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The Genesis and Classification of Soil on Serpentinite Bedrocks in The Toposequence of Bohusimale Mountain in Indonesia

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ABSTRACT
The topographical diversity of Bohusimale Mountain with its serpentinite bedrocks under the influence of tropical climate accounts for the differences of the process of soil formation and the characteristics of the formed soils. A research was conducted to study the genesis and classification of the soils on the serpentinite bedrocks. Observation was conducted on the summit, backslope, and footslope of the mountain. The physical, chemical, and mineral properties of the soil and rock samples were analyzed in the laboratory. Result of the research showed that the specific processes of the formation of the soils on the serpentinite bedrocks were desilication and ferrallization. The formed soil contained clay minerals dominated by goethite and magnetite, Fe_d (13.91-22.28%), Fe_t (17.80-25.81%) and a high ratio of Fe_d/Fe_t (0.75-0.91). The soils that had the highest level of development were the soils on the footslope, then on the summit, and on the backslope. The soils that were formed on the serpentinite bedrocks on the summit and the backslope were classified as Rhodic Kanhaplustalfs, whereas the soil on the footslope was classified as Petroferric Haplustox.

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INTRODUCTION

A study of soil genesis can help to reveal and understand the existence of the characteristics of the formed soil, to categorize soils according to similarity of properties and functions, and to determine the appropriate use and management of soils (Buol *et al*., 2003). In this connection, a study of the genesis of soils on Bohusimale Mountain is greatly needed, considering that the location has been granted a nickel concession (BPS, 2012). Right understanding of soil characteristics in the location is very useful particularly for the reclamation of lands postmining (Chodak and Niklińska, 2010).

The soils that formed on the mountain originated from serpentinite bedrocks (Kadarusman *et al*., 2004; Simandjuntak *et al*., 1994a & 1994b). Serpentinite rocks are hypothermal alterations at low temperatures (200-500°C) from ultramafic rocks, including rocks rich in magnesium (Lee *et al*., 2001; Azer and Khalil, 2005). Azer and Khalil state that serpentinite rocks are dominated by minerals of the serpentine group especially chrysotile [$Mg_3Si_2O_4(OH)_4$], antigorite [Mg_{48} $Si_{34}O_{85}(OH)_{62}$], and lizardite [$Mg_3Si_2O_4(OH)_4$] and in small quantity magnetite minerals (F_3O_4), amphibole, pyroxene and talc [$Mg_3Si_4O_{10}(OH)_2$], and also (Lee *et al*., 2004) there are tremolite minerals [Ca_2Mg_5 (Si_8O_{22})OH_2]. According to the results of research by Tufaila *et al*. (2011), the serpentinite rocks on Tolinku Mountain (Indonesia) are composed of serpentine minerals (90%), olivine (2%), pyroxene (3%) and chromite and opaque (5%)

The characteristics of the formed soil are determined not only by the bedrocks but also by other factors such as topographical diversity (toposequence) (Buol *et al*., 2003). Bonifacio *et al*. (1997) reports that the soils that are formed from the serpentinite bedrocks on the Alps and Apennines in the north of Italy are greatly influenced by topographical diversity; the soils that are formed on the summit, backslope, and footslope have different soil characteristics. Darmody *et al*. (2005) states that toposequence causes differences in soil drainage and soil characteristics.

Up until now, there have been little research on the influence of toposequence on the process of soil formation on the serpentinite bedrocks in tropical areas such as Indonesia. Therefore, this research aims to

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investigate the genesis and classification of soils that were formed on the serpentinite bedrocks in the toposequence of Bohusimale Mountain in Indonesia.

