 mm with an ultrasonic probe. The dispersed suspension was then screened through a 50 μm-sieve, the sand was retained and the silt and clay-containing suspension were collected into a 1,000 ml beaker glass. The retained sand was quantitatively transferred into aluminum pans, oven dried ($110^{\circ}C$) and weighed.

The clay was separated from the silt by repeated sequential dispersion and siphoning. The collected clay suspension was then flocculated by adjusting its pH to about 4.0 with 1 M HCl solution. The dispersion was done when the suspension's pH was brought to about 4.0. Flocculation is usually successfully carried out after adjusting the pH of clay suspension to near neutral, pH 6 to 7.

The flocculated clay was then transferred to a 250-ml plastic bottle, and repeatedly washed and centrifuged. The Na-saturated clay was then dialyzed in distilled water until free of salts as indicated by electrical conductivity.

Optical analysis

Sand from soil samples of selected horizons was separated according to a method described in the Soil Survey Investigation Report No. 1 (SCS-USDA, 1972). The sand was deferrated using a citrate-bicarbonate-dithionite (CBD) extractant. About half of the sand was fractionated into 5 subfractions, very coarse (1,000-2,000 μm), coarse (500-1,000 m), medium (250-500 μm), fine (100-250 μm) and very fine (50-100 μm). Total mineralogy was determined for the fine sand (100-250 μm) and was examined using the petrographic microscope for mineral identification (Cady, 1965).

X-ray diffraction analysis (XRD)

Two small portions, about 0.3 gram, of the clay prior to analysis were treated each with 50 ml 1 M $MgCl_2$ and 50 ml 1 M KCl. Salt saturation was done twice by dispersion and centrifugation. The Mg- and K-clays were then freed of excess salt by washing twice, once with distilled water and once with 60% methanol. The washing was repeated until the supernatant solution showed no evidence of Cl^- with silver nitrate ($AgNO_3$). The clays were then ready for x-ray diffraction analysis.

The natural, undeferrated clay sample was analyzed by x-ray diffraction using Mg-and K-saturated clay specimens prepared for analysis by the smearing technique of Theisen and Harward (1962). XRD-patterns from four standard pretreatments were run. These treatments were air-dried Mg-saturated and glycerol-solvated Mg-clays, air-dried K-saturated, and 550°C-preheated K-clays. X-ray diffraction analysis was conducted with a diffractometer type PW3710 BASED using CuKα-radiation. The diffractometer was equipped with a 1° beam divergence slit, a medium resolution soller slit, a diffracted beam monochromator and a gas-sealed proportional counter. The x-ray tube was operated at 40 kilovolts (kV) with current ranges from 6 to 30 mA to attain comparable peak intensities. A one-second time constant and a 1,000 count-per-second (cps) attenuation were utilized. X-ray diffractograms were recorded from 3 to 30° (2θ) for Mg-saturated specimens, from 3 to 20° (2θ) for all air-dry and 350-to 550°C-heated K-clays, and from 3 to 25° (2θ) for glycerol-solvated Mg-clays, respectively. The scanning speed was 2° (2θ) per minute and a recorder speed of 2 cm per minute. About 2 ml of a 50-mg clay-containing suspension was poured onto a dry ceramic block. For this moist clay specimen, an x-ray diffractogram was run from 3 to 30° (2θ).

Differential thermal analysis (DTA)

Deferrated clay samples obtained after sodium citrate dithionite extraction (Coffin, 1963) was analyzed by using a Thermal Analyzer. About 50 mg of deferrated Na-clays was weighed into 5 ml polystyrene beakers and equilibrated in a desiccator over saturated $Mg(NO_3)_2$ solution (produces 54% relative humidity). About 20 mg of these Na-clays was gently packed into a platinum (Pt) sample cup and again stored at 54% relative humidity. They were then positioned in the high temperature cell of the Thermal Analyzer. The sample was heated from room temperature (25°C) to approximately 950°C, in flowing N_2-gas at a linear heating rate of 50°C per minute.

The area of the characteristic endothermic peaks of kaolin minerals and gibbsite were measured by calculating the area of their right triangles fit within those peaks. The peak area was then converted to weight percentage utilizing standard curves developed for kaolinite and gibbsite.

RESULTS AND DISCUSSIONS

Primary minerals

Fine sand is basically the product of physical disintegration of the parent rock. Its composition generally reflects the mineralogical composition of the parent rock. Moreover the amount of primary mineral alteration could be a criterion for the advancement of soil formation.

The primary minerals in fall face unit were found dominated by opaque minerals (70 to 89%), followed by gibbsite (2 to 17%), unidentified weathered minerals (2 to 13%), and quartz (3 to 5%). The rest are weatherable minerals (less than 10% of total sand) that are composed of volcanic glass, plagioclase, K-feldspars, hornblende, augite, and hypersthene. According to Mohr and van Baren (1954) the composition of such volcanic rocks is called dacitic to andesitic.

In the transportational midslope, the primary minerals show a similar composition to those of fall face unit. The opaque minerals, however, exhibited to lesser amounts of 55 to 68%. While the amount of quartz (both turbid and transparent quartz) increased with soil depth from 13% in the surface horizon to 27% in the lowest horizon. Then, unidentified weathered minerals consisted of 1 to 8% and gibbsite from 3 to 6%. The weatherable minerals (volcanic glass, feldspars, amphiboles and pyroxenes) were found to be less than 10%, except in the surface horizon which was approximately 11%. Accessory minerals of zircon, zeolite, and organic SiO_2 were less than 2%.

