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The Pedogenesis of Inceptisols on Southeast Toposequence of Mount Manglayang in West Java, Indonesia

Ganjar Herdiansyah[1], Mahfud Arifin[2], and Abraham Suriadikusumah[2]

[1]Study Programme of Soil Science, Faculty of Agriculture, Universitas Sebelas Maret
[2]Department of Soil Science and Land Resource, Faculty of Agriculture, Universitas Padjadjaran

Corresponding author: ganjar_counter@yahoo.co.id
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Abstract - The most potential soil order in Indonesia is dominated by Inceptisols, whereas the topography combined with a climatic factor are the main factors to regulate pedogenetic process. This research was intended to determine the pedogenetic process and soil development on various terrain positions at the southeast toposequence of Mount Manglayang areas that have hilly topography. The researched area was 28.83 ha. Based on those conditions, this research aims to study the pedogenetic process and soil development in the southeast slope toposequence of Mount Manglayang, the relationship between the physical, chemical, and mineralogical soil properties, the soil classification to family level based on soil taxonomy, National Soil Classification, and FAO soil classification systems. This research used survey, descriptive, and comparative methods. The result showed that the pedogenetic processes identified were the formation of B horizon through clay accumulation, soil colour, and soil structure development, and the formation of amorphous kaolinite and halloysite minerals. Based on soil taxonomy, the soil were classified as Fluventic Humudepts, coarse-loamy, kaolinitic, isohyperthermic at the upper slope and Fluventic Dystrudepts, fine-loamy, kaolinitic, isohyperthermic at the middle and lower slopes. According to National Soil Classification, the soil is Humic Cambisol at the upper slope, Distric Cambisol at the middle slope, and Cromic Cambisol at the lower slope. FAO classified the soil as Umbric Cambisols at the upper slope and Dystric Cambisols at the middle and lower slopes.

Keywords: profile, pedogenesis, soil taxonomy, toposequent, Mount Manglayang

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Introduction

The southeast toposequence of Mount Manglayang, Subregency of Jatinangor, Sumedang Regency, has an area of 26.2 km^2. It has undulating to hilly topography with the altitude of 725 - 900 m asl. and the mean rainfall of 492.64 mm/month. Jatinangor is categorized as the B_2 agro-climatic zone (Oldeman, 1975) with the mean rainfall of 1,500 - 2,000 mm/year. This research was conducted along the upper, middle, and lower slopes of the southeast toposequence of Mount Manglayang. The location was an intensive agricultural area. Land use is one of factors that can influence soil development. An intensive tillage is considered to have an impact on the process of soil formation and development.

The relationship between slope and soil properties varies in every location. The more various the factors of soil formation, the more complex the soil is. The slope consists of crest, upper slope, middle slope, and lower slope (Hardjowigeno, 2003). Slope gradient highly affects weathering, leaching, and transportation of soil materials due to soil erosion. This phenomenon furthermore leads to the difference of soil properties morphologically, physically, chemically, and mineralogically, because the relationship between slopes and soil properties is not always the same in all places (Hardjowigeno, 2010).

Soils have different properties and characteristics, hence they need a classification to describe their characteristics (Hardjowigeno, 2003). This classification is required to simplify and to classify the various soil properties in order to understand and to manage them easily (Hardjowigeno, 2003). In addition, the soil classification systems can facilitate soil scientists in communicating with each other.

Information about pedogenetic processes and soil classification in the Jatinangor area, based on various soil classification systems, such as Key to Soil Taxonomy (Soil Survey Staff, 2014a), National Soil Classification (Subardja *et al.*, 2014), and FAO soil classification (FAO, 2015) were needed for agricutural land development, considering that this location is a dry land agricultural area. Therefore, the research is important to identify the soil pedogenetic processes as a basic data of soil characteristics on the southeast slope of Mount Manglayang.

Methods and Materials

Observation of soil morphology and environmental condition, and also sampling for laboratory analysis (physical, chemical, and mineralogical) were conducted on a toposequence covering upper, middle, and lower slopes of Cileles Village, Jatinangor Subregency, Sumedang Regency (Figure 1). The soil developed

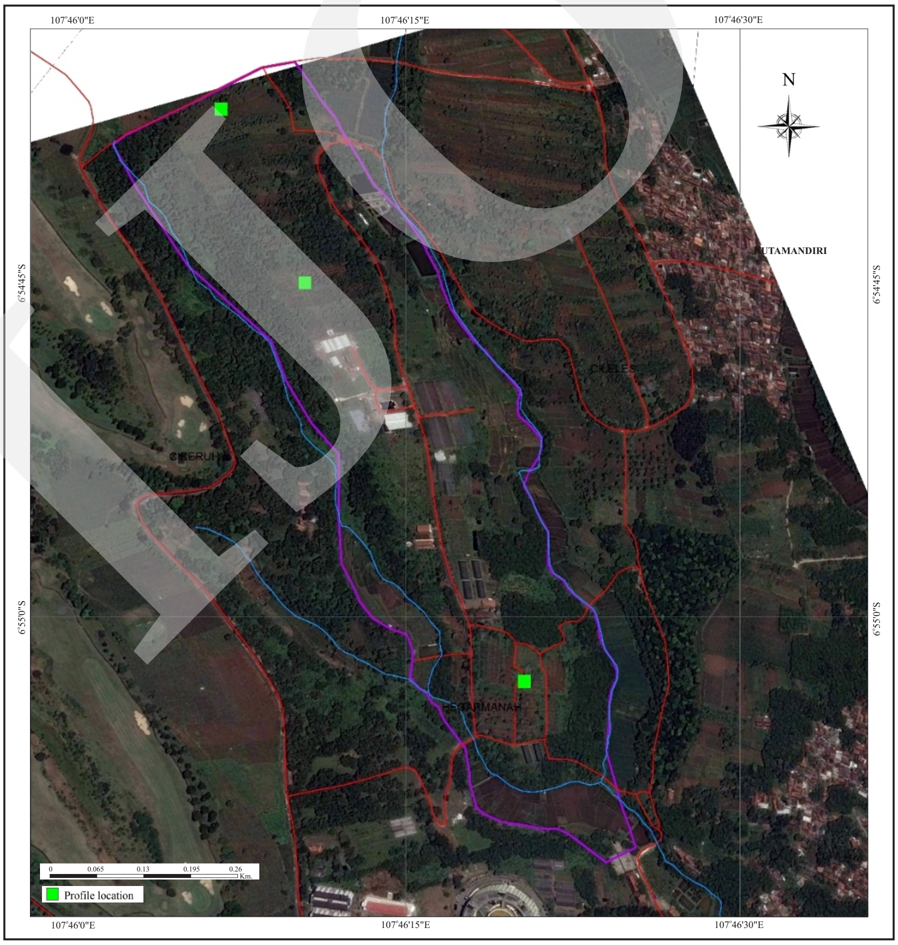

Figure 1. Aerial photograph of soil profile observation location in the studied area.