MATERIALS AND METHODS

Observation of soil with serpentinite bedrocks was conducted in three topographical sequences of Bohusimale Mountain in North Konawe Regency (Indonesia), namely on the summit (profile 1), situated at a height of 317 m above sea level with the slope 0-8%, on the backslope (profile 2) situated at a height of 145 m above sea level with the slope 25-45%, and on the footslope (profile 3), situated at a height of 37 m above sea level with the slope 0-8%. In each topographical sequence a soil profile was made and described, from each horizon three soil samples were taken (two samples of undisturbed soil and 1-2 kg of disturbed soil) for analysis of the physical, chemical, and mineral properties in the laboratory. About 1-2 kg of serpentinite rock sample was taken for analysis. The method of soil observation in the field refers to the Soil Survey Manual (Soil Survey Division Staff, 1993); Instructions on Soil Profile Description (FAO, 1990), and Field Handbook on Soil Description and Sampling (Schoeneberger *et al*., 2002).

Analysis of soil samples in the laboratory covered the distribution of soil fractions (pipette), BD (bulk density) and PD (particle density) (gravimetry), permeability (constant head permeameter), pH H_2O and KC1 (glass electrode), electric conductivity (conductivitymeter), C-organic (Walkley-Black), N total (Kjeldahl), P and K total (HC1 25%), available P (Bray or Olsen); exchangeable cation (K_e, Ca_e, Mg_e, and Na_e) (NH_4OAc-pH 7 extraction); Al_e and H_e (1N KC1 extraction), CEC (cation exchange capacity) (NH_4OAc-pH 7), and BS (base saturation) (NH_4OAc-pH 7) adopting the method described in Soil Survey Field and Laboratory Methods Manual (Soil Survey Staff, 2009); Fe, A1, and free Si (Dithionite-Citrate); Fe, A1, and Si amorph (amonium oxalate extraction); and Fe, A1, and Si complex organic (Sodium Pyrophosphat) adopting the method described in Procedure for Soil Analysis (ISRIC, 1993). For analysis of sand mineral a polarization microscope was used with line counting method, and for analysis of clay fractions x-ray difractometer (XRD) was used with saturation method Mg^{2+}, Mg^{2+} + glycerol, K^+, and K^+ + heating up to 550°C (Moore and Reynolds, 1989). Redness rating used the formula (Torrent *et al*., 1983): RR = (10–H).C/V, if 10YR then H = 10 and if 10R then H = 0, C is chroma and V is value. Analysis of rock samples includes pH abrasion (glass electrode), PD (particle density) (gravimetry); oxide Ca, Mg, Mn, P, K, Na, Fe, Al, and Si total (HNO_3 + HF extraction) (Kon *et al*., 2011), and for analysis of rock minerals polarisation microscope was used. Soil classification refers is to Soil Taxonomy (Soil Survey Staff, 2010).

RESULTS AND DISCUSSION

Characteristics of Serpentinite Rocks:

The serpentinite bedrock on Bohusimale Mountain is composed of 55-85% serpentinite minerals of the lizardite type (30-45%) and antigorite (25-40%), olivine (2-28%), orthopyroxene of the enstatite type (2-10%), brucite (<4%), chromite and opaque (<5%). This rock has pH abrasion of 8.21-8.75 and PD (particle density) of 2.35-2.45 with contents of SiO_2 31.40-34.49%, Al_2O_3 0.76-1.31%, Fe_2O_3 8.27-8.84%, MnO 0.11-0.15%, MgO 34.76-43.08%, CaO 0.27-0.68%, Na_2O 0.17% and K_2O 0.01%. The dominant serpentinite minerals on the serpentinite rock belong to the minerals that easily undergo weathering (Hršak *et al*., 2008; Lee *et al*., 2001; Lee *et al*., 2003; Farahat, 2008; Bashir *et al*., 2009). The dominance of minerals that easily weather and pH abrasion as well as a high MgO content, under the effect of heavy rainfall, leads to intensive weathering of rocks and produces soils that undergo further development (Certini and Scalenghe, 2006; Schaetzl and Anderson, 2005). The research site has a heavy annual rainfall, i.e 2,000 mm $year^{-1}$(BPS, 2012; Tufaila *et al*., 2011).