The composition of sand particles in colluvial footslope were dominated by opaque minerals which ranged from 77 to 90%, followed quartz comprising about 6 to 11%. Unidentified weathered minerals were about 3 to 4% and gibbsite about 1 to 2%. The amount of weatherable minerals of volcanic glass, feldspars, amphiboles, and pyroxenes was less than 10 % of the total sand fraction. Likewise,

the accessory minerals were present in trace amount.

Sand fraction of the upper part of the alluvial toeslope unit was observed to be still dominated by opaque minerals (52 to 76%), and then followed by quartz (20 to 36%). The unidentified weathered minerals made up 4 to 5% while weatherable and accessory minerals were less than 10%. In the lower part of alluvial toeslope, the content of opaque minerals were lower than those in the upper part position and exhibited an amount of 26 to 48%. On the contrary, the amount of quartz was higher in the lower part position which ranged from 48 to 72%.

Channel bed unit, in which the soils are expected to develop from alluvium materials, has the composition of sand fraction dominated by unidentified weathered minerals (21 to 40%), followed by opaque minerals (13 to 44%), and by rock fragment (11 to 19%). Weatherable minerals of volcanic glass comprised 1 to 3%, plagioclase of labradorite species 8 to 16%, augite 2 to 6%, and hypersthene 7 to 10%. The others were accessory minerals with less than 10%. In general, the amounts of weatherable minerals entirely ranged from 33 to 49%.

The fine sand fraction of the soils of Mt. Hulu Sabuk, as shown in Table 1, were found to consist mostly of opaque minerals comprising about >50% of the total sand mineralogy and the second greatest amount is made up of quartz (turbid and transparent). Other minerals include volcanic glass, feldspars, amphiboles, and pyroxenes. The higher amounts of volcanic glass and intermediate plagioclases in the surface horizons and the presence of green hornblende in the surface horizon suggest a recent addition of ash material.

Total sand fraction of the soils in Mt. Hulu Sabuk indicates an advanced of soil weathering. The amounts of opaque minerals, quartz and unidentified weathered mineral grains were high. Conversely, the amounts of rock fragments, volcanic glass and other weatherable minerals were low.

Table 1. The composition and contents of primary minerals of Mt. Hulu Sabukarea

Depth	Horizon	Op	Zi	Tbq	Trq	Ic	Os	Ze	Gb	Wm	Rf	Vg	Ab	Oc	An	Lr	Sn	Gh	Bh	Au	Hp	Total
cm												%										
Andic Dystrudepts (BA 1)																						
0-20	A1	74	tr	tr	3	tr	tr	tr	2	3	3	3	-	-	-	7	tr	tr		2	3	100
20-55	Bw1	88	tr	1	4	tr	-	tr	4	2	tr	tr	-	-	-	-	tr	tr		-	1	100
55-110	Bw2	89	tr	1	3	-	-	tr	4	3	tr	tr	-	tr	-	-	tr	tr		-	tr	100
110-150	C	67	tr	tr	tr	1	-	1	17	13	1	tr	-	-	-		-	-		-	tr	100
Humic Kandiudox (BA 2)																						
0-13	Ap	64	tr	1	12	1	tr	tr	4	7	2	3	-	tr	-	4	tr	-		tr	2	100
13-50	Bo1	66	tr	3	16	-	1	1	3	8	tr	1	-	-	-	1	tr	tr		-	tr	100
50-93	Bo2	68	tr	tr	16	tr	1	1	4	10	tr	-	-	-	tr	-	tr	-		-	tr	100
93-150	Bo3	55	tr	5	22	tr	-	2	6	10	tr	-	-	-	tr	-	tr	tr		tr	tr	100
Typic Hapludox (BA 3)																						
0-12/15	Ap	77	tr	3	5	1	1	tr	1	3	tr	2	-	-	-	5	tr	-		tr	2	100
12/15-40	Bo1	90	tr	2	4	tr	-	tr	1	3	tr	-	-	-	-	-	tr	-		-	tr	100
40-90	Bo2	88	tr	3	4	tr	-	-	1	4	-	-	-	-	-	-	-	tr		-	tr	100
90-150	Bo3	84	tr	1	10	-	-	tr	2	3	tr	-	-	-	-	-	-	-		-	tr	100
Typic Palehumults (BA 4)																						
0-8	Ap	52	tr	8	23	tr	tr	tr	tr	5	2	3	-	-	-	6	tr	-		tr	1	100
8-29	Bt1	59	1	10	26	tr	-	tr	-	4	tr	tr	-	-	-	tr	tr	tr		tr	tr	100
29-60	Bt2	76	tr	5	15	tr	-	tr	-	4	tr	-	-	-	-	tr	tr	-		-	tr	100
60-105	Bt3	59	tr	8	28	tr	-	tr	-	5	-	-	-	-	-	-	tr	tr		-	tr	100
Typic Palehumults (BA 5)																						
0-17	Ap	36	tr	31	20	tr	tr	-	tr	1	2	2	-	tr	tr	3	tr	-		2	3	100
17-52	Bt1	29	1	40	24	tr	1	tr	-	tr	1	tr	1	-	-	1	2	-		tr	tr	100
52-70	Bt2	26	tr	48	24	tr	tr	tr	-	1	1	tr	-	-	-	-	-	-		tr	tr	100
105-150	Bt4	48	tr	30	18	tr	-	-	-	2	2	-	-	tr	tr	tr	-	-		-	-	100
Oxyaquic Eutrudepts (BA 6)																						
0-13	Ap	25	-	1	2	1	tr	1	tr	21	19	2	-	-	-	14	-	tr		4	10	100
13-27	Bw1	43	tr	tr	tr	tr	tr	-	tr	24	14	1	-	-	tr	8	-	1	tr	2	7	100
27-51	Bw2	13	tr	2	tr	2	-	tr	tr	39	18	1	-	-	tr	15	tr	1	tr	2	7	100
73-115	3C2	25	-	2	2	tr	tr	1	tr	24	11	3	1	-	1	16	tr	tr	tr	6	8	100