from andesitic volcanic ash materials resulted from the eruption of Mount Tangkuban Parahu and Mount Tampomas in Holocene age. The site of soil profiles was selected and determined based on the preliminary observation in the cultivated land. Soil samples were taken in every identifiable horizon in all profiles. The upper, middle, and lower slopes had 7; 6 and 7 identifiable horizons respectively to be sampled.

Chemical and physical analyses were done in the Soil Fertility and Physical Laboratories, Faculty of Agriculture, Universitas Padjadjaran. Clay fraction analyses using the X-ray diffraction method was done in the Soil Research Centre, Bogor, and in the Center for Mineral, Coal, and Geothermal Resources, Bandung. Most of the laboratory analyses like particle size analysis, pH H_2O, pH_{KCl}, organic carbon, basic cations, cation exchange capacity, exchangeable acidity for H and Al, X-ray diffraction, mineralogical of the sand fraction followed Soil Survey Staff (2014b). Analyses of XRD used Phillips APD (Automatic Power Diffractions) with Cu Kv. Determination of the clay mineral after XRD analyses followed Brown and Brindley (1980). Soil bulk density and permeability were measured by referring to Oldeman (1975).

Results and Discussion

Topography

The location of the researched area was dominated by slope gradient of more than 40% of an area of 17.83 ha or 61.84% out of the total researched area. The area with the slope of 0 − 3% was 0.33 ha (1.14%), slope of 3−8% was 1.03 ha (3.56%), slope of 15 − 25% was of 2.31 ha (8.00%), and slope of 25−40% was 5.59 ha (19.28%). Those phenomena are commonly found in a mountainous area.

Climate

The researched area showed that the mean annual rainfall within ten years (2004–2014) was 3.6 of dry months and 6.7 of wet months. Based on those data, it was categorized as C rainfall type, which means having slightly wet rainfall according to Schmidt-Fergusson (1951) classification with a Q value of 0.576 or 57.6%. Mean rainfall in the researched area was 2,000 - 2,500 mm/year. The dry season occurs from June until September, while the wet season occurs from November until April. This rainfall type is considered to have a moderate impact on soil erosion in a sloping area, therefore the transportation of soil materials and leaching process unintensively occur.

Soil Morphology

The profile in the upper slope had the soil colour from very dark (7.5YR 2/3) in the Ap horizon, dark brown (7.5YR 3/3) in the AB horizon, brown (7.5YR 4/3) in the Bw horizon, dark brown (7.5YR 3/4) in the BA horizon, very dark brown (7.5YR 2/3) in the 2Ab horizon, brown (7.5YR 4/3) in the 2AB and light brown (7.5YR 4/6) colours in the 2Bw horizon. The profile in the middle slope had a very dark brown (7.5YR 2/3) (Ap), reddish dark brown (5YR 3/6) (AB), dark brown (7.5YR 3/4) (Bw), reddish dark brown (5YR 3/6) (2A’b), and light brown (7.5YR 5/6) (2BC and 2C) colours. The profile in the lower slope showed a very dark brown colour (7.5YR 2/3) (Ap), reddish dark brown (5YR 3/4) (AB), reddish light brown (5YR 4/3) (Bw), reddish dark brown (5YR 3/6) (2A’b), reddish-brown (5YR 4/6) (2BC), yellowish brown (10YR 5/6) (2CB), and yellowish light brown (10YR 6/8) (2C) colours. The upper slope profile had different soil colour variations vertically, the top layer is a dark soil colour that gets brighter downwards, but at a depth of 140 cm the soil colour darkens and at the depth after that the soil colour gets lighter. It is suspected that there is a soil accumulation due to different volcanic eruption materials. The profile on the upper slope showed two different sequms (lithologic discontinuity). Each sequm revealed different genetic horizons. The first horizon (0 - 18 cm) consisted of one horizon named as Ap horizon, second horizon (18 - 40 cm) was AB horizon, third horizon (40 - 91 cm) was Bw horizon, fourth horizon (9H40 cm) was BA horizon, fifth horizon (140 - 156 cm) was 2Ab horizon, sixth horizon (156 - 178 cm) was 2AB horizon, and seventh horizon was 2 Bw horizon. This phenomenon showed that there iss accumulation materials deposited in a long period pedogenically (Arifin *et al*. 2017).

Soil structure in each profile did not show any clear different structure, although it had different topography. Observation in the field exposed that most of the horizons had sub-angular blocky and blocky structures of fine to medium size in moderate development. In the upper horizons, the structure was crumb and vertically changing into subangular blocky in the deeper depths with a higher level of soil development.

The soil was generally presented in friable to firm consistency. In the upper horizons, the consistency was friable and became firm in the lower horizons, but the consistency in BC and C horizons were friable again. The consistency change in the BC and C horizons was due to the weathering process of the parent material (regolith) that was still going on.

Morphological characteristics of profile in the middle slope showed that there were consisted of six horizons. First horizon (0 - 16 cm) was Ap, second horizon (16 - 44 cm) was AB, third horizon (44 - 78 cm) was Bw, fourth horizon (78 - 102 cm) was 2Ab, fifth horizon (102 - 148 cm) was BC, and sixth horizon was CB.

Observation of profile in the lower slope showed that there were consisted of seven horizons. First horizon (0 - 3 cm) was Ap, second horizon (13 - 38 cm) was AB, third horizon (38 - 77 cm) was Bw, fourth horizon (77 - 99 cm) was BA, fifth horizon (99 - 125 cm) was 2Ab, and sixth horizon was CB, and seventh horizon was C or parent material.