Soil Properties:

Soil Physical Properties:

Table 1 shows that the soil on the backslope (profile P2) and the footslope (profile P3) have a higher clay content than that on the summit (profile P1) of Bohusimale Mountain. It is presumed that the soils on profiles P2 and P3, besides the clay that originates from the intensive weathering process in the soil body, also receive additional clay that is translocated from a steeper topography. The ratios of f.C/c.C on each profile shows the amount of clay that is translocated from the steeper topography and shows the intensiveness of clay translocation in the soil body. The BD (bulk density), the quantity of pores, and varying permeability on each profile are probably affected by the difference in distribution or configuration of soil subfractions and by the organic material content on each profile. The particle density of soil on profile P2 that is lower than those on the other profiles is presumably caused by the high declivity of the slope, which reduces the intensity of the weathering process of the bedrock. The soil on profile P2 has a lower RR due to the low free iron content (Fe_d) and total iron (Fe_t) (Table 3). The soil on the backslope (P2) with higher slope reduces the intensity of weathering and soil development.

Soil Chemical Properties:

The soil that formed on the serpentinite bedrock in the whole topographical sequence generally has a low level of fertility. The soil on the footslope (P3) tends to have a lower level of chemical properties (Table 2) and has higher contents and accumulation of Fe and A1 and a lower Si content or a higher Si leaching than those of the other profiles (Table 3). This is because the soil on the footslope makes it possible for water to infiltrate in greater amount, there is cationic leaching of high mobility (base cation) along with water percolating through the soil body more intensively and there is cationic accumulation of low mobility such as more Fe and A1 in the soil body.

The $A1_e$ and H_e contents of all the horizons is extremely low. Intensive weathering and soil development result in the formation of more A1 of free oxide than in the exchangeable form of A1. The electric conductivity of all the horizons is very low or shows very low level of salinity in the soil as a result of cationic and anionic leaching with high mobility (such as Na and C1) outside the soil body.

Table 3 shows that all the soils from the summit to the footslope have Fe content dominated by Fe in the form of free oxide (Fe_d), i.e. 13.91-22.28% and a high ratio of Fe_d/Fe_t, i.e. 0.80-0.95 or 80-91% of total Fe in the form of Fe_d. The very high value of Fe_d/Fe_t ratio shows the intensiveness of soil weathering (Bonifacio, 1997; Rasmussen, 2007; Quantin, 2002). The total Fe and A1 contents of the soil are higher than those of its bedrock, whereas the total Si of the soil is lower than that of its bedrock. This shows that on the soil that formed on the serpentinite bedrock in Bohusimale Mountain there occurs an accumulation of Fe and A1, or the soil undergoes a ferrallization process, whereas Si tends to be leached outside the soil body or the soil undergoes a desilication process (Buol *et al*., 2003).

Table 1: The physical properties of soils formed on the serpentinite bedrock in profiles P1, P2, and P3

