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The Investigation of Ultic Horizon on Andisols Derived from the Eruption of Mount Tilu (Pleistocene, Basaltic) in West Java, Indonesia

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Abstract - Ultic is the soil characteristics in soil taxonomy when argillic or kandic horizon is found within the depth of 125 cm with the base saturation of less than 35 % on the overall of upper 50 cm. The purpose of this research is to investigate whether ultic horizon was found in the soil developing from the Pleistocene eruption of Mount Tilu (basaltic parent materials), in West Java, Indonesia. The method used was descriptive and comparative surveys of three profiles in the area around Mount Tilu, including the investigation of andic soil properties and the formation of argillic or kandic horizon. The result showed that the soils fulfilled the requirements of andic soil properties to be classified as Andisols. Soil never dried for ninety days cumulative (udic) to be classified as Udands. There were Fulvudands and Hapludands in this location. Accumulation of clays was more than 1.2% higher than the overlying horizon found at the depth of 90, 79, and 51 cm in those three profiles. Base saturation in upper 50 cm ranged from 1.07 to 6.86 cmol kg^{-1} or less than 35 %, making the soils were classified as Ultic Fulvudands and Ultic Hapludands. The high rainfall in the tropics and Pleistocene age led to the leaching of clays for a long period to form the argillic horizon. The influence of rain was stronger than the basaltic parent materials in forming Ultic Hapludands. Basaltic parent material was not strong enough to produce base saturation of more than 35 %.

Keywords: andic soil properties, argillic horizon, base saturation, soil moisture regime

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Introduction

Soil formation is influenced by five factors, such as parent material, climate, organism, topography, and time (Jenny, 1941). This statement was issued decades ago, however it is still very relevant nowadays. Soil derived from the ash of the eruption of volcanoes for example, is heavily influenced by the volcanic ash parent materials. When the soil characteristics meet the prerequisite of andic soil properties, it will be classified as Andisols (Soil Survey Staff, 2014).

The concept of Andisols itself had previously stated by The Third Division of Soils (1973), including the parent material of ash of volcanic eruption, dark colour of A horizon over the brown to yellowish B horizon, high content of vitric materials and allophane minerals, low bulk density and exchange capacity, and high P retention. Meanwhile, Andisols according to Smith (1978) were soil developed from ash, pumice, cinder, or other volcanoclastic materials, showing broad reflection when were analyzed with X-ray Diffractometer. The soil is dominated by volcanic glass, aluminum (Al), silicon (Si), and amorphous humus compound, and they had some diagnostic horizons.

Andisols concept covers two important aspects: volcanic ash parent material and non-crystalline minerals in the clay fraction (Nanzyo, 2002). Dark colour and high organic matter content, however have not been covered in this concept. Soil Survey Staff (2014) presupposed that the soil could be classified as Andisols if fulfilling the requirements of andic soil properties such as organic matter content must be 25 % or lower, bulk density must be 0.9 g cm^{-3} or lower, P retention must be 85 % or higher, and Al + ½ Fe (with acid ammonium oxalate) must be 2 % or higher.

Those five soil-forming-factors as stated by Jenny (1941) can be equal or one more prominent than the others. The formation of Andisols is hardly influenced by the parent material originating from the volcanic eruption. Climate factors, both temperature (as soil temperature regime) and precipitation (as soil moisture regime) were found as the differentiator in the suborder level (Soil Survey Staff, 2014). Other factors such as organism, topography, and time were found as the lower level in the soil classification. The type of parent material reflected in the value of base saturation and cation exchange capacity can also influence in the lower level. Basaltic parent material will develop the soil with higher alkaline cation content than the andesitic, showed as a higher base saturation value. Meanwhile. the climatic factors, like soil moisture and temperature regime, will determine the degree of weathering, soil reaction, and the presence or absence of the cations, organic material, iron, and clay.

The information of soil forming factors of Andisols at the lower and specific level of soil classification, especially in Indonesia, was not widely reported. This article aims to investigate the development of soil derived from the Pleistocene basaltic volcanic material of Mount Tilu in West Java Province, Indonesia, to the subgroup level. The data obtained will provide the pictures of the influence of soil formation namely type of parent material, climate, vegetation, relief, and time.

Methods

This research was located in the area of Mount Tilu, Pulosari Village, Pangalengan Sub-regency, Bandung Regency, West Java Province, Indonesia. The altitude is 1482 - 1484 m asl., in the coordinates of 107^0 32 '31.4 "E and 07^0 10' 49.7"S, about 90 km from Bandung City to the south. The vegetations are pine forest (*Pinus mercusii*), coffee plantation (*Caffea sp.*), tea plantation (*Camellia sinensis*), and grass *(Pennisetum sp.*). Soil sampling from three soil profiles (TL1, TL2, and TL3) was done on the eastern slopes of Mount Tilu (Figure 1) on a slope of 9 %, as descripted in Tables 1, 2, and 3. The parent material is Pleistocene basaltic tuff and breccia of Mount Tilu. The geological map (Figure 1) used is the Garut and Pameungpeuk Quadrangle (Alzwar *et al.,* 1992).

Profile description and soil sampling were done according to the guidelines of National Soil Survey Center/NSSC (2002), including the use of Soil Munsell Colour Charts in determining the soil colour. Soil analyses were carried out by following Reeuwijk (2002) for analyzing organic carbon, pH H_2O, pH KCl, basic cations, cation exchange capacity of sum of cations, and extractable acidity with $BaCl_2$, Fe, Al, and Si with acid ammonium oxalate and texture; Blakemore *et al.* (1987) for analyzing P retention; Blake and Hartge (1986) for analyzing bulk density; and Schmidt *et al.* 1999) for dispersing silt and clay by hydrometer ultrasound separation.