Remarks : tr = trace (<1%), Op = Opaque, Zi = Zircon, Tbq = Turbid quartz, Trq = Transparent quartz, Ic = Iron concretion, Os = Organic SiO_2,
Ze = Zeolite, Gb = Gibbsite, Wm = Weathered minerals, Rf = Rock fragment, Vg = Volcanic glass, Ab = Albite, Oc = Oligoclase, An = Andesine,
Lr = Labradorite, Sn = sanidin, Gh = Green hornblende, Bh = Brown hornblende, Au = Augite, Hp = Hypersthene

Secondary minerals

The secondary mineral of the soils of the entire land surface units of Mt. Hulu Sabuk is characterized by the presence of X-ray diffraction and DTA reaction peaks (Figures 3 to 7 and Figures 8 to 13). X-ray diffraction and DTA reaction of clay size particles have been used to identify the secondary minerals of the selected soil samples.

Kaolinite was identified by XRD peak at 7.15 to 7.20 Å, which did not change with Mg saturation or glycerol solvation but disappeared after heating the K saturated sample at 550°C. The presence of kaolinite was also exhibited by DTA endothermic and exothermic reaction peaks. The first appeared at temperatures of 500–520°C (average 510°C) and the last at 940°C. Normally, DTA kaolinite has an approximately 550°C peak (Hsu, 1989). The relatively low dehydroxilation temperature for the kaolinite observed in this study could be attributed to its small particle size and poor crystallinity. Similar results were also reported by Singh (1991) for kaolinite from western Australia with the average peak of 488°C and observed by Prasetyo (1993) for kaolinite from west Java with an average peak of 490°C.