Horizon/depth (cm)	Distribution of soil subfraction (%)										Distribution of soil fractions (%)			Class of Texture	Class of particle size	f.C/c.C	BD	PD	Total of pores (%)	RR
	vc.Sa	c.Sa	m.Sa	f.Sa	vf.Sa	c.Si	m.Si	f.Si	c.C	f.C										
	1-2	0.5-1	0.2-0.5	0.1-0.2	0.05-0.1	20-50	5-20	2-5	0.2-2	<0.2										
	mm					µm					Sa	Si	C				g.cm^{-3}			
Profile 1 (P1)																				
A1 (0-20/27)	0.0	0.7	1.5	2.6	2.4	37.7	26.1	6.5	13.3	9.2	7.2	70.3	22.5	SiL	fSi	0.69	1.08	2.56	57.74	10.00
A2 (20/27-37/64)	0.1	0.8	2.9	4.2	3.0	24.3	32.1	12.8	13.0	6.8	11.0	69.2	19.8	SiL	fSi	0.52	1.04	1.67	37.79	10.00
Bt (37/64-96/140)	0.1	0.9	2.6	5.7	4.6	16.2	14.6	8.7	10.7	35.9	13.9	39.5	46.6	C	fC	3.36	1.35	2.22	39.34	13.33
BC (96/140-200)	0.1	1.3	2.7	5.5	4.4	11.9	14.7	8.9	12.9	37.6	14.0	35.5	50.5	C	fC	2.91	1.46	2.30	36.27	10.00
Proportional mean P1	0.1	1.0	2.6	5.1	4.0	18.1	18.4	9.1	12.2	29.5	12.8	45.5	41.7	SiC	fC	2.48	1.32	2.22	40.03	11.12
Profile 2 (P2)																				
A1(0-16/38)	0.1	1.3	1.2	2.2	2.6	2.6	23.3	4.5	27.7	34.5	7.4	30.4	62.2	C	vfC	1.25	1.33	2.58	48.67	10.00
A2(16/38-40/46)	0.1	1.7	1.9	2.7	2.6	16.6	12.5	15.1	15.2	31.6	9.0	44.2	46.8	SiC	fC	2.08	0.97	2.14	54.87	10.00
A3(40/46-65/67)	0.1	0.7	3.0	6.0	3.8	17.2	15.1	22.4	20.4	11.3	13.6	54.7	31.7	SiCL	fSi	0.55	1.04	1.75	40.45	10.00
Bt1(65/67-94/104)	0.0	0.8	2.6	5.5	4.2	16.7	10.7	21.5	23.0	15.0	13.1	48.9	38.0	SiCL	fC	0.65	1.17	1.84	36.34	10.00
Bt2(94/104-106/121)	0.1	0.5	2.1	4.5	4.0	21.6	4.1	16.5	24.1	22.5	11.2	42.2	46.6	SiC	fC	0.93	1.23	2.67	53.99	13.33
BC(106/121-200)	0.0	0.7	2.9	5.1	4.9	22.3	9.3	5.4	20.1	29.3	13.6	37.0	49.4	C	fC	1.46	0.98	1.39	29.44	10.00
Proportional mean P2	0.0	0.9	2.5	4.6	4.1	17.6	12.0	11.5	21.5	25.3	12.1	41.1	46.8	SiC	fC	1.20	3.45	4.44	29.18	10.44
Profile 3 (P3)																				
A1 (0-21/28)	1.4	5.1	4.0	5.6	6.2	10.0	25.2	3.9	11.8	26.8	22.3	39.1	38.6	CL	fC	2.27	1.46	1.98	26.14	10.00
A2 (21/28-42/62)	1.0	3.8	3.2	3.9	2.1	1.0	12.1	1.0	15.0	56.9	14.0	14.1	71.9	C	vfC	3.79	1.51	2.31	34.63	10.00
A3 (42/62-91/110)	0.2	1.5	1.6	2.5	2.2	6.3	39.2	22.7	23.0	0.8	8.0	68.2	23.8	SiL	fSi	0.03	1.21	2.41	49.89	13.33
Bo (91/110-126/141)	0.0	0.7	1.3	2.4	2.0	4.4	21.3	1.1	18.5	48.3	6.4	26.8	66.8	C	vfC	2.61	1.42	2.45	42.10	10.00
Proportional mean P3	0.5	2.4	2.3	3.3	2.9	5.4	26.6	9.4	18.2	28.9	11.5	41.5	47.1	SiC	fC	1.85	1.37	2.32	40.46	11.21

Note : Distribution of soil subfractions : f.C = fine clay, c.C = c.C = coarse clay; f.Si = fine silt; m.Si = moderate silt, c.Si = coarse silt, vf.Sa = very fine sand, f.Sa = fine sand, m.Sa = moderate sand, c.Sa = coarse sand, vc.Sa = very coarse sand; distribution of soil fractions : Sa = sand, Si = silt, C = clay; Class of texture : SiL = silt loam, SiC = silt clay, SiCL = silt clay loam, CL = clay loam, C = clay, Class of particle size : fC = fine clay, fSi = fine silt, vfC = very fine clay; BD = bulk density, PD = particle density, RR = redness rating