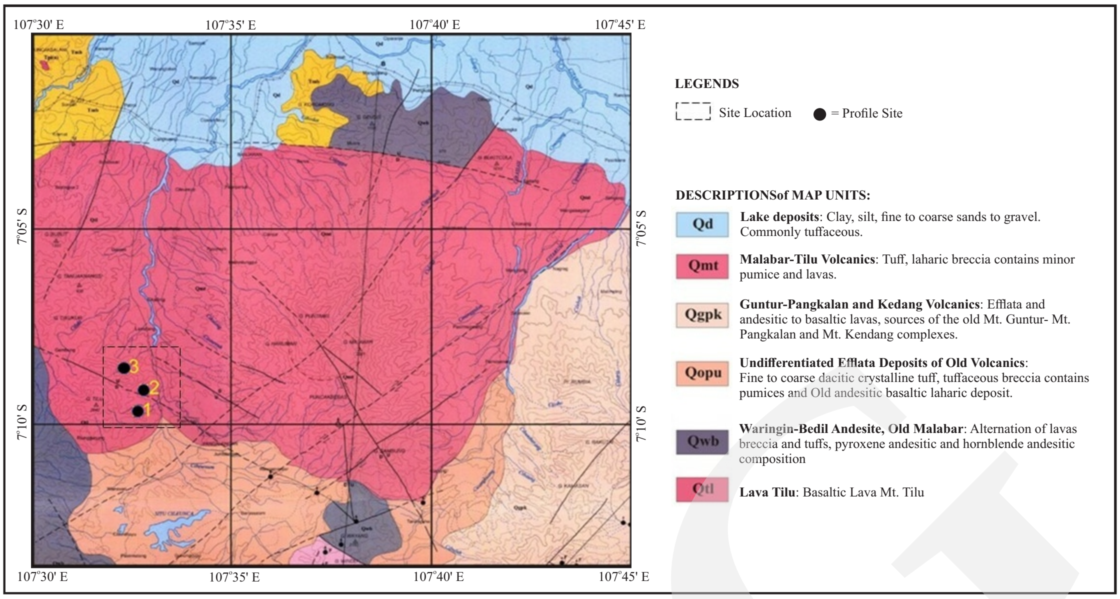

Figure 1. Geological map of Mount Tilu. Source : Systematic Geological Map of Garut and Pameungpeuk Quadrangle (Alzwar *et al*., 1992).

Mineralogical analyses were done quantitatively and qualitatively. Quantitative analyses were performed to silt and clay fractions to determine the noncrystalline minerals like allophane, imogolite, and ferrihydrite by extracting oxalic acid and pyrophosphate, based on Reeuwijk (2002). The percentages of allophane, imogolite, and ferrihydrite were calculated on the basis of Si, Al, and Fe extracted with oxalic acid and pyrophosphate using the equation proposed by Parfit dan Wilson (1985) which mentioned that the percentage of allophane could be calculated by multiplying 7.14 to the percentage of Si_o. The percentage of imogolite is equal to the percentage of the difference of Al_o to Al_p (Al_o-Al_p) multiplied by 1.7, and the percentage of ferrihydrite can be extracted from the percentage of Feo multiplied by 1.7

Minerals in silt and clay fraction were analyzed with XRD. The amorphous or non-crystalline minerals were firstly removed by oxalic acid. The suspensies of oriented samples were dried slowly on the glass specimen, and then were analyzed with XRD. The samples, if necessary, would be saturated with Mg^{+2}, saturated with Mg^{+2} and glycol, saturated with K^+, and heated at 350 and 550 ^{0}C.

Results and Discussions

Morphological Characteristics

Morphological characteristics were focused on insitu descriptions as shown in Tables 1, 2, and 3. The colour of the soil in the three profiles showed the similar pattern as in the upper layer, ranging from dark brown 10YR 3/3 to dark yellowish brown 10YR 3/4 and brown 10YR 4/3. The colour became lighter by the increasing depth as indicated by the increasing of the value and chroma till 5/6 to 6/8. At a certain depth (135, 130, and 109 cm in Tables 1, 2, and 3), there were a changing of trend colour where the colour becoming darker again, indicated by the lowering of value and chroma to 4/6 (Tables 1 and 2) to 4/6 (Table 3).

The soil colours of those three profiles were not as dark as often be portrayed to Andisols, indicated by the value and chroma which were not 2 or lower. However, Soil Survey Staff (1990 and 2014) clearly did not mention the dark colours as the prerequisite for Andisols. On the other hand, those three profiles showed the lithologic discontinuity pattern, characterized by the decreasing value and chroma at a certain depth, compared to the overlying horizon. Lithologic discontinui-

Table 1. Soil Profile Description of Eastern Slope of Mount Tilu

Depth (cm)	Horizon	Description
0-7	Ap1	Dark brown (10YR 3/3); silt loam; crumb, very fine, weak, very friable; few macro- and mesopores, abundant micropores; no large roots, few meso- and fine roots; pH 5; diffuse and wavy horizon boundary
7-18	Ap2	Dark yellowish brown (10YR 3/4); silt; crumbs, fine, medium, friable; few macro- and micropores, abundant micropores; no large and medium roots, many small roots; pH 5; diffuse and flat horizon boundary
18-31	Ap3	Dark yellowish brown (10YR 4/4); silt; crumbs, rather subtle, moderate, friable; few macro- and mesopores, abundant micropores; no large roots, few medium roots, no small roots; pH 5; diffuse and flat horizon boundary
31-57	Bw1	Dark yellowish brown (10YR 4/6); silt loam; subangular blocky, fine, weak, friable; few macro- and mesopores, abundant micropores; no large, medium and fine roots, pH 5; clear and flat horizon boundary
57-70	Bw2	Yellowish brown (10YR 5/8); silt loam; sub angular blocky, weak, friable; few macro- and mesopores, abundant micropores, no large, medium and small roots; pH 5; diffuse and wavy horizon boundary
70-79	Bt1	Yellowish brown (10YR 5/6); silt loam; angular blocky, somewhat soft, medium, firm; few macro- and mesopores, abundant micropores; no large, medium and fine roots, pH 5; clear and flat horizon boundary
79-90	Bt2	Brownish yellow (10YR 6/8); silty clay loam; angular blocky; weak, firm; few macro- and micropores, abundant micropores; few large, medium and small roots; pH 5; clear and flat horizon boundary
90-116	BC	Dark brown (7.5YR 5/8) and brownish yellow (10YR 6/8); silty clay loam; crumbs, moderate to fine, friable; few macro- and mesopores, abundant micro- pores; few large and medium roots, abundant fine roots, pH 5; clear and flat horizon boundary
116-135	CB	Yellowish brown (10YR 5/8); silty clay loam; crumbs, fine, friable; few macro- and mesopores, abundant micropores; few large roots, abundant medium and fine roots, pH 5; clear, flat horizon boundary
135-148	2 Ab	Dark Yellowish brown (10YR 4/6); silty clay loam; angular blocky, medium, firm; few macro- and mesopores, abundant micropores; few large, medium and fine roots; pH 5; clear and flat horizon boundary
148-162	2 Bw1	Dark yellowish brown (10YR 4/6); silt; angular blocky, medium, friable; few macro- and mesopores, abundant micropores; few large, medium and fine roots; pH 5; clear and flat horizon boundary
162-200	2 Bw2	Yellowish brown (10YR 5/6); silt; blocky angular, angular blocky, medium, friable; few macro- and mesopores, abundant micropores; few large, medium and fine roots; pH 5