The dominance of kaolinite in almost all these soils, except channel bed unit, is consistent with the chemical data as shown in Table 2. These data represent the typical results of the weathering processes in tropical areas.
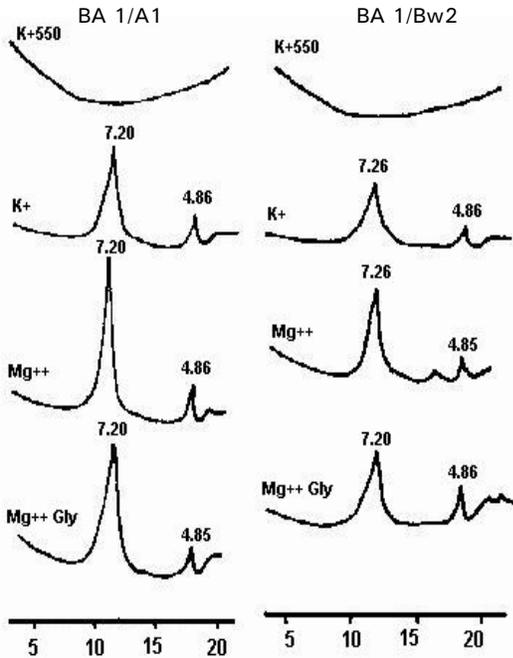
Figure 3. XRD of the clay minerals in the fall face unit of A1 horizon and Bw2 horizon
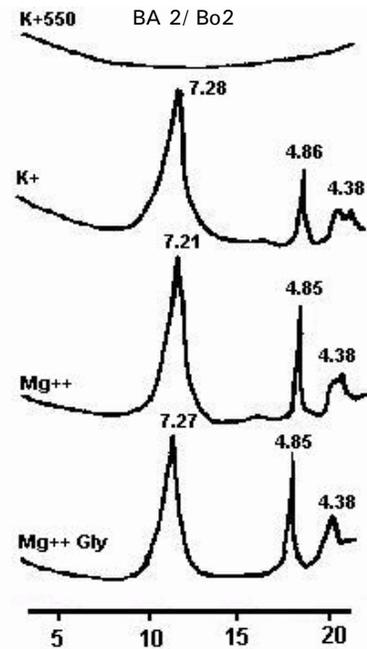
Figure 4. XRD of the clay minerals in transportational midslope
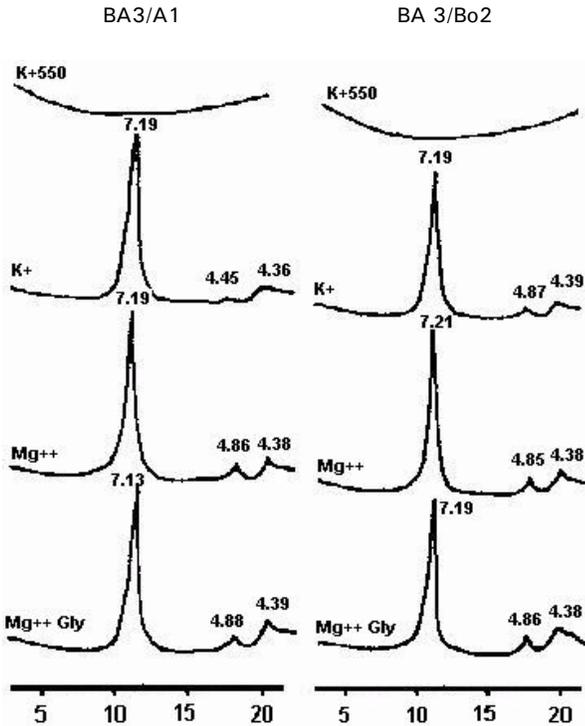
Figure 5. XRD of the clay minerals in the colluvial foot-slope unit of A1 horizon and Bo2 horizon
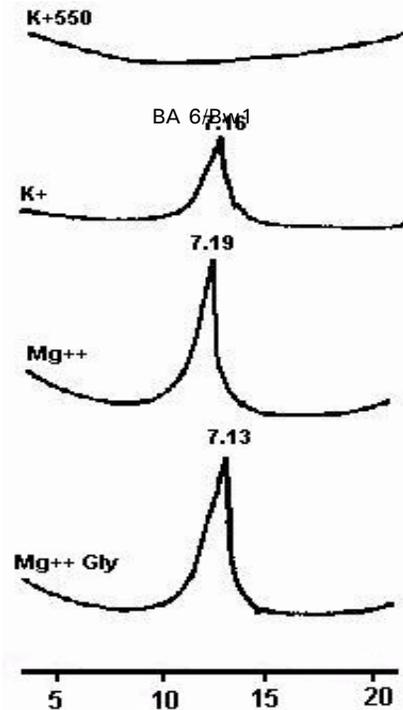
Figure 6. XRD of the clay minerals in the channel bed unit
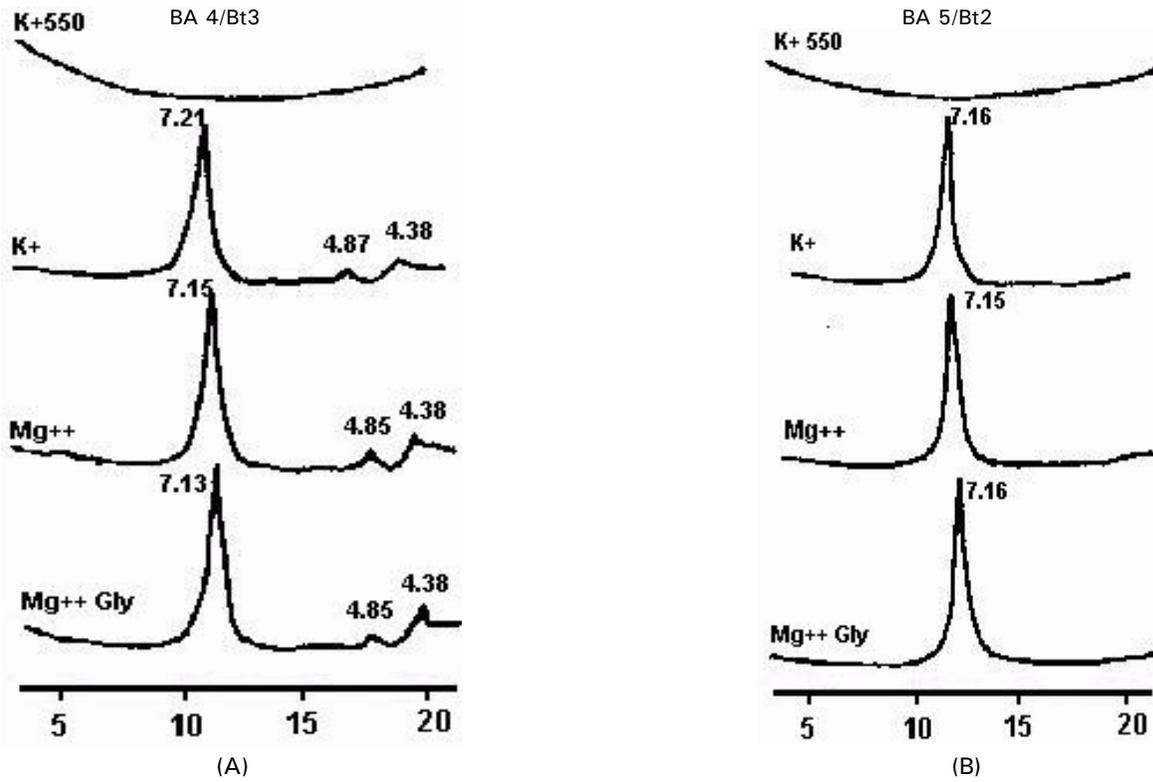
Figure 7. XRD of clay minerals in the alluvial toeslope unit with upper slope (A) and lower slope (B)
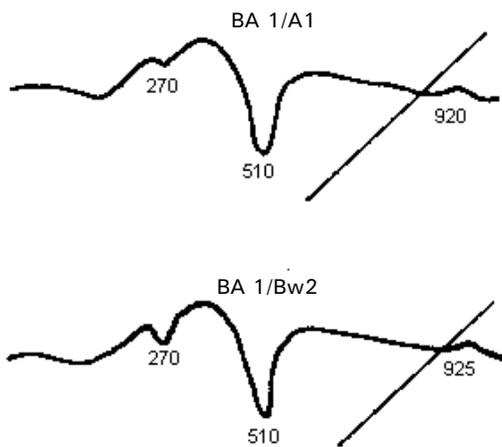
Figure 8. DTA of clay minerals in the fallface unit
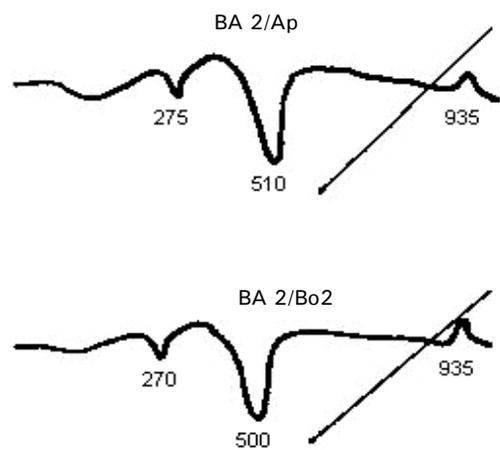
Figure 9. DTA of the clay minerals in the midslope unit