All profiles at the observation site showed lithologic discontinuity (Table 1). Lithologi-

Table 1. Soil Morphology Properties of Profiles

Profile	Horizon	Depth (cm)	Horizon Boundary	Soil Colour	Structure	Consistency	Texture	Pore	Root
Upper slope	Ap	0-18	a/s	7.5YR 2/3	gr	fr	SiCL	mi, a	2, a
	AB	18-40	a/w	7.5YR 3/3	gr	fr	SiCL	mi, a	2, m
	Bw	40-91	d/s	7.5YR 4/3	abk	fi	SiC	mi, a	1, f
	BA	91-140	d/s	7.5YR 3/4	sbk	fi	SiC	mi, a	1, f
	2Ab	140-158	a/w	7.5YR 2/3	sbk	fr	SiC	mi, m	-
	2AB	158-178	d/w	7.5YR 4/3	sbk	fr	SiC	mi, m	-
	2Bw	178-200	d/w	7.5YR 4/6	sbk	fi	SiC	mi, f	-
Middle slope	Ap	0-16	a/w	7.5YR 2/3	gr	fr	SiCL	mi, a	2, a
	AB	16-44	d/s	5YR 3/6	sbk	fi	SiC	mi, a	1, f
	Bw	44-78	a/w	7.5YR 3/4	abk	fi	SiC	mi, a	1, f
	2A'b	78-102	d/s	5YR 3/6	abk	fi	SiC	mi, m	1, f
	2BC	102-148	d/s	7.5YR 5/6	abk	fi	SiC	mi, m	1, f
	2CB	148-200	d/w	7.5YR 5/6	gr	fr	SiC	mi, m	-
Lower slope	Ap	0-13	c/s	7.5YR 2/3	sbk	fr	SiCL	mi, a	2, m
	AB	13-38	d/s	5YR 3/4	sbk	fr	SiCL	mi, a	2, f
	Bw	38-77	d/s	5YR 4/3	abk	fi	SiC	mi, a	2, f
	2A'b	77-90	d/s	5YR 4/6	abk	fi	SiC	mi, a	2, f
	2BC	90-125	d/s	5YR 4/6	abk	fr	SiC	mi, m	2, f
	2CB	125-184	d/s	10YR 5/6	gr	fr	SiC	mi, m	2, f
	2C	184-200	d/s	10YR 6/8	-	fr	SiC	mi, m	2, f

Notes: a= abrupt, d= diffuse, c= clear, s= smooth, w= wavy, gr= granular, sbk= subangular blocky, abk= angular blocky, SiCL= silty clay loam, SiC= silty clay, mi= micro, 1= fine, 2= moderate, a= abandon, m= many, f= few.

cal discontinuity was indicated by a significant change in soil colour in the observed profile. According to Ahr *et al*. (2017) lithologic discontinuity occurred because of significant changes in various things such as colour, particle size, and mineralogy that represent lithological differences in one soil profile. This phenomenon occured when there were two or more different parent materials developed vertically, causing variations in the soil formation process and the resulting soil (Devnita *et al*., 2018).

Chemical Properties

Soil pH

Laboratory analysis (Table 2) in each profile generally revealed that pH H_2O was higher than pH_{KCl} except 2AB and 2Bw horizons in the upper slope. Profile in the upper slope displayed the increase of pH H_2O with depths from 4.80 to 5.35. The same pattern was also shown by the profile in the middle slope (pH 5.12 – 5.30), but did not show a regular increase in depths. Conversely, the profile in the lower slope showed a decrease pH value, from 6.19 to 6.04, except the lowest horizon which had higher pH than the horizon above. Factors affecting soil pH in this research were vegetation, soil drainage, rainfall, parent material, and human activities. In the upper slope profile, there was leaf litter on the surface soils. The decomposition of these litters can release dissolved CO_2, which reacted with water molecules and later produced carbonic acid, so the upper soils became acid. In addition, human activities, such as soil tillage and fertilization also caused soils to become acid. The lower layers in the upper slope profile showed higher pH with increasing depths due to basaltic parent material, which tended to increase soil base content. On the other hand, the

Table 2. Soil Chemical Properties of Profiles

Profile	Horizon	Depth (cm)	Soil pH		OC	Exchangeable (cmol/kg)		Ca	Mg	K	Na	CEC	BS
			H_2O	KCl	%	Al	H	cmol/kg					%
Upper slope	Ap	0-18	4.80	3.58	2.97	3.85	3.02	6.02	2.95	0.57	0.44	25.50	39.16
	AB	18-40	4.70	3.27	1.88	1.81	1.00	4.89	1.67	0.30	0.25	27.28	26.04
	Bw	40-91	5.16	4.82	0.73	0.00	0.21	6.09	3.19	0.12	0.52	24.66	40.25
	BA	91-140	5.48	4.90	1.19	0.00	0.52	4.13	2.80	0.09	0.35	26.91	27.40
	2A'b	140-158	5.41	5.11	2.13	0.00	0.94	3.27	1.86	0.56	0.35	19.78	30.53
	2AB	158-178	5.30	5.78	1.18	0.00	0.00	3.59	2.21	0.13	0.38	18.50	34.15
	2Bw	178-200	5.35	5.92	0.59	0.00	0.10	4.12	3.03	0.13	0.37	16.33	46.89
Middle slope	Ap	0-16	5.12	3.74	1.97	2.41	1.23	2.23	1.21	0.20	0.28	22.62	17.35
	AB	16-44	5.69	4.19	1.33	0.20	0.42	5.39	2.16	0.14	0.28	26.08	30.55
	BA	44-78	5.35	4.18	0.30	0.40	0.53	3.38	1.74	0.14	0.25	22.99	23.93
	2A'b	78-102	4.47	4.24	1.20	0.20	0.32	3.58	2.16	0.15	0.31	21.94	28.27
	2BC	102-148	4.54	4.06	0.60	1.21	-0.58	4.58	2.88	0.15	0.78	23.34	35.96
	2CB	148-200	5.30	4.10	0.61	1.01	0.35	4.77	3.06	0.10	0.41	19.16	43.56
Lower slope	Ap	0-13	6.19	4.72	2.85	0.00	0.10	8.71	4.19	0.72	0.23	26.61	52.04
	AB	13-38	5.85	4.46	1.61	0.00	0.31	6.76	3.07	0.77	0.64	28.77	39.09
	Bw	38-77	5.60	4.87	0.60	0.00	0.13	6.78	3.06	0.42	0.43	25.26	42.28
	2A'b	77-90	5.51	4.85	0.90	0.00	0.10	7.47	3.20	0.25	0.59	25.93	44.38
	2BC	90-125	5.76	4.99	0.61	0.00	0.10	6.24	3.01	0.20	0.47	25.84	38.34
	2CB	125-184	5.50	4.91	0.47	0.00	0.10	6.11	3.09	0.54	0.48	27.72	36.86
	2C	184-200	6.04	4.90	0.31	0.00	0.10	6.21	2.99	1.28	0.51	26.96	40.75

Information: OC= Organic Carbon, CEC= Cation Exchange Capacity, BS= Base Saturation.

profile in the lower slope showed a lower pH H_2O. It was due to intensive leaching of basic cations in the upper slope profile. Therefore, the deeper the depths, the lower pH values, except in the lowest horizon (2C) that had high pH due to the influence of basaltic parent material.