Note: TL 1 Pulosari Village, Pangalengan Subregency, Bandung Regency, X = 1070 32' 34", Y = 070 10' 07", 9 % slope, well drained, rapid permeability, *Pinus mercusii*, *Pennisetum* sp., and *Camellia sinensis* vegetation, tuff and breccia lava parent material of Mount Tilu, 1492 m above sea level, Udic soil moisture regime, iso hyperthermic soil temperature regime.

ties are the meaningful and uncommon changes in various things in one soil profile, like colour or other physico-chemical parameters (Ahr *et al.*, 2016; Arifin *et al.,* 2019). It was called as an A buried horizon (2 Ab), positioned below the B, C, or BC horizons. This is the suggestion that the A buried horizon developed from another source of ash eruption, and developed from different periods of eruption (Tan, 1984).

Horizon sequences in those three profiles showed a similarity as: Ap-Bw-Bt-BC-CB-2AB-2BW. Ap horizon indicated that A horizon had been disturbed by man activities (Hartemink, 2020). In this case, cultivation and logging were done in such area, developed the Ap horizons to the depth of 31, 27, and 30 cm in TL 1, TL 2, and TL 3, respectively (Tables 1, 2, and 3). The B horizons were found in all profiles, indicated that the soils have been developed. The Bw horizons indicate a weak different colour and/or weak different structure with A overlying horizons (NSSC, 2002). The structure changed from crumb in A

Table 2. Soil Profile Description of Eastern Slope of Mount Tilu

Depth (cm)	Horizon	Description
0-7	Ap1	Dark brown (10YR 3/3); silt loam; crumb, very fine, weak, friable; few marcopores, abundant meso- and micropores; no large roots, abundant medium and fine roots; pH 5; clear and flat horizon boundary
7-12	Ap2	Brown (10YR 4/3); silt loam; crumb, very fine, weak, very friable; few marcopores, abundant meso- and micropores; no large roots, abundant medium and fine roots; pH 5; clear and flat horizon boundary
12-27	Ap 3	Dark yellowish brown (10YR 3/4); silt loam; crumb, very fine, weak, very friable; few macropores, abundant meso- and micropores; no large roots, abundant medium and fine roots; pH 5; clear and flat horizon boundary
27-37	Bw1	Dark yellowish brown (10YR 4/4); silt loam; crumb, very fine, weak, very friable; few macropores, abundant meso- and micropores; no large roots, abundant medium and fine roots; pH 5; clear and flat horizon boundary
37-46	Bw2	Dark yellowish brown (10YR 3/6); silt loam; subangular blocky, fine, medium, friable; few macropores, abundant meso- and micropores; few large roots, abundant medium and fine roots; pH 5; clear and flat horizon boundary
46-58	Bw3	Dark yellowish brown (10YR 4/4); silt loam; subangular blocky, fine, medium, friable; few macro- and mesopores, abundant micropores; few large roots, abundant medium and fine roots; pH 5; clear and flat horizon boundary
58-80	Bt1	Dark yellowish brown (10YR 4/6); silty clay loam; angular blocky, fine, medium, firm; few macro- and mesopores, abundant micropores; no large roots, few medium and fine roots; pH 5; clear and flat horizon boundary
80-99	Bt2	Yellowish brown (10YR 5/6); silty clay loam; angular blocky, fine, medium, firm; few macro- and mesopores, abundant micropores; no large roots, few medium and fine roots; pH 5; clear and flat horizon boundary
99-114	BC	Yellowish brown (10YR 5/8); silt loam; angular blocky, fine, medium, firm; few macro- and mesopores, abundant micropores no large roots, few medium and fine roots; pH 5; clear and flat horizon boundary
114-130	CB	Yellowish brown (10YR 5/6); silt loam, angular blocky, fine, medium, firm; few macro- and mesopores, abundant micropores; no large and medium roots, few fine roots; pH 5; clear and flat horizon boundary
130-156	2 Ab	Dark yellowish brown (10YR 4/6); silt, crumbs, rather subtle, moderate, friable; few macro- and mesopores, abundant micropores; no large, medium and fine roots; pH 5; clear and flat horizon boundary
156-200	2 Bw	Dark yellowish brown (10YR 4/4); silt, angular blocky, fine, medium, friable; few macro- and mesopores, abundant micropores: no large, medium and fine roots; pH 5

Note: TL 2, Pulosari Village, Pangalengan Subregency, Bandung Regency, X= 1070 32' 27", Y= 070 10' 28", 9 % slope, well drained, rapid permeability, *Pinus mercusii, Pennisetum* sp., *Coffea* sp., and *Camellia sinensis* vegetation, tuff and breccia lava parent material of Mount Tilu, 1,482 m above sea level, udic soil moisture regime, iso hyperthermic soil temperature regime.

horizon to subangular blocky in Bw horizon, and even no change at all in Bw 1 TL 2 and Bw 1 TL3. In this case, the colour changed subtle from 3/4 to 4/4 (TL2) and from 4/4 to 3/6 (TL 3). Bw horizon can be an information of lower degree of weathering as informed by Szymanski and Szkaradek (2018).