Soil Mineral Composition:

Table 4 shows that the soil on the footslope with the slope 0-8% is dominated by weatherproof sand minerals such as opaque and quartz (Lee *et al*., 2001; Velder and Meunier, 2008), whereas the summit and backslope are dominated by sand minerals that easily weather such as garnet and enstatite (primary minerals) (Bashir *et al*., 2009; Gasperini *et al*., 2006; Licker, 2003; Palandri and Reed, 2004). This shows the great intensity of weathering on the footslope, whereas the clay minerals are all dominated by weatherproof clay minerals such as goethite and magnetite. The soil formation on the serpentinite bedrock leads to the accumulation of Fe so that clay minerals are dominated by oxide and hydroxide such as goethite (FeOOH) and magnetite (Fe_3O_4) (Bonifacio, 1997).

Goethite and magnetite belong to amphoteric minerals that have weak electronegative content in acid condition and weak electropositive content in basic condition (Lee *et al*., 2001; Lee *et al*., 2003; Schaetzl and Anderson, 2005) so that the soils that are dominated by the two clay minerals have a low CEC (Cation Exchange Capacity), which results in low soil fertility. The mineral contents of goethite and magnetite and very high Fe_d affect the soil color. Goethite minerals convey the impression of yellow, red, and deep brown, while magnetite minerals convey the impression of blackish (Licker, 2003). The dominance of these minerals causes the soils to have dull reddish brown color, reddish brown, dark reddish brown and dark red.

Table 2: Soil chemical properties formed on the serpentinite bedrock in profiles P1, P2, and P3

Horizon/Depth (cm)	pH		C-org (%)	Total N	C/N	Total P_2O_5	Total K_2O	Available P_2O_5	Ca_e	Mg_e	K_e	Na_e	Quantity	CEC	BS (%)	Al_e	H_e	EC ($dS.m^{-1}$)
	H_2O	KCl		(%)		mg.(100 g)$^{-1}$		(ppm)	cmol(+).kg^{-1}							cmol(+).kg^{-1}		
Profile 1 (P1)																		
A1 (0-20/27)	6.1	5.4	0.89	0.07	13	1.96	2.00	19.00	0.57	0.55	0.04	0.13	1.29	3.49	36.96	0.00	0.03	0.05
A2 (20/27-37/64)	5.6	5.4	2.97	0.23	13	3.72	6.00	14.00	0.64	7.35	0.12	0.32	8.43	13.30	63.38	0.05	0.19	0.02
Bt (37/64-96/140)	5.5	5.2	1.09	0.09	12	1.66	2.00	14.00	0.54	9.81	0.03	0.21	10.59	15.75	67.24	0.01	0.02	0.01
BC (96/140-200)	5.7	5.4	0.48	0.05	10	1.42	2.00	4.00	0.51	9.50	0.03	0.14	10.18	14.88	68.41	0.00	0.02	0.02
Proportional mean P1	5.7	5.3	1.07	0.09	11.4	1.87	2.54	10.49	0.54	8.26	0.04	0.19	9.04	13.62	63.6	0.01	0.04	0.02
Profile 2 (P2)																		
A1(0-16/38)	5.9	5.6	0.45	0.04	11	1.78	2.00	10.00	0.69	10.16	0.03	0.14	11.02	11.20	98.39	0.00	0.03	0.04
A2(16/38-40/46)	5.5	5.3	1.88	0.16	12	4.39	10.36	26.01	0.40	3.84	0.19	0.14	4.57	11.41	40.05	0.00	0.05	0.01
A3(40/46-65/67)	5.7	5.6	0.81	0.07	12	4.37	5.00	11.23	0.34	4.44	0.09	0.11	4.98	9.90	50.30	0.00	0.05	0.01
Bt1(65/67-94/104)	5.8	5.7	0.54	0.04	14	4.02	3.00	19.00	0.58	4.72	0.06	0.17	5.53	10.34	53.48	0.00	0.00	0.06
Bt2(94/104-106/121)	5.8	5.7	0.46	0.03	15	3.88	4.00	14.00	0.63	6.50	0.07	0.16	7.36	11.41	64.50	0.00	0.03	0.02
BC(106/121-200)	5.7	5.6	0.42	0.03	14	3.16	3.00	5.05	0.70	11.78	0.06	0.17	12.71	15.80	80.44	0.00	0.03	0.03
Proportional mean P2	5.7	5.6	0.61	0.05	13.28	3.41	3.76	11.06	0.61	8.53	0.07	0.16	9.37	12.93	70.56	0.00	0.03	0.03
Profile 3 (P3)																		
A1 (0-21/28)	5.7	4.8	2.58	0.21	12	3.93	4.00	1.89	0.11	0.19	0.08	0.07	0.45	6.84	6.58	0.05	0.07	0.03
A2 (21/28-42/62)	5.5	4.9	1.34	0.11	12	4.40	2.00	4.50	0.27	0.10	0.03	0.02	0.42	3.68	11.41	0.01	0.02	0.01
A3 (42/62-91/110)	5.6	4.9	0.93	0.07	13	4.81	3.00	1.93	0.22	0.09	0.05	0.02	0.38	2.78	13.67	0.00	0.05	0.01
Bo (91/110-126/141)	5.7	4.9	0.93	0.07	13	3.67	3.00	3.05	6.20	0.03	0.06	0.10	6.39	2.46	100	0.00	0.00	0.01
Proportional mean P3	5.6	4.9	1.32	0.10	12.61	4.28	2.98	2.73	1.69	0.10	0.05	0.05	1.89	3.63	33.24	0.01	0.04	0.01