Delta pH

The result revealed that delta pH in the upper slope profile was around 0.23 to 1.23, while in the lower slope the profile was around 0.59 to 1.47. Those results showed the different soil development in each profile. It was expected that the lower slope profile had advanced soil development compared to the upper slope and middle slope profiles. The upper slope profile showed negative delta pH, -0.48 (2AB horizon), -0.57 (2Bw horizon), hence these horizons were expected to have a variable charge. Delta pH is a parameter that can assess the level of soil development, where the difference in pH_{KCl} and pH H_2O can be used to predict soil development based on the sign and magnitude of variable charge (Arifin and Harryanto, 1999). Uehara and Gillman (1981) and Sakurai *et al*. (1988) stated that the point of zero charges (ZPC) was highly correlated with pH_{KCl} than pH H_2O.

Organic Carbon

The result showed that the profile in the upper slope had the highest organic carbon in Ap (2.97%) and 2A'b (2.13%) horizons. The lowest organic carbon was 0.73% (Bw), 0.59% (2 Bw), 1.88% (AB), 1.19% (BA), and 0.59% (2Bw). The profile in the upper slope showed a lithologic discontinuity in which the organic carbon increased in 2A'b horizons (2.13%). An increase in organic carbon at considerable depths from the soil surface is not common unless it indicates a previously developed or buried horizon (lithologic discontinuity) (Devnita *et al*., 2018). Meanwhile, the profile in the lower slope had a lower organic carbon content with increasing depths. The highest organic carbon was 2.85% in the Ap horizon and the lowest was 0,31% in the 2C horizon.

Soil forming factors influence the difference in soil organic carbon. The decrease of organic carbon with depths in the soil profile might due to the less supply of vegetation in the cultivated land. Loss of vegetation will trigger the penetration of sunlight which can increase soil temperature, thereby spurring the decomposition of organic matter (Sabaruddin *et al*., 2009). This land use type only depended on seasonal crops and grass as a source of organic carbon (Sugirahayu and Rusdiana, 2011).

Cation Exchange Capacity

Results of the analyses informed that all profiles showed the decreasing of the CEC value along with the increasing of soil depth. The upper slope profile had the highest CEC value on the AB horizon (27.28 cmol/kg) and the lowest on the 2Bw horizon (16.33 cmol/kg). Therefore, this upper slope profile had experienced weathering along with increasing depth. The middle slope profile had the highest CEC value in the AB horizon (26.08 cmol/kg) and the lowest in the 2CB horizon (19.16 cmol/kg).

The lower slope profile had the highest CEC value in the AB horizon (28.77 cmol/kg) and the lowest in the Bw horizon (25.26 cmol/kg), but in the 2CB and 2C horizons the CEC value was higher than the overlying horizon, showing that the level of weathering in the 2CB and 2C horizons was lower than the 2BC horizon. Similar to the upper slope profile, the middle and lower slope profiles showed the decreasing CEC value along with the increasing of soil depth. It can be said that these three profiles had continued weathering. The high CEC value on the AB horizon in each research profile showed that the leaching of cations that occurs on the AB horizon was still going on (Arabia *et al*., 2018).

Base Saturation

The profile in the upper slope had base saturation around 26.04 - 46.89%, categorized as low to medium. The profile in middle slope had base saturation around 17.35 - 43.65%, also classified as low to medium. Meanwhile, the profile in the lower slope had base saturation around 36.86 - 52.04% categorized as medium to high. Base saturation describes the level of leaching of base cations in the soils (Sudaryono, 2009). Laboratory analyses showed that all observed profiles had low to high base saturation. Therefore, high leaching of base cations might not occur in upper, middle, and lower slope profiles. Base saturation also describes the percentage of basic cations to cation exchange capacity. It is not always due to leaching. It can be found in every horizon, with or without leaching.

Physical Soil Properties

Soil Texture

Table 3 showed that the upper slope profile generally had silty loam texture in the Ap, AB, Bw, and BA horizons. In those horizons, the amount of sand fraction was less than silt fraction, while clay fraction was less than silt fraction, except in 2Ab, 2AB, and 2 Bw horizons. Sandy loam texture had more sand fractions than silt and clay fractions. Generally, the sand fraction was less compared to the silt fraction, while the silt content was higher than the clay fraction. Therefore, the upper slope profile was dominated by silt fraction.

The high content of silt in the upper slope profile was assumed due to the ongoing process of weathering. The same result was also observed in each horizon of the middle slope profile, but it had more clay content than in the upper slope profile. The upper slope profile did not show a regular decrease or increase of sand, silt, and clay fractions based on soil depths as a diagnostic horizon. It might be due to more intensive weathering and clay leaching from surface soils.

The lower slope profile showed the same result as profiles in the upper and middle slopes, dominated by silt fraction. Meanwhile, the amount of sand fraction was less than silt and clay fractions in these profiles. However, the clay fraction exhibited an increase amount based on soil depths. It might be due to clay leaching from surface soils.