Contrast to a weak differentiation of Bw horizon, the underlying Bt horizon showed a clear distinction. The structure changed from crumb (Ap) to angular blocky (Bt). The colour also changed from the value and chroma of 4 or less to 8 or less. Bt horizon is the indication of the clay leaching, known as an argillic horizon (Makhrawie *et al.*, 2020). The thickness of the argillic horizon must be 15 cm or more, and clay content is 1.2 % higher or more compared to the overlying horizon as mentioned in Soil Survey Staff (2014). The leaching reflected in Bt horizons was found in every profile, even though at a different depth. However, they were found at the depth of less than 125 cm. Argillic horizons can be formed if the rainfall was high enough to support the clay leaching. This area has udic soil

Table 3. Soil Profile Description of Eastern Slope of Mount Tilu

Depth (cm)	Horizon	Description
0-11	Ap1	Dark brown (10YR 3/3); silt loam; crumb, very fine, weak, very friable; few macropores, abundant meso- and micropores; abundant large, medium and fine roots; pH 5; clear and flat horizon boundary
11-19	Ap2	Dark yellowish brown (10YR 3/4); silt loam; crumb, fine, weak, very friable; few macro- and mesopores, abundant micropores; abundant large roots, few medium and fine roots; pH 5; clear and flat horizon boundary
19-30	Ap 3	Dark yellowish brown (10YR 4/4); silt; crumb, fine, medium, weak, friable; few macro- and mesopores, abundant micropores; no large and medium roots, few fine roots; pH 5.5; clear and flat horizon boundary
30-51	Bw1	Dark yellowish brown (10YR 3/6); silt; crumb, fine, medium, weak, friable; few macro- and mesopores, abundant micropores; few large roots, abundant medium roots, few fine roots; pH 5.5; clear and flat horizon boundary
51-65	Bw2	Dark yellowish brown (10YR 4/6); silt loam; subangular blocky, fine, medium, friable; few macro- and mesopores, abundant micropores; no large and fine roots, few medium roots; pH 5; clear and flat horizon boundary
65-75	Bt	Yellowish brown (10YR 5/6); silty clay loam; angular blocky, fine, medium, friable; few macro- and mesopores, abundant micropores; few large and medium roots, no fine roots; pH 5; clear and flat horizon boundary
75-92	BC	Yellowish brown (10YR 5/8); silty clay loam; crumb, fine, medium, friable; abundant macro- and mesopores, few micropores; no large and fine roots, medium roots, no fine roots; pH 5; clear and flat horizon boundary
92-109	2 Ab1	Dark yellowish brown (10YR 4/4); silt; crumb, fine, medium, friable; abundant macro-, meso- and fine pores; no large and fine roots, few medium roots; pH 5; clear and flat horizon boundary
109-126	2 Ab2	Dark yellowish brown (10YR 4/6); silt; crumb, fine, medium, friable; abundant macro- and mesopores, few micropores; no large roots, few medium and fine roots; pH 6; clear and flat horizon boundary
126-158	2 Bw1	Yellowish brown (10YR 5/6); silt loam; angular blocky, fine, medium, firm; abundant macro- and mesopores, few micropores; no large and medium roots, few fine roots; pH 5; difuse and flat horizon boundary
158-173	2 Bw2	Yellowish brown (10YR 5/8); silt; angular blocky, fine, medium, firm; abundant macro- and mesopores, few micropores; no large, medium and fine roots; pH 5; difuse and flat horizon boundary
173-200	2 Bt	Brownish yellow (10YR 6/8); silt loam; subangular blocky, fine, medium, friable; few macro- and mesopores, abundant micropores; no large, medium and fine roots; pH 5

Note: TL 3, Pulosari Village, Pangalengan Subregency, Bandung Regency, X= 1070 32' 27", Y= 070 10' 58", 9 % slope, well drained, rapid permeability, *Pinus mercusii, Pennisetum* sp., *Coffea* sp., and *Camellia sinensis* vegetation, tuff and breccia lava parent material of Mount Tilu, 1,472 m above sea level, udic soil moisture regime, iso hyperthermic soil temperature regime.

moisture regime with B1 climate type according to Oldeman and Frere (1982) which supported the clay leaching. According to Khormali *et al.* (2012) Bt horizon were associated more with subhumid and humid than with drier climate. The Pleistocene epoch sustained that clay leaching had happened for a long period. Morphologically, Bt horizons were reflected by the changes of texture from silty loam in the Bw overlying horizon to a silty clay loam in the underlying Bt horizon (Tables 1, 2, and 3). However, the existence of the clay leaching that fulfilled the requirements of an argillic horizon have to be proved by the textural class of laboratory analyses.

Buried horizons were found at the depth of 92 cm to 135 cm, showing that the soil above them had reached a depth that close to 1 m and even more with a complete developed horizon (James *et al.,* 2015). The depth and complete horizons in every profile were attributed to well-developed soil that related to the age of their development since the Pleistocene epoch. In soil forming factors, time is a decisive one that determines the development of soil processes, the formation of epipedons, subsurface, and any other diagnostic horizons (Ubalde *et al.*, 2011).

In the early stage of the soil formation, it only had A and C horizons (Hillel, 2015). Continuing time followed by the continuing of soil processes create the additions, reductions, transportations, and transformations of the soil process and soil reactions. The formation of Ap, Bw, and Bt above the BC and CB horizons and further above the buried horizons were the consequences of those soil forming process. Parent rock from Pleistocene epoch ranging from 1.8 million and lasted until about 11,700 years ago informed the long period of soil formation, and long period of addition, reduction, transportation, and transformation of soil materials and soil processes.