BA 3/Ap

935

510

BA 3/Bo2

275

505
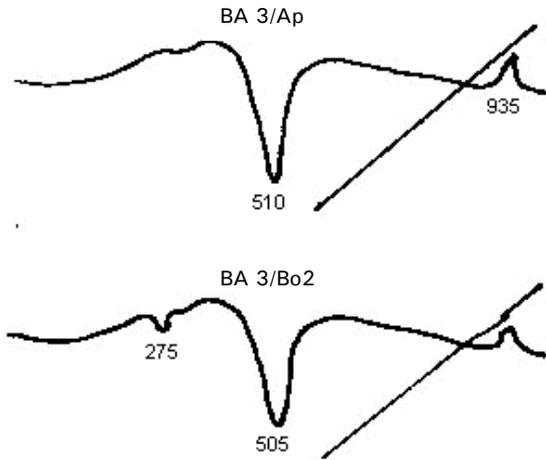
Figure 10. DTA of the clay minerals in the colluvial footslope unit

BA 4/Ap

940

500

BA 4/Bt2

265

950

500
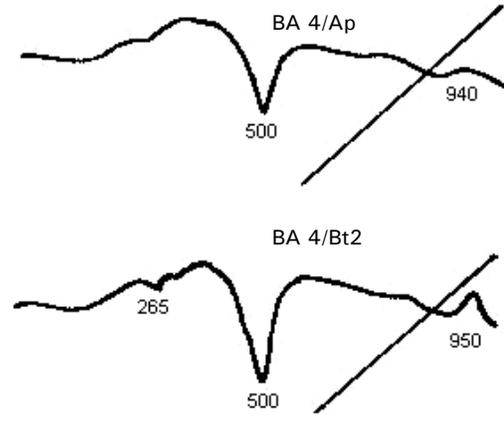
Figure 11. DTA of the clay minerals in upper part of the alluvial toeslope unit

BA 5/Ap

275

935

505

BA 5/Bt2

940

510
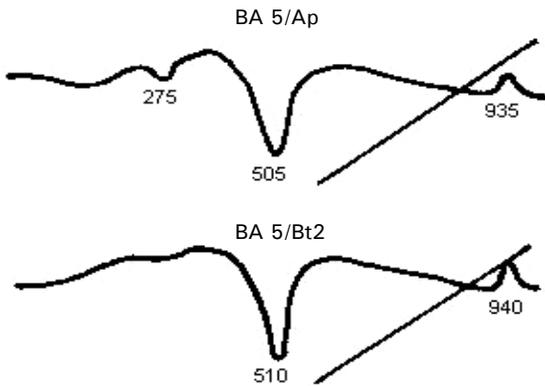
Figure 12. DTA of clay minerals in the lower part of the alluvial toeslope unit

BA 6/Ap

270

940

500

BA 6/Bw2

940

500
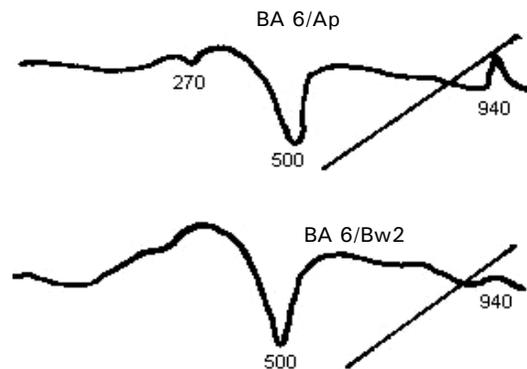
Figure 13. DTA of the clay minerals in the channel bed unit

The data in Table 2 shows that these soils are generally extremely acid to very strongly acid, except for that of the channel bed which was strongly acid to slightly acid. Commonly, the values of soil pH in the surface horizons are lower than those of the sub-surface horizons. The pH values at surface horizons in fall face to alluvial toeslope are extremely acid to strongly acid (pH 4.2 – 5.1). While soils in the channel bed position are strongly acid to slightly acid (pH 5.1– 6.4).