Table 3. Soil Texture Classes of Profiles

Profile	Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Class of Texture
upper slope	Ap	0-18	43.25	40.69	16.06	Loam
	AB	18-40	40.08	45.24	14.68	Loam
	Bw	40-91	24.55	51.52	23.94	Silty loam
	BA	91-140	35.25	50.98	13.77	Silty loam
	2A'b	140-158	62.88	28.97	8.15	Sandy loam
	2AB	158-178	57.59	32.51	9.90	Sandy loam
	2Bw	178-200	39.77	43.18	17.06	Loam
middle slope	Ap	0-16	37.69	42.55	19.76	Loam
	AB	16-44	18.91	52.35	28.74	Silty clay loam
	BA	44-78	25.79	47.61	26.60	Clay loam
	2A'b	78-102	20.86	51.23	27.91	Silty clay loam
	2BC	102-148	30.65	45.17	24.18	Clay loam
	2CB	148-200	14.72	55.36	29.92	Silty clay loam
lower slope	Ap	0-13	47.43	38.88	13.69	Loam
	AB	13-38	28.34	49.12	22.54	Loam
	Bw	38-77	21.50	51.66	26.84	Silty loam
	2A'b	77-90	22.07	50.85	27.08	Silty loam
	2BC	90-125	35.76	42.30	21.94	Loam
	2CB	125-184	39.23	40.21	20.55	Loam
	2C	184-200	53.52	31.76	14.72	Sandy loam

On the other hand, the amount of clay decreased in the 2 BC, 2CB, and 2 C horizons while sand content increased. It was assumed due to the advanced weathering of the parent material.

Particle Size Distribution

Based on the particle size distribution analyses of grains (Table 4), the profile in the upper slope had the distribution of grain class comprising two different parent materials, which differed in the time of deposition, namely coarse loam above the sand, and arrangement of sandy fraction in 2A'b, and 2AB horizons which had a bigger size than grains in other horizons.

Lithologic discontinuity in the soil parent material and different weathering could be seen from the distribution of soil particle size. This process was observed in the upper slope profile. This profile was dominated by sand fraction type III (medium sand), silt fraction type IV (medium silt), and clay fraction type IX (fine clay). Different level of weathering between the first and second parent materials was clearly detected from the arrangement of medium silt and medium sand fractions.

Profile in the middle slope was dominated by fine loam, because it had a higher silt fraction than other soil fractions. It also had clay fraction around 18 – 34%. This profile was dominated by sand fraction type III (medium sand), silt fraction type IV (medium silt), and clay fraction type IX (fine clay). In addition, this profile was also detected to have deposition from two different

Table 4. Particle Size Distribution of Profiles

Profile	Horizon	Particle Size Distribution									
		% Fraction I	% Fraction II	% Fraction III	% Fraction IV	% Fraction V	% Fraction VI	% Fraction VII	% Fraction VIII	% Fraction IX	% Fraction X
upper slope	Ap	3.10	7.03	23.18	10.49	0.55	14.87	14.87	10.95	9.67	6.39
	AB	4.15	6.28	19.74	9.92	1.01	16.80	16.70	11.74	8.50	6.17
	Bw	2.02	3.64	11.92	6.87	0.61	17.68	18.38	15.45	13.94	10.00
	BA	1.52	4.99	16.38	9.65	0.11	18.44	18.11	14.43	5.75	8.03
	2Ab	3.29	6.34	21.15	24.03	6.83	12.84	9.63	6.50	4.69	3.46
	2AB	2.97	8.42	23.68	18.15	4.21	13.37	11.30	7.84	5.94	3.96
	2Bw	4.78	5.56	15.89	12.77	2.34	15.69	15.20	12.28	9.65	7.41
middle slope	Ap	3.73	9.19	22.01	11.44	1.13	15.16	14.73	12.65	11.01	8.75
	AB	3.50	2.30	8.09	4.92	0.11	18.14	18.25	15.96	16.07	12.68
	Bw	3.27	4.78	11.67	6.42	0.47	17.27	16.34	14.00	14.35	12.25
	2A'b	5.99	3.85	7.27	4.49	0.53	17.22	18.61	15.40	15.29	12.62
	2BC	15.75	3.28	6.28	4.69	1.59	15.56	15.28	14.34	12.84	11.34
	2CB	4.00	2.12	4.48	5.18	1.06	19.79	19.20	16.37	16.25	13.66
lower slope	Ap	13.40	5.13	15.21	10.84	1.05	15.68	14.16	9.03	7.89	5.80
	AB	6.72	3.93	10.86	6.31	1.03	18.20	17.17	13.75	12.72	9.82
	Bw	8.45	3.21	6.42	4.28	0.75	18.40	18.18	15.08	14.65	12.19
	2A'b	4.90	2.13	7.04	3.84	3.94	16.95	17.70	16.20	14.29	12.79
	2BC	12.61	4.95	8.50	5.51	4.76	14.75	14.85	12.70	11.76	10.18
	2CB	8.45	10.59	12.01	5.52	4.54	13.61	13.79	12.81	10.94	9.61
	2C	4.50	12.91	22.77	9.50	5.44	11.17	10.95	9.64	8.05	6.67

Notes: fraction I= 2.00 – 1.00 mm; fraction II= 1.00 – 0.50 mm; fraction III= 0.50 – 0.25 mm; fraction IV= 0.25 – 0.10 mm; fraction V= 0.10 – 0.05 mm; fraction VI= 0.05 – 0.02 mm; fraction VII= 0.02 – 0.005 mm; fraction VIII= 0.005 – 0.002 mm; fraction IX= 0.002 – 0.0005; fraction X= < 0.0005 mm.

parent materials, which were observed from the arrangement of medium silt and fine clay fraction.

Profile in the lower slope also had the same distribution of soil particle size as upper slope and middle slope profiles. However, the profile in the upper slope had younger parent material (dominated by the sand fraction) compared to the profile in the middle slope (dominated silt fraction). Conversely, the profile in the lower slope had the oldest parent material among all profiles, although the other profiles were dominated by silt fraction. In the process of soil development, the coarse fraction (sandy) will be weathered into a finer fraction (silt and clay) (Hardjowigeno, 2015).