Investigation of Soil Order, Suborder, and Great Group Level

The investigation of Ultic Andisols started with the inquiry to classify the soil order level. Referring to Soil Survey Staff (2014), Ultic Andisols firstly had to fulfill the requirements of andic soil properties to the depth of 60 cm, to be classified as Andisols. The organic carbon content must be 25 % or less, bulk density must be 0.9 g cm^{-3} or less, P retention must be 85 % or higher, and the content of aluminum plus half of iron analyzed by acid ammonium oxalate ($Al_o + ½ Fe_o$) must be 2 % or higher. Table 4 shows all criteria are fulfilled for the whole profiles at those three locations, therefore the soils can be classified as Andisols. Arifin and Devnita (2008), Devnita *et al*. (2010), and Devnita (2012) stated that soils which fulfilled these criteria were also found in several other locations around the volcanic areas in West Java, like around Mount Tangkuban Parahu and Mount Patuha.

The whole soil profiles had been noticed in fulfilling the criteria of Andisols. The eruption of Mount Tilu made the basaltic tuff and breccia lava as the parent rock (Alzwar *et al.*, 1976) altered as the parent materials of volcanic soils. The duration of weathering since Pleistocene age, together with the high soil temperature regime of isohyperthermic and high humidity of udic soil moisture optimized the soil processed to be classified as Andisols.

Classification on suborder level of Andisols proposed by Soil Survey Staff (2014) is based on the soil temperature regime and soil moisture regime, namely Aquand, Geland, Cryand, Torrand, Xerand, Vitrand, Ustand, and Udand. Soils on the area of Mount Tilu were never dry cumulatively for ninety days, and fixed to be classified as Udands.

Udands in this area do not meet some requirements at the great group level as having no placic horizon, not cemented, no melanic epipedon, no contact densic, lithic, or paralithic, therefore cannot be classified as Placudands, Durudands, Melanudands, and Hydrudands. Further investigation found that profile TL 1 and TL 3 fulfilled the requirements of Fulvudands since they had layers that meets the depth, thickness, and organic-carbon requirements for a melanic epipedon. However, in this case, the moist colour requirements did not fufill the melanic epipedon since the value and chroma was not less than 2.5 and 2 respectively, but they fulfilled the requirements of the percentage of organic carbon content (4 % or more) in all layers as can be seen in Table 5. In this case, according to Soil Survey Staffs (2014) this Udands was therefore classified as Fulvudands instead of Melanudands.

The interesting difference was found in profile TL 2, where the organic carbon content to the depth of 40 cm was not 4 or more in all layers. This profile, therefore, cannot be classified as Fulvudands, but as Hapludands.

Investigation of Ultic Horizon in Subgroup Level

Investigations for soil classification at the subgroup level referred firstly to the profile description, showing the presence of Bt horizons in all profiles. Bt horizon is the horizon of clay accumulation as the prerequisite of argillic horizon in which soils can be classified to have an ultic horizon. To be classified as argillic, the depth of Bt horizons must be at least 7.5 cm thick (Soil Survey Staffs, 2014). Data on Table 5 informs

Table 4. Analysis Results for Investigation of Andic Soil Properties of Profiles from Mount Tilu

Profile	Hor	Depth cm	Bulk Density $g\ cm^{-3}$	Organic Carbon %	Al+1/2Fe %	P-retention %	Σ of Basic Cations cmol kg^{-1}	CEC Sum of Cations cmol kg^{-1}	Base Saturation (sum of cations) %
TL 1	Ap 1	0 - 7	0.62	9.48	5.3	96.73	1.57	52.1	3.01
	Ap 2	7 - 18	0.60	9.83	3.4	96.38	1.77	76.7	2.31
	Ap 3	18 - 31	0.64	6.71	3.5	96.45	4.26	62.1	6.86
	Bw 1	31 - 57	0.63	6.20	3.4	96.57	3.89	60.3	6.45
	Bw 2	57 - 70	0.69	5.93	3.5	96.52	3.05	99.2	3.07
	Bt 1	70 - 79	0.66	5.58	3.9	96.44	3.67	72.7	5.05
	Bt 2	79 - 90	0.65	4.72	5.4	96.50	3.85	72.8	5.29
	BC 1	90 - 116	0.72	3.55	6.7	96.48	4.93	77.2	6.39
	CB	116 - 135	0.80	6.01	5.8	96.47	2.19	83.2	2.63
	2 AB 1	135 - 148	0.74	4.21	5.7	96.42	3.75	72.3	5.19
	2 Bw 1	148 - 162	0.76	2.85	2.3	96.37	3.89	61.1	6.37
	2 Bw 2	162 - 200	0.64	3.32	2.6	96.33	3.05	71.8	4.25
TL 2	Ap 1	0 - 7	0.67	7.34	4.7	98.80	2.38	65.9	3.61
	Ap 2	7 - 12	0.75	6.53	3.9	97.40	1.06	72.2	1.47
	AB	27 - 12	0.62	3.62	4.8	99.30	1.75	81.2	2.16
	Bw 1	27 - 37	0.71	3.18	5.2	99.40	1.06	99.1	1.07
	Bw 2	37 - 46	0.65	2.83	4.5	99.30	1.02	81.6	1.25
	Bw 3	46 - 58	0.64	2.10	4.4	98.90	2.27	96.3	2.36
	Bt 1	58 - 80	0.66	1.71	5.1	99.10	1.42	94.1	1.51
	Bt 2	80 - 99	0.72	1.47	5.7	99.20	1.54	74.7	2.06
	BC	99 - 114	0.65	1.06	6.4	99.90	1.51	68.1	2.22
	2 AB 1	114 - 130	0.72	1.00	5.7	99.40	1.43	76.2	1.88
	2 AB 2	130 - 156	0.71	0.84	5.5	99.70	1.42	85.2	1.67
	2 Bw 1	156 - 200	0.67	0.61	2.6	98.90	1.54	88.9	1.73
TL 3	Ap 1	0 - 11	0.78	10.14	4.5	96.31	1.3	71.3	1.82
	Ap 2	11 - 19	0.66	8.66	4.4	96.52	2.67	84.7	3.15
	AB	19 - 30	0.59	9.98	5.1	96.19	1.65	78.9	2.09
	Bw 1	30 - 51	0.64	8.66	5.7	96.29	1.35	52.3	2.58
	Bw 2	51 - 65	0.56	7.33	6.4	96.44	1.47	64.6	2.28
	Bt	65 - 75	0.74	5.27	5.7	96.44	1.52	74.5	2.04
	BC	75 - 92	0.71	7.45	5.5	96.60	1.18	69.8	1.69
	2 AB 1	92 - 109	0.73	4.76	2.6	96.55	1.85	77.1	2.40
	2 AB 2	109 - 126	0.77	6.05	2.6	96.45	1.65	84.2	1.96
	2 Bw 1	126 - 158	0.83	5.97	2.6	96.52	1.35	91.7	1.47
	2 Bw 2	158 - 173	0.74	6.20	5.7	96.51	3.67	89.3	4.11
	2 Bt	173 - 200	0.76	4.52	5.1	96.27	3.85	85.1	4.52