Note : CEC = cation exchange capacity; BS = base saturation; EC = electric conductivity; e = exchangeable

Table 3: Fe, A1, and Si in profiles P1, P2, and P3

Horizon/Depth (cm)	Fe_d	Al_d	Si_d	Fe_o	Al_o	Si_o	Fe_p	Al_p	Si_p	Fe_t	Al_t	Si_t	Fe_d/ Fe_t
	%												
Profile 1 (P1)													
A1 (0-20/27)	18.87	1.89	0.48	1.17	0.41	1.97	0.82	0.11	0.09	20.86	2.41	2.53	0.90
A2 (20/27-37/64)	16.27	1.34	0.47	0.83	0.32	1.66	0.70	0.10	0.08	17.80	1.75	2.21	0.91
Bt (37/64-96/140)	17.31	0.93	0.58	0.92	0.19	1.10	0.98	0.21	0.53	19.21	1.33	2.20	0.90
BC (96/140-200)	16.96	1.04	0.59	0.94	0.29	1.88	1.79	0.46	0.04	19.69	1.79	2.51	0.86
Proportional mean P1	17.21	1.14	0.56	0.95	0.27	1.60	1.26	0.29	0.22	19.41	1.70	2.37	0.88
Profile 2 (P2)													
A1(0-16/38)	16.20	0.98	0.89	0.95	0.25	3.06	1.35	0.33	0.49	18.50	1.56	4.44	0.88
A2(16/38-40/46)	16.70	1.34	0.71	0.96	0.26	3.11	1.30	0.35	0.45	18.96	1.95	4.26	0.88
A3 (40/46-65/67)	16.88	1.32	0.81	1.39	0.30	2.27	1.36	0.35	0.46	19.63	1.97	3.53	0.86
Bt1(65/67-94/104)	16.97	1.27	0.85	1.45	0.30	3.54	2.71	0.74	0.83	21.13	2.31	5.22	0.80
Bt2(94/104-106/121)	13.91	1.17	0.84	1.37	0.30	3.72	2.95	0.89	1.12	18.23	2.35	5.68	0.76
BC(106/121-200)	14.17	1.08	0.68	1.30	0.27	3.67	3.40	1.00	1.30	18.86	2.35	5.65	0.75
Proportional mean P2	15.40	1.15	0.77	1.27	0.28	3.36	2.57	0.73	0.94	19.24	2.16	5.06	0.80
Profile 3 (P3)													
A1 (0-21/28)	22.28	4.92	0.40	0.82	0.41	0.20	2.71	0.94	0.03	25.81	6.27	0.63	0.86
A2 (21/28-42/62)	20.30	4.20	0.51	0.63	0.35	0.22	2.10	0.69	0.02	23.04	5.23	0.75	0.88
A3 (42/62-91/110)	20.52	3.66	0.23	0.76	0.31	0.42	1.50	0.47	0.02	22.78	4.44	0.67	0.90
Bo (91/110-126/141)	17.45	2.98	0.25	0.74	0.31	0.26	1.45	0.45	0.02	19.64	3.74	0.53	0.89
Proportional mean P3	20.04	3.83	0.32	0.74	0.34	0.30	1.83	0.60	0.02	22.61	4.77	0.64	0.89