Distribution of Soil Mineralogy

Primary Minerals

Analyses of the sand fraction (Table 5) showed the different age of the deposition of volcanic materials. It can be seen from the mineral content (opaque minerals) in each profile, although having the same basalt parent materials. This condition occurred in soils developed from volcanic ash as a result of an intermittent eruption in the different time interval (Purwanto *et al.*, 2018). The opaque mineral was higher than iron concretion in each profile, however, this concretion was high in Ap horizon. This results are in the assumption that all profiles had old volcanic material, because the iron concretion will change to magnetite as the material get older (Arifin *et al.*, 2017). All profiles show the weathering process, based on the mineral content in the sand fraction. It could be seen from the high amount of weathering mineral. Profile in the upper slope had lithologic discontinuity where the second deposition (2A'b, 2AB, and 2 Bw) had older materials than the first deposition (Ap, AB, Bw, and BA). According to Aini *et al.* (2018) the shape of land affects the velocity and amount of deposited volcanic material, area that is in close proximity to the source of the eruption that will have a unique soil characteristics. The higher the frequency of the area gets additional new material, pedogenesis will occur more easily. The huge amount of rock fragments in the second deposition than the first deposition showed that phenomenon. The mineral content of weathered material or the results of weathering of the originating minerals in all profiles are moderate to large. This phenomenon was the result of the eruptions from the surrounding volcano (Mount Tangkuban Parahu). This showed that the volcanic material as the main material for the upper slope, middle slope, and lower slope profiles were young at the upper horizon (Quaternary or Holocene). Materials from volcanic materials include hornblende. Hornblende spreads in all profiles, especially in the first material. Hornblende is a primary mineral belonging to the ferromagnesian group that based on its chemical structure, it is indicated to be able to be used as a nutrient resource for plant growth, especially Ca, Mg, and Fe (Aini *et al.*, 2019).

Secondary Minerals

Secondary mineral observations were based on the peak curve that appears from the X-ray diffraction analyses (Figures 2, 3, and 4). A peak X-ray diffraction graph was generated when an X-ray at a certain angle scans a crystal that has a certain atomic distance. The X-ray diffraction on certain minerals will be produced in certain diffraction peaks, because each crystal has a typical atomic structure that is different from another (Brown and Brindley, 1980). The upper and middle slope profiles were dominated by amorphous minerals, small and very small amount of kaolinite and halloysite, respectively (Figures 2 and 3). Amorphous minerals were described in irregular form. On the other hand, the lower slope profile (Figure 4) was dominated by kaolinite minerals. It was detected by the high peak on 7.28 Å, 4,45 Å, and 3,6 Å. Halloysite mineral was detected on 7,28 Å and 3,6 Å peaks (Table 6). The formation of kaolinite in the upper slope profile may be from the recrystallization of silicate minerals in an acid environment due to the leaching of base cations (characterized by well drained and high rainfall).

Soil Formation (Pedogenesis)

Based on the criteria of soil formation by Mohr and Van Baren (1960), the level of weathering in

Table 5. Composition of Primary Minerals (Sand Fraction) in All Profiles

Profile	Horizon	Type of Minerals (%)																												
		Op	Zi	Dq	Cq	Ic	Li	SiO	Ze	Hd	Wm	Rf	Vg	Al	An	Lb	Bi	At	Or	Sn	Mu	Bt	Gh	Bh	Au	Hi	Ol	Ep	Tu	Es	Tr	At
upper slope	Ap	27	-	sp	6	sp	sp	1	sp	sp	5	2	sp	-	1	13	2	-	-	-	-	1	31	sp	5	4	-	sp	1	1	sp	-
	AB	26	-	sp	5	-	sp	1	sp	-	10	2	1	-	1	12	1	-	-	-	-	sp	34	-	4	3	-	sp	sp	sp	sp	-
	Bw	25	-	sp	3	-	2	sp	1	sp	33	sp	sp	-	1	9	sp	-	-	-	-	sp	24	-	1	1	-	-	-	sp	sp	-
	BA	27	-	3	4	sp	2	sp	4	sp	32	sp	-	-	sp	8	-	-	-	sp	-	-	19	sp	sp	1	-	-	sp	sp	sp	-
	2A'b	18	-	2	3	sp	2	sp	3	1	37	1	1	-	1	12	-	-	-	-	-	-	18	-	sp	sp	-	-	sp	-	1	-
	2AB	8	-	3	3	sp	7	sp	sp	-	45	13	1	-	sp	11	sp	-	-	sp	-	-	8	-	sp	sp	-	-	1	-	sp	-
	2Bw	12	-	2	-	-	3	-	4	-	51	8	1	sp	-	12	-	-	-	sp	-	-	7	-	sp	sp	-	sp	sp	-	sp	-
middle slope	Ap	20	-	sp	1	sp	sp	6	sp	-	42	7	sp	sp	1	11	1	-	-	-	-	-	11	-	sp	sp	sp	sp	sp	sp	sp	-
	AB	18	-	1	1	-	sp	4	sp	-	42	5	-	sp	1	12	1	-	-	-	-	-	14	-	1	sp	-	-	sp	-	sp	-
	BA	14	-	2	4	sp	sp	sp	sp	-	45	sp	sp	-	sp	15	sp	-	sp	-	-	-	20	sp	sp	sp	-	sp	sp	-	sp	-
	2A'b	21	-	3	10	-	sp	sp	2	-	47	3	sp	-	-	6	-	-	-	-	-	-	6	-	1	1	-	-	-	-	sp	-
	2BC	19	-	5	7	-	2	sp	3	-	49	1	sp	-	sp	8	-	-	-	-	-	-	6	-	-	-	-	sp	-	sp	sp	-
	2CB	18	sp	2	3	sp	sp	1	11	-	50	sp	3	-	-	5	-	-	-	-	-	-	5	-	1	1	-	-	-	-	sp	-
lower slope	Ap	31	-	sp	3	sp	3	sp	1	sp	26	2	sp	-	1	17	sp	sp	sp	sp	-	-	15	-	sp	1	sp	sp	sp	-	-	sp
	AB	18	-	2	3	sp	2	sp	1	sp	33	sp	sp	sp	1	21	1	sp	sp	sp	-	-	14	-	1	3	sp	sp	sp	-	-	sp
	Bw	27	-	2	3	sp	sp	-	1	sp	38	sp	sp	sp	sp	16	-	-	sp	sp	-	-	11	-	1	1	sp	sp	-	-	-	sp
	2A'b	19	-	1	4	1	1	sp	2	-	40	3	1	sp	1	15	-	-	sp	-	-	-	10	-	sp	1	-	-	-	-	-	1
	2BC	22	-	5	4	-	sp	-	6	sp	41	1	sp	-	sp	10	-	-	1	-	sp	-	10	-	-	-	-	-	-	-	-	sp
	2CB	28	-	10	3	-	sp	sp	3	sp	46	2	sp	-	-	6	-	-	-	sp	sp	-	1	-	-	-	-	-	-	-	-	1

Notes: Op= opaque, Zi= zircon, Dq= cloud quartz, Cq= clear quartz, Ic= iron concretion, Li= limonite, SiO= organic SiO2, Ze= zeolite, Hd = hydrargillite, Wm = weathering mineral, Rf= rock fragment, Vg= volcanic glass, Al= albite, Ol= oligoclase, An= andesine, Lb= labradorite, Bi = bytownite, At = anorthite, Or= orthoclase, Sa= sanidine, Mu= muscovite, Bt= biotite, Gh= green hornblende, Bh= brown hornblende, Au= augite, Hi = hypersthene, Ga = garnet, Ep= epidote, Tu= tourmaline, Es= enstatite, Tr= tremolite, At= anorthoclas, sp= sporadic, cloud quartz = smoky quartz.