The results of soil analyses, as compared to FAO standard (FAO Staff, 1976), showed that the amounts of exchangeable bases in all landsurface units, except channel bed, are low to very low. In the channel bed unit the findings are medium to low. Quantitatively, the amount of exchangeable bases followed the order $Ca > Mg > Na > K$.

The sum of exchangeable bases is affected greatly by the levels of exchangeable calcium and magnesium. Those land surface units with high amounts of these two elements correspondingly showed the highest sum of exchangeable bases. Soils in the fall face, transportational midslope, and colluvial footslope showed a range from 0.67 to

Table 2. Some chemical data of soils in the study area

Depth	Horizon	Soil pH		Exchangeable Bases					CEC	Exchangeable		Saturation of	
		H_2O	KCl	Ca	Mg	K	Na	Sum		Al^{3+}	H^+	Base	Alum
cm				------------------------------------ $cmol_c\ kg^{-1}$ ------------------------------------								----------- % ------	
Fall face unit (Andic Dystrudepts)													
0-20	A1	4.2	3.8	0.87	0.57	0.26	0.17	1.87	20.98	3.40	1.02	8.91	64.50
20-55	Bw1	4.5	4.1	0.53	0.10	0.05	0.07	0.75	15.48	1.55	0.53	4.84	67.34
55-110	Bw2	4.6	4.1	0.39	0.09	0.07	0.12	0.67	12.49	1.65	0.34	5.36	71.12
110-150	C	4.5	4.1	0.33	0.16	0.07	0.16	0.72	17.09	2.73	0.37	4.21	79.14
Transportational midslope unit (Humic Kandiudox)													
0-13	Ap	4.4	4.0	0.49	0.27	0.11	0.02	0.89	12.17	1.82	0.47	7.31	67.13
13-50	Bo1	4.4	4.0	0.55	0.18	0.09	0.07	0.89	9.69	1.52	0.43	9.18	63.04
50-93	Bo2	4.3	4.1	0.52	0.17	0.07	0.07	0.83	7.54	1.49	0.38	11.01	64.25
93-150	Bo3	4.6	4.1	0.38	0.09	0.04	0.39	0.90	7.39	0.98	0.29	12.18	52.16
Colluvial footslope unit (Typic Hapludox)													
0-12/15	Ap	4.5	4.0	1.07	0.33	0.11	0.03	1.54	11.46	1.01	0.31	13.44	39.51
12/15-40	Bo1	4.7	4.2	0.65	0.23	0.07	0.00	0.95	7.32	0.76	0.20	12.98	44.31
40-90	Bo2	4.7	4.2	0.32	0.14	0.02	0.02	0.50	5.82	0.73	0.20	8.59	59.36
90-150	Bo3	4.7	4.2	0.27	0.16	0.02	0.02	0.47	4.74	0.77	0.31	9.92	62.23
Alluvial toeslope unit-1 (Typic Palehumults)													
0-8	Ap	4.8	4.2	1.98	0.60	0.11	0.05	2.74	10.68	0.45	0.30	25.66	14.11
8-29	Bt1	4.7	4.2	0.48	0.19	0.06	0.00	0.73	7.25	0.51	0.13	10.07	41.29
29-60	Bt2	5.1	4.6	0.80	0.26	0.09	0.06	1.21	5.76	1.51	0.30	21.01	55.51
60-105	Bt3	4.9	4.3	0.64	0.25	0.04	0.00	0.93	5.29	0.34	0.24	17.58	26.89
105-150	Bt4	4.9	4.3	0.53	0.14	0.02	0.02	0.71	4.68	0.45	0.23	15.17	38.79
Alluvial toeslope unit-2 (Typic Palehumults)													
0-17	Ap	4.5	4.0	0.59	0.09	0.15	0.00	0.83	8.68	1.54	0.37	9.56	64.94
17-52	Bt1	4.7	4.2	1.17	0.30	0.04	0.02	1.53	6.23	0.49	0.20	24.56	24.31
52-70	Bt2	4.5	4.1	0.86	0.23	0.02	0.00	1.11	4.80	0.81	0.20	23.13	42.33
70-105	Bt3	4.4	4.1	0.74	0.24	0.02	0.02	1.02	3.66	1.06	0.24	27.87	50.90
105-150	Bt4	4.4	4.2	0.90	0.26	0.02	0.05	1.23	4.30	1.12	0.09	28.60	47.66
Channel bed (Oxyaquic Eutrudepts)													
0-13	Ap	6.4	5.3	8.97	3.09	1.24	0.05	13.35	12.02	0.00	0.04	100.00	0.00
13-27	Bw1	5.5	4.3	6.07	2.50	0.64	0.08	9.29	11.39	0.07	0.13	81.56	0.70
27-51	Bw2	5.4	4.2	6.53	2.71	0.20	0.18	9.62	13.03	0.24	0.09	73.83	2.45
51-73	2BC	5.4	4.1	7.19	2.92	0.09	0.37	10.57	12.56	0.44	0.22	84.16	3.96
73-115	3C1	5.2	4.0	5.07	2.12	0.13	0.26	7.58	14.18	0.53	0.40	53.46	6.52
115-150	3C2	5.1	3.8	5.23	2.01	0.18	0.33	7.75	13.19	0.93	0.76	58.76	10.76