Note: d = Dithionite-Citrate extraction; o = Ammonium oxalate extraction; p = Sodium pyrophosphate extraction; t = total

Table 4: Composition of sand and clay minerals in profiles P1, P2, and P3

Profile	Sand Mineral (%)$^{*)}$												Clay Mineral $^{**)}$						
	Op	Qu	Li	Si	Hi	Wm	Rf	Mu	Ga	En	Cl	RA	Go	Mg	Ka	Gi	An	Sm	La
P1	9	-	-	<1	-	27	3	-	5	56	-	-	+++	+++	++	-	+	+	(+)
P2	9	1	-	<1	-	7	1	<1	17	66	<1	-	++++	+++	-	-	-	-	-
P3	38	39	14	<1	<1	5	-	<1	1	1	-	2	++++	++	-	++	+	-	-

Note : $^{*)}$ Op = opaque, Qu = quartz, Li = limonite, Si = SiO_2-organic, Hi = hidrargillite, Wm = weathered minerals, Rf = rocks fragment, Mu = Muscovite , Ga = garnet, En = enstatite, Cl = chlorite, RA = rutile +anatase
$^{**)}$ Go = goethite, Mg = magnetite, Ka = kaolinite, Gi = gibbsite, An = anhydrite, Sm = smectite, La = Laumonite, ++++ = dominant (80-100%), +++ = many (60-80%), ++ = moderate (30-60%), + = minor (10-30%), (+) = trace (<10%)

Soil Development:

The Soil on the Summit (P1):

The soil on the summit with the slope 0-8% at a height of 317 meters above sea level consists of four layers. On the surface of the soil, there is an accumulation of litter forest vegetation in considerable quantity (thickness < 30 cm); this development process is called littering. The first layer is called horizon A1 and has a distribution of sand subfractions that differs from the layer beneath it; it is presumed that the soil material of this horizon comes from a different place that silted up in a new place (P1) (Table 1); this process is called cumulation. On the first and second layers as horizons A1 and A2, there is weak eluviation as proved by the clay content and the f.C/c.C ratio of < 1 (Table 1). On the third layer as horizon Bt there is accumulation of illuviated clay as proved by the clay content and a higher f.C/c.C ratio than that of the previous horizon. The fourth layer as horizon BC consists of a mixture of fine soil fractions (< 2 mm) with rock fragments, it has a more dominant clay content which comes from the translocation of the clay of the previous horizon compared to the result of the weathering of the bedrock, as proved by a higher clay content and a f.C/c.C ratio of > 1. Besides clay translocation in the soil body, there is leaching of ions with high mobility outside the soil body and there is accumulation of ions with low mobility. This is evidenced by the low proportional mean of the quantity of base cation, which is only 9.04 cmol(+).kg^{-1} (Table 2), there is accumulation of Fe and A1, and leaching of Si and formation of secondary minerals, i.e. a considerable quantity of goethite clay mineral and a moderate quantity of kaolinite (Table 4). Based on this condition, the main processes of soil development that mainly characterize the soil body on the summit (P1) are littering, cumulation, eluviation, illuviation, leaching, and synthesis of secondary minerals, desilication, and ferrallization.