that Profile TL 1 was 20 cm thick Bt horizon (70–90 cm), profile TL 2 was 41cm thick (58 - 99cm), and pofile TL 3 was 10 cm thick (65 - 75 cm). The depth of Bt horizons of those three profiles fulfilled the prerequisite depth of argillic.

The existence of Bt horizons in the field was indicated by the textural changes from silt loam to silty clay loam (Ibrahim, 2011). This changing was re-examined through the textural analysis in the laboratory to have the data of the total clay

Table 5. Sand, Silt, Clay, and Fine Clay Contents, Ratio Fine Clay/Total Clay of Mount Tilu

			Texture content (%)					Ratio (%		
Profile	**Horizon**	**Depth (cm)**	**Sand**	**Silt**	**Clay**	**Average Clay in Eluvial and Illuvial**	**Fine clay**	**Fine clay/ Total clay**	**Average Ratio Eluvial and Illuvial**	**Ratio Illuvial/ Eluvial**
TL1	Ap1	0-7	31	53	16	15.2	3	19	21.40	1.64
	Ap2	7-18	10	81	**9**		2	22		
	Ap3	18-31	7	81	12		3	25		
	Bw1	31-57	15	65	20		4	20		
	Bw2	57-70	11	70	19		4	21		
	Bt1	70-79	23	50	27	30	10	37	35.19	
	Bt2	79-90	15	52	33		11	33		
	BC	90-116	20	42	38		5	13		
	CB	116-135	25	41	34		5	15		
	2 Ab	135-148	28	39	33		5	15		
	2 Bw1	148-162	8	80	12		4	33		
	2 Bw2	162-200	9	79	12		4	33		
TL 2	Ap1	0-7	19	61	20	19.3	2	10	21.22	1.39
	Ap2	7-12	24	55	21		2	10		
	Ab	12-27	17	63	20		1	5		
	Bw1	27-37	26	55	19		2	11		
	Bw2	37-46	28	55	17		13	76		
	Bw3	46-58	30	51	19		3	16		
	Bt1	58-80	22	42	36	36.6	6	38	29.56	
	Bt2	80-99	23	42	37		8	22		
	BC	99-114	10	54	27		4	15		
	CB	114-130	11	60	29		3	10		
	2 Ab	130-156	7	82	11		3	27		
	2 Bw	156-200	8	81	11		3	27		
TL 3	Ap1	0-11	18	60	22	15.6	2	9	21.00	1.33
	Ap2	11-19	19	60	21		2	10		
	Ab	19-30	20	79	11		4	36		
	Bw1	30-51	9	79	12		3	25		
	Bw2	51-65	7	81	12		3	25		
	Bt	65-75	13	55	32	32	9	28	28	
	BC	75-92	15	55	30		4	13		
	2 Ab1	92-109	16	83	11		3	27		
	2 Ab2	109-126	17	82	11		4	36		
	2 Bw1	126-158	19	81	10		4	40		
	2 Bw2	158-173	19	81	10		4	40		
	2 Bt	173-200	15	55	30		4	13		

and fine clay. The ratio of fine clay to the total clay in the illuvial horizon must be greater than 1.2 times or more than the ratio in the eluvial (Soil Survey Staff, 2014). Data in Table 5 informs that the ratios were 1.64 (TL 1), 1.39 (TL 2) and 1.33 (TL 3), which indicated that another prerequisite of argillic was also fulfilled.

The increasing of clay content from eluvial to illuvial as mentioned by Soil Survey Staff (2014) must be 30 cm in the vertical distance, where if in any part had less than 15 % out of the total clay in eluvial horizon (TL 1 and TL 3), and the illuvial must contain at least 3 % more than eluvial. In another case in any part, it had 15 to 40 % of the total clay (TL 2), and the illuvial must contain 1.2 times more than eluvial. The average total clay in eluvial horizon in TL 1 and TL 3 was 15.2 and 15.6 % respectively, and the total clay in illuvial horizon was 30 and 32 %. The eluvial horizon in TL 2 had 19.2 % clay, and illuvial horizon had 36.6 % clay. The clay content in eluvial and illuvial in those three profiles fulfilled the prerequisite of argillic horizon.

The investigation of ultic horizon on Andisols derived from the eruption of Mount Tilu (Pleistocene, Basaltic) in West Java, Indonesia, had been proved through these three profiles, due to the ultic horizon requirements that had been fulfilled. The depth of Bt horion is not less than 7.5 cm, the ratio of fine clay to total clay in the illuvial against eluvial horizon is greater than 1.2 times, the increasing of clay content from eluvial to illuvial (if less than 15 %) must be at least 3 % more; if 15−40 % must be 1.2 % more. The clay iluviation that constracted the Bt and argillic horizon was the major pedogenic process. A large amount of rainfall accelerated the clay translocation from the eluvial to illuvial horizon.