Source : Alkasuma, 2000

1.87 $cmol_c\ kg^{-1}$ followed by the alluvial toeslope that ranged from 0.71 to 2.84 $cmol_c\ kg^{-1}$. Apparently, the channel bed had the highest sum of exchangeable bases ranging from 7.58 to 13.35 $cmol_c\ kg^{-1}$.

The values of soil CEC (by NH_4-OAc, pH 7) in fall face units ranged from 12.49 to 20.98 $cmol_c\ kg^{-1}$ (medium to high). In surface horizon soil CEC is 20.98 $cmol_c\ kg^{-1}$ or high and decreased to 15.48 $cmol_c\ kg^{-1}$ (moderately high) and 12.49 $cmol_c\ kg^{-1}$ (medium) in Bw1 and Bw2 horizons, respectively. It

slightly increased to 17.07 $cmol_c\ kg^{-1}$ or moderately high in the C horizon.

Except in the upper horizons, the soil CEC in transportational midslope and colluvial footslope were moderately low (5.82 to 9.69 $cmol_c\ kg^{-1}$). In the surface horizons its values were medium which ranged from 11.46 to 12.17 $cmol_c\ kg^{-1}$. In the lowest horizon of colluvial footslope, soil CEC exhibited a low value of 4.74 $cmol_c\ kg^{-1}$. Generally, the soil CEC values decrease from the surface horizons toward the bottom horizons.

In the alluvial toeslope, the soil CEC at surface horizons are low to medium (8.68 to 10.68 $cmol_c$ kg^{-1}). In the upper part of Bt-horizons the soil CEC ranges from 6.23 to 7.25 $cmol_c$ kg^{-1} or moderately low. While in the middle and lower parts of Bt-horizons it varied from 5.76 to 3.66 $cmol_c$ kg^{-1} or moderately low to low.

The soil CEC in the channel bed unit is medium that ranged from 11.39 to 14.18 $cmol_c$ kg^{-1}. Compared with the other units, the soil CEC in the channel bed changes alternately up and down with the increase in soil depth, but its values are still within the medium range (10 to 15 $cmol_c$ kg^{-1}).

Exchangeable aluminum has a great influence on the soil acidity. These soils showed that the highest values of exchangeable aluminum were registered by fall face unit which ranged from 1.55 to 3.40 $cmol_c$ kg^{-1} soil. Then, followed by the transportational midslope that has exchangeable aluminum of 0.98 to 1.82 $cmol_c$ kg^{-1} soil. In the colluvial footslope and alluvial toeslope units, exchangeable aluminum registered values of 0.45 to 1.54 $cmol_c$ kg^{-1} soil. In contrast with the previous landsurface units, the channel bed had the lowest values of exchangeable aluminum. They exhibited amounts which were undetected in the surface horizon, then regularly increased to 0.93 $cmol_c$ kg^{-1} soil towards the bottom layer. In general, the exchangeable aluminum will determine the soil pH values.

Kaolinite can form directly from primary minerals as an alteration product of 2:1 clay minerals, or by resilication of aluminum oxides if the weathering zone is invaded by silica rich water (Millar *et al*., 1966). In subhumid and humid conditions kaolinite can be formed from pyroclastic materials through the sequence allophane → halloysite (metahalloysite) → kaolinite (Fieldes, 1955) as cited by Allen and Hajek (1989).

Gibbsite was identified by XRD resulting in peaks at 4.85 Å. With DTA identification, gibbsite could be detected and showed only an endothermic reaction peak at 275°C. Gibbsite is one of the main minerals in many Oxisols and commonly, gibbsite together with various polymorphs of iron oxyhydroxide and oxide are the end products of intense weathering (Hsu, 1989). Wada and Aomin (1966) have shown that gibbsite also occurs as a major mineral in some young soils on volcanic ash (Andisols) in Japan. Gibbsite can be formed directly from primary aluminum silicates (Young and Stephen, 1965) or from a primary aluminum silicate via the formation of clay minerals as intermediates (Bates, 1962). Irrespective of whether gibbsite formed directly from primary aluminum silicates or via clay minerals gibbsite formation is governed by the intensity of leaching which is affected by a number of factors such as rainfall, temperature, parent rock, topography, ground water table position, vegetation and time (Hsu, 1989). In the fall face, which still has tropical rainforest vegetation, was estimated to have a higher rainfall. Under these conditions, leaching, and desilication, processes have intensively occurred. As a result the formation of gibbsite mineral would be more favorable.

Based on XRD and DTA, all landsurface units of Mt. Hulu Sabuk area were found to be predominated by kaolinite clay mineral while gibbsite clay mineral may existed in small amount. The presence of two of these clay minerals was probably related to the pedogenic processes, which have undergone intensive leaching and advanced weathering. This condition is favorable to the formation of old soils such as Oxisols and Ultisols.