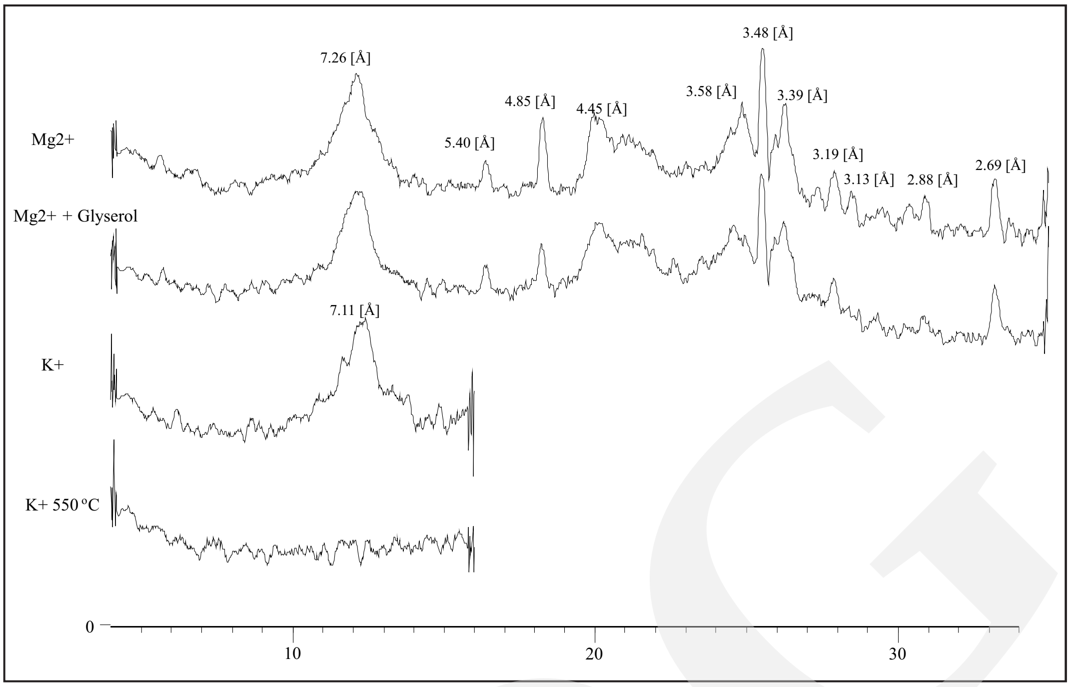

Figure 2. X-ray Diffractograms of upper slope profile.

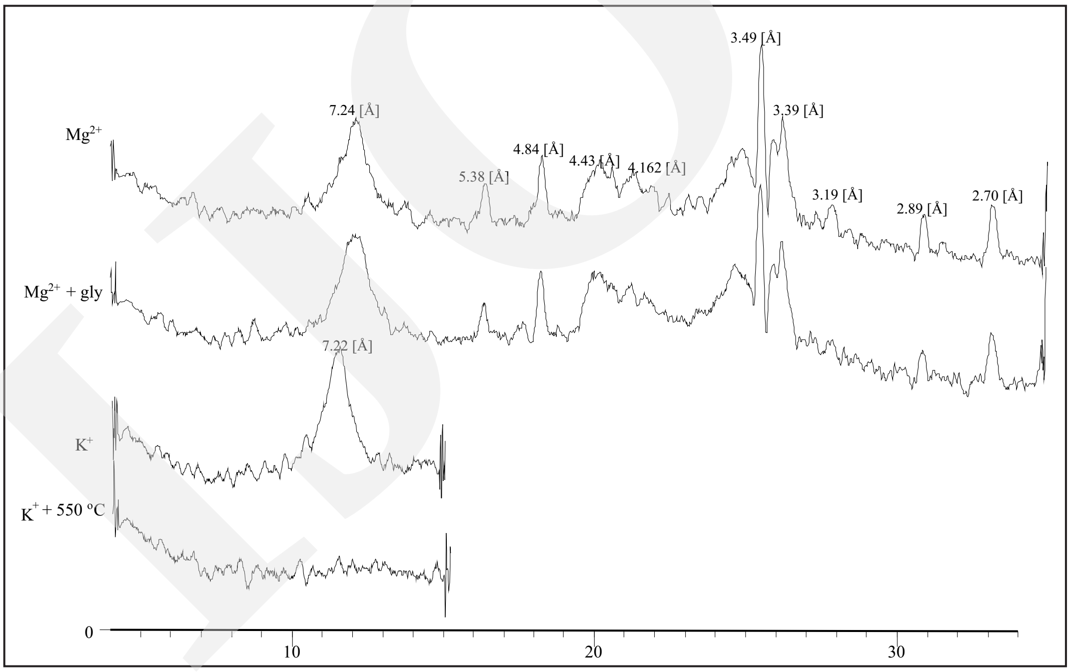

Figure 3. X-ray Diffractograms of middle slope profile.

all profiles was viril. It was due to the high amount of weatherable minerals and already weathering. In addition, the physical and morphological characteritics showed an increase of clay content. The upper slope profile was old deposition that had weathered. It may be concluded that the upper slope profile originated from old parent material contaminated by the last eruption of Mount Tangkuban Parahu. According to an analysis of X-ray diffraction, all profiles were dominated by amorphous, kaolinite, and halloysite minerals developed from old volcanic material that were in the