The existence of the argillic horizon must then be followed by basic saturation data (number of cations) to determine whether it was Ultic Hapludands or Alfic Hapludands. The results of texture analysis (Table 5) and base saturation based sum of cations (Table 4) show that the requirements had been met.

Argillic horizon clay was found by an increase of more than 1.2 % compared to the overlying horizon of the depths of 90, 79, and 51 cm on all three profiles. Base saturation in the top 50 cm ranged from 1.07 to 6.86 % or less than 35 %, which led to classification on a subgroup level as Ultic Fulvudands and Ultic Hapludands. The high rainfall in the tropics and Pleistocene age (11.5000 up to 1.8 million years ago) in the region led to the leaching of clay for a long period that allowed the formation of argillic horizon at this Andisols. The rainfall also had a greater influence on the formation of Ultic Hapludands compared to the basaltic parent materials. Basaltic parent material in this case was not strong enough to produce more than 35 % of base saturation to build Alfic Hapludands. Ultic Hapludands in this site were formed as ash parent materials of Mount Tilu evolved since the Pleistocene epoch in a high rainfall area that is never dry cumulatively for ninety days in a year.

Investigation on Clay Mineral Content

Investigation on clay minerals content were done by XRD with some treatments like normal treatment (without pretreatments), pretreatments with oxalate, saturation with Mg, K plus glycol and K, and heated at 350 ^{0}C and 550 ^{0}C. The results can be seen in Figures 2, 3, 4, 5, and 6.

The clay mineral content also covered quartz mineral. Quartz is usually found in sand fractions,

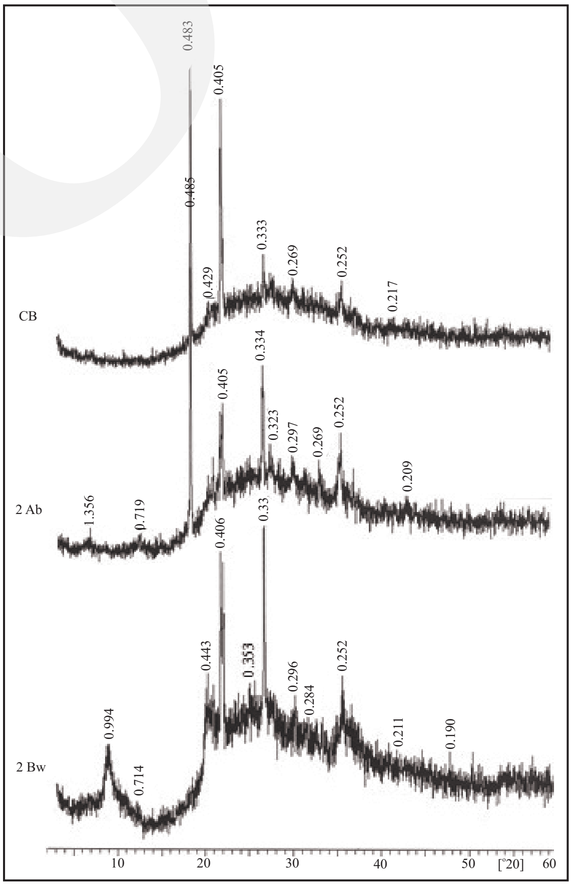

Figure 2. Increasing quartz intensity on the three lowest horizons of the TL 2.

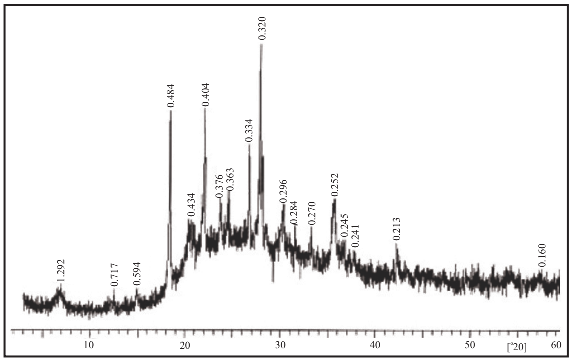

Figure 3. Halloysite in Ap horizon of TL 1.

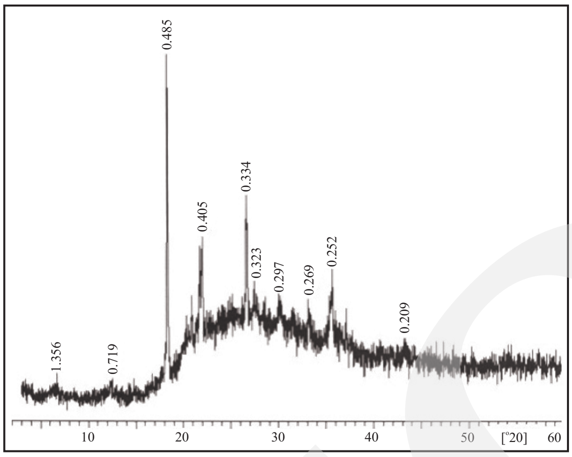

Figure 4. The 1:1 and 2:1 minerals in Bw horizons of TL 3.