By X-ray identification, kaolinite in the fall face, transportational midslope, and channel bed units show broad basal reflection and lower peaks. According to Brown (1980) this performance indicates that the kaolinite is of small crystal size and has a poor crystallinity. Conversely, kaolinite from the colluvial footslope and the alluvial toeslope exhibits narrow basal reflection and higher peaks. In general, it is said that the kaolinite found in these land surface units has a good crystallinity degree.

CONCLUSIONS

The warm and humid climate conditions, intermediate parent rocks, and slope of mountainous area were predicted to be factors enhancing the volcanic ash weathering in this study area.

Weathering of parent rocks has resulted in the loss of silica and bases and has led to the accumulation of opaque minerals and formation of new minerals. Probably the sequence of mineral formation followed the order of: volcanic ash → allophane → halloysite → kaolinite and/or gibbsite.

The presence of secondary minerals such as kaolinite, gibbsite, and accumulation of opaque minerals indicates that the soils have already been in the highly weathered stage.

Most of these soils, except channel bed position, have already approached an advanced degree of weathering which were characterized by low soil pH, low exchangeable bases, low base saturation, low soil CEC, and high aluminum saturation.

Acknowledgment

REFERENCES

Alkasuma. 2000. Morphology, characteristics and genesis of soils on Mount Hulu–Sabuk Volcano, Tanjung Raja, Lampung, Indonesia. MS-Thesis. Dept. of Soil Sci., UPLB College, Laguna, The Philippines. (Unpubl.)

Allen, B.L. and B.F. Hajek. 1989. Mineral occurrence in soil environments. *In*: J.B. Dixon and S.B. Weed (Co-Eds.). Minerals in Soil Environments. Soil Science Society of America. Madison, Wisconsin, USA. S.S.S.A Book Series No. 1: 1-34.

Bates, T.F. 1962. Halloysite and gibbsite formation in Hawaii. Clays and Clay Min. 9: 315-328.

Bloom, A.L. 1978. Geomorphology. A systematic Analysis of Late Cenozoic Landforms. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 510 p

Brown, G. 1980. Associated minerals. *In*: G.W. Brindley and G.Brown (*Eds*). Crystal Structure of Clay Minerals and Their X-ray Identification.. Mineralogy Soc., London.

Cady, J.G. 1965. Petrographic microscope techniques. *In*: C.A. Black (Co-Ed). Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. Am. Soc. Agric. & Am. Soc. Test. And Materials. No. 9 in the series Agronomy. P 604-630.

Coffin, D.E. 1963. A method for the determination of free iron in soils and clays. Can. J. Soil Sci. 43:7-17.

Hsu, P.H. 1989. Aluminum Oxides and Hydroxides. *In*: J.B. Dixon and S.B. Weed (Co-Eds.). Minerals in Soil Environments. Soil Science Society of America. Madison, Wisconsin, USA. S.S.S.A Book Series No. 1:331-371

Jackson, M.L. 1979. Soil Chemical Analysis. Advance Course. 2nd ed. 11th print. Published by the author Madison, Wisconsin.

Millar, C.E., L.M. Turk, and H.D. Ford. 1966. Fundamental of Soil Science. John Wiley and Sons. New York.

Mohr, E.C.J. and F.A. Van Baren. 1954. Tropical Soils. A critical study of soil genesis as related to climate, rock and vegetation. Interscience Publishers, Inc. New York. 498 p.

Prasetyo, B.H. 1993. Chemical, mineralogical and P-sorption characteristics of some red soils from west Java. MS. Thesis. The University of Western Australia. (Unpubl.)

Schulze, D.G. 1989. An Introduction to Soil Mineralogy. *In*: J.B. Dixon and S.B. Weed (Co-Eds.). Minerals in Soil Environments. Soil Science Society of America. Madison, Wisconsin, USA. S.S.S.A Book Series No. 1: 1-34.

SCS-USDA 1972. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Investigation Report No. I. U.S. Gov. Print. Office, Washington, DC.

SCS-USDA 1984. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Investigation Report No. I. U.S. Gov. Print. Office, Washington, DC.

Singh, B. 1991. Mineralogical and chemical characteristics of soils from Southwestern Australia. Ph.D. dissertation. Soil science and Plant Nutrition. The University of Western Australia. (Un publ.).

Soil Survey Staff. 1951. Soil Survey Manual. USDA-SCS Agric. Handbook No. 18. U.S. Gov. Print. Office Washington DC.

Soil Survey Staff. 1981. A new soil survey manual. Chapter 4. Description of soils in the fields. USDA-SCS. Washington DC.

Soil Survey Staff. 1998. Keys to Soil Taxonomy. 8th ed. NRCS-USDA, Washington DC.

Theisen, A.A. and M.E. Harward. 1962. A paste method for preparation of slides for clay mineral identification by x-ray diffraction. S.S.S.A Proc. 26:90-91

Wada, K and S. Aomin. 1966. Occurrence of gibbsite in weathering of volcanic materials at Kuroishibaru, Kumamoto. Soil Sci. Plant Nutr. 12: 151-157.

Young, A. and I. Stephen. 1965. Rock weathering and soil formation on high altitude plateaux of Malawi. Soil Sci. J. 16:322-333.