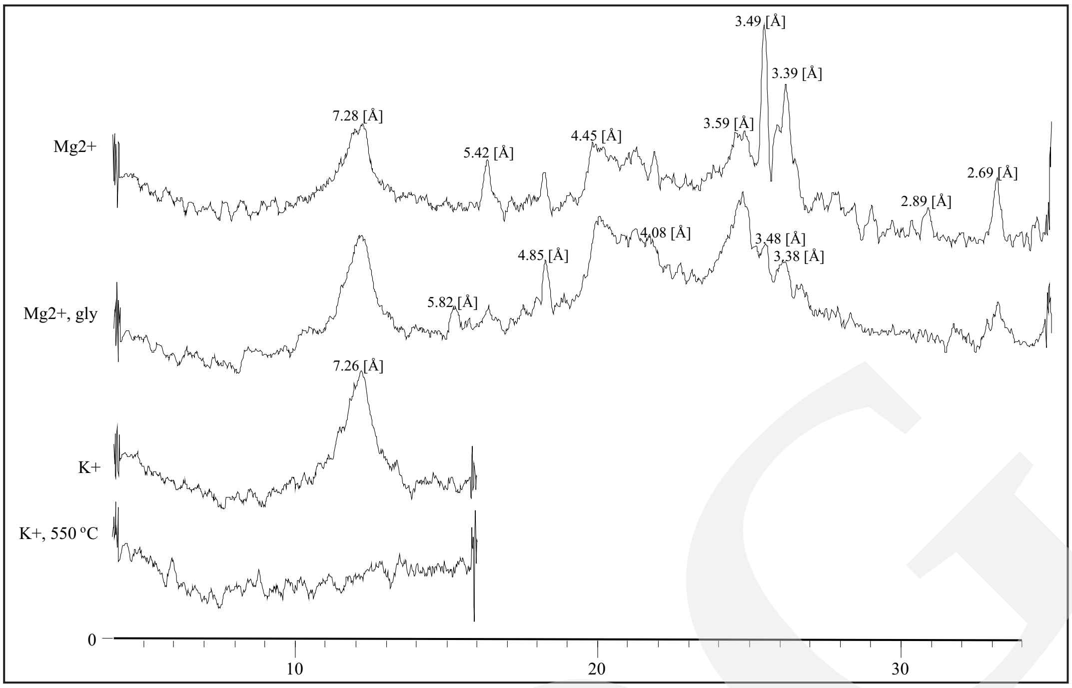

Figure 4. X-ray Diffractograms of lower slope profile.

Table 6. Clay Mineralogical Composition of Selected Horizons in All Profiles

Profiles	Clay mineral	Peak of XRD (Å)	Amount
upper slope	kaolinite	7,26; 4,4; 3,5	abundant
	halloysite	7,26	very small
	amorphous	-	small
middle slope	kaolinite	7,23; 4,44	abundant
	halloysite	4,42	small
	amorphous	-	small
lower slope	kaolinite	7,28; 4,45; 3,6	abundant
	halloysite	7,28; 3,6	small
	amorphous	-	small

cambic stage. The type of mineral and its content can be used to determine the level of weathering (Tavernier and Eswaran, 1972, in Arifin, 1994).

Soil Classification

The horizon in the upper slope profile was identified as umbric epipedon up to depth of 18 cm and had organic carbon of 0.2% in the depth of 125 cm, but did not categorize as other identifier horizons. Umbric epipedon was obtained based on observations of soil depth of ≥ 18 cm, dark soil colour (value/chroma ≤ 3), organic carbon of > 2.5%, or ≥ 0.6% higher than horizon C, and base saturation of <50%. It also had a slope of > 25% and a decrease of organic carbon in the depth of 25 - 125 cm. The high amount of kaolinite mineral makes this profile be categorized as a kaolinitic class mineral. This profile had >15% of particle diameter around 0.1 - 7.5 mm (fine sand or coarser) and < 18 % clay content, so it was categorized as coarse loam. Furthermore, all the profiles were classified as isohyperthermic in which the average soil temperature in every year is > 22°C, and the difference of average temperature in dry and rainy season is < 6°C. On the other hand, the middle slope and lower slope profiles were analyzed as having kaolinite mineral and classified as a kaolinitic class mineral. The middle slope profile had >15% of particle diameter around 0.1 - 7.5 mm (fine sand or coarser) and 18 - 35% of clay in the fine fraction.

Soil taxonomy differentiates all of the three profiles to the level of the family. The upper slope profile was classified as Fluventic Humudepts, coarse-loamy, kaolinitic, isohyperthermic; middle slope profile as Fluventic Dystrudepts, fine-loamy, kaolinitic, isohyperthermic, and lower slope profile as Fluventic Dystrudepts, fine-loamy, kaolinitic, isohyperthermic.

Based on the National Soil Classification system year 2014, the profiles had different soil types. The upper slope profile was classified as Humic Cambisol, the middle slope profile was Distric Cambisol, and the lower slope profile was Cromic Cambisol. All profiles had a cambic B horizon, umbric epipedon, and did not show hydromorphic reactions to a depth of 50 cm from the surface. The diagnostic feature of the upper slope profile was the umbric epipedon. The middle slope profile had a base saturation of <50% on the B horizon. The lower slope profile had a soil colour on the B horizon, which was dark brown to dark red (hue was redder than 5 YR).

FAO classification shows that the upper slope profile was classified as Umbric Cambisol indicated by umbric epipedon, chroma of < 3.5, organic carbon of > 1%, and base saturation NH_4O_{ac} of < 50%. The midslope profile was classified as Dystric Cambisols, with base saturation of less than 50% in some parts of the B horizon. The downslope profile was classified as Dystric Cambisols.

Conclusions

The development of these inceptisols was indicated by the formation of B horizon with acumulation of clay, development of structure, colour alteration, and formation of amorphous, kaolinite, and halloysite minerals. All of the profiles were in viril or cambic stage.

Based on soil taxonomy, the upper slope profile was classified as Fluventic Humudepts, coarse-loamy, kaolinitic, isohyperthermic. Middle slope and lower slope profiles were classified as Fluventic Humudepts, fine-loamy, kaolinitic, isohyperthermic. Based on the National Soil Classification, middle slope and lower slope profiles were classified as Chromic Cambisol and upper slope profile as Humic Cambisol. Based on FAO Soil Classification, the upper slope was classified as Umbric Cambisol, while middle and lower slopes were classified as Dystric Cambisol.

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