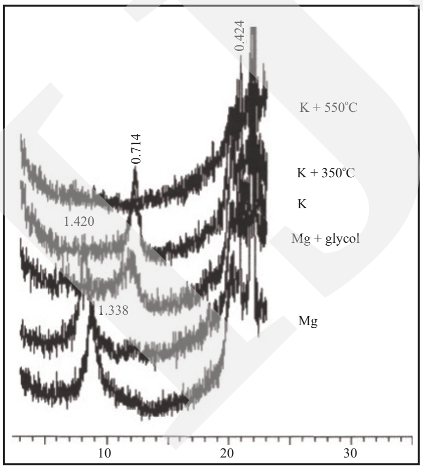

Figure 5. Reflection of 1:1 and 2:1 minerals after treatment with oxalate, saturation with Mg, Mg + glycol and K and heating at 350 ^{0}C and 550 ^{0}C of profile TL 2.

but it is also present on a smaller amount in silt and clay fraction. In XRD, quartz is identified by sharp reflections at 0.334 nm and 0.426 nm. Those reflections were found in CB, 2 AB, and

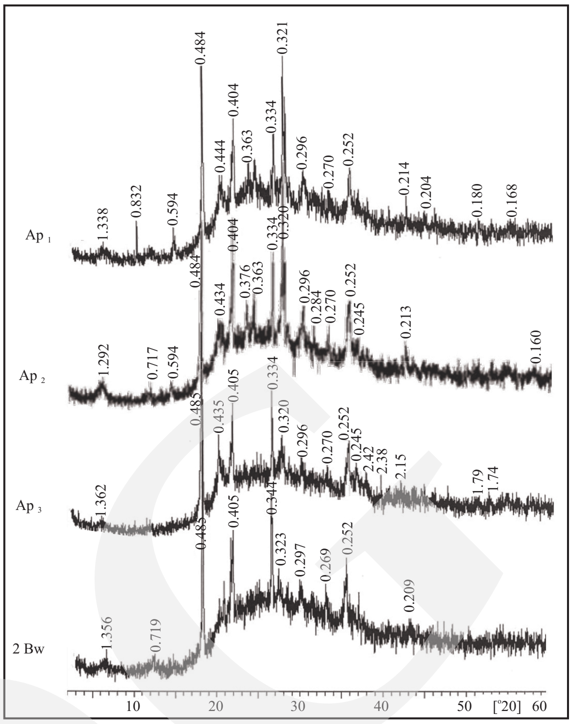

Figure 6. Mineral 2:1 and 1:1 at upper horizon through lower horizon in TL profile.

2 Bw horizons of TL 2 as can be seen in Figure 2. Referring to the intensity of the reflections, it showed a considerable increase of quartz at the lowest horizons of 2 Ab and 2 Bw compared to the overlying horizon of CB (Figure 2). It indicated that the buried horizons of 2 AB and 2 Bw had been weathered in advance and left the resistant weatherable mineral like quartz. This corresponded to the age of the old parent material (Pleistocene) that allowed the advanced weathering.

Halloysite was found as shown by widened reflections with peaks of 1.02, 0.720, 0.443, and 0.357 nm. Halloysite was found in several horizons, especially Ap horizon (Figure 3). Halloysite is a common mineral in the soils developed from volcanic ash, and usually present in environment of Si rich (Parfit and Wilson, 1985).

The reflections of 1.428, 1.377, 1.247, 1.00, and 0.715 nm, although not sharp and symmetrical on some horizons especially in horizon B, indicated the presence of 2:1 and 1:1 crystalline minerals although the numbers are small (Figure 4). The minerals were probably smectite (1.42, 1.38, 1.00 nm), halloysite, and kaolinite (0.714 nm). The presence of crystalline minerals in the B horizon shows that the short-ranged-ordered minerals (noncrystalline minerals) have been weathered to crystalline minerals as the time goes by since Pleistocene epoch.

Oxalate treated exhibit fewer but relatively sharper and symmetrical peak reflections primarily for crystallobalite, quartz, and gibbsite minerals. This treatment caused the peak of 1:1 and 2:1 sharper, due to the dispersion of clay from sand and silt fraction as can be seen in Figure 5.

The 1:1minerals were likely halloysite with the reflections at 1.04, 0.714, 0.441 nm. The reflection of 1.04 shifted to 0.714 after being heated at 35 ^{0}C and lost after being heated at 550 ^{0}C. The presence of halloysite was the result of dry period and a leaching. Climate data informed that although the total rainfall was high and classified as C1 referred to Schmidt and Fergusson (1951), there was dry season every year. The period of drought produces a rich environment of Si which allows the formation of halloysite (Churchman and Lowe, 2012).

Torn and Masiello (2002) stated that the begining of early 150,000 years of soil development, the volcanic ash material weathered into a less stable noncrystalline minerals, and then alterred into 2:1 and 1:1 crystalline minerals. Crystalline minerals were found on several horizons, as seen through the analysis with XRD. The 100,000 year span before nowadays (Pleistocene epoch) not only produces noncrystalline minerals, but also 2:1 and 1:1 crystalline minerals (Figure 6).

With the passage of time, the amount of noncrystalline minerals decreased to form crystalline minerals (Mikutta *et al*., 2002). Advanced pedogenesis processes drive the noncrystalline minerals to develop into crystalline minerals such as halloysite and gibbsite. Arifin (1994) showed that 1:1 crystalline minerals (kaolinite and halloysite) and gibbsite were found in Andisol in West Java, as the result of the soil pedogenesis process in that area. Supriyo *et al*. (1992) found smectite, halloysite, and gibbsite on some of Andisol in Java. Fiantis *et al.* (2000) found halloysite and gibbsite on Andisols in West Sumatra. Meanwhile in this study, the noncrystalline and crystalline minerals like smectite, illite, and halloysite were found on several horizons. This indicates that in tropical area with high rainfall conditions, the non-crystalline minerals alter into 2:1 and 1:1 crystalline minerals and hydroxides (gibbsite) have occurred with a time span faster than 150,000 years.

Conclusion

Ultic horizons were found in Andisols derived from the eruption of Mount Tilu, indicated by the presence of Bt horizons in the whole three profiles marked by the accumulation of clay 1.2 times higher or more in B horizon than the overlying horizon (known as argillic). It was completed by the value of base saturation that is not more than 35 %. The high rainfall in the tropics and Pleistocene age led to clay leaching, allowing the formation of argillic horizon with low base saturation resulted in Ultic Fulvudands and Ultic Hapludands.

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