Soil on the Backslope (P2):

The soil on the backslope with the slope 26-45% at a height of 145 meters above sea level consists of six layers. On the surface of the soil there is accumulation of litter forest vegetation in considerable quantity (thickness of < 30 cm); this development process is called littering. The first and second layers are called horizon A1 and A2 and have a distribution of sand subfractions which are different from the layer beneath it; it is presumed that the soil material of this horizon comes from a steeper topography which silted up in a new place (P2) as also proved by the f.C/c.C ratio of > 1 (Table 1); this process is called cumulation. On the second and third layers as horizons A2 and A3 there is weak eluviations as proved by the lower clay content than that of the previous horizon, and on the fourth layer as horizon Bt there is accumulation of iluviated clay as proved by higher clay content and f.C/c.C ratio than those of the previous horizon. On the fifth layer as horizon Bt2, a continuation of horizon Bt2, there is accumulation of iluviated clay. The sixth layer as horizon BC consists of a mixture of fine soil fractions (< 2 mm) with rock fragment which have a clay content dominantly comes from the clay translocation of the previous horizon rather than from the weathered bedrock as proved by the clay content and f.C/c.C ratio of > 1. The development process of the soil body on this backslope results from the height of the slope (26-45%), the formed soil materials are always transported by erosion. Besides this process in the soil body, there is leaching of ions with high mobility outside the soil body and there is accumulation of ions with low mobility. This is proved by the low proportional mean of the quantity of base cation, which is only 9.37 cmol(+).kg^{-1} (Table 2), there is accumulation of Fe and A1, and leaching of Si (Table 3) and formation of a secondary mineral, i.e. a large quantity of goethite clay mineral (Table 4). Based on this condition, the soil development processes that mainly characterize of the soil body on the backslope (P2) are littering; cumulation, erosion, eluviation, illuviation, leaching, synthesis of secondary mineral, desilication, and ferrallization.

The soil on the Footslope (P3):

The soil on the footslope with the slope 0-8% at a height of 37 meters above sea level consists of five layers. On the surface of the soil there is accumulation of littering in small quantity because of land clearing for agricultural activity. The first and second layers called horizons A1 and A2 have a distribution of sand fractions which are different from the layer beneath; it is presumed that the soil material of the horizon comes from a steeper topography which silted up in a new place (P3), as also proved by the f.C/c.C ratio of > 1 (Table 1); this process of development is called cumulation. On the third layer as horizon A3 there is weak eluviation as proved by the f.C/c.C ratio of < 1. On the fourth layer as horizon B oxic (Bo) there is accumulation of iluviated clay as proved by the higher f.C/c.C ratio than that of the previous horizon, and has an oxic characteristic as proved by CEC of < 16 cmol(+).kg^{-1} (Table 2) and has sand minerals that easily weather < 10% (Table 4). On the fifth layer as horizon Bm there is accumulation of petroferric sesqui-oxide containing Fe_2O_3 36.79%, Al_2O_3 9.22%, SiO_2 2.05%, and MnO 0.90%. In addition, there is leaching of ions with high mobility outside the soil body and there is accumulation of ions with low mobility. This is proved by the low proportional mean of the quantity of base cation, which is only 1.89 cmol(+).kg^{-1} and BS of 33.24% (Table 3), there is accumulation of Fe and A1, and leaching of Si (Table 3) as well as the formation of secondary minerals, i.e. goethite clay mineral in large quantity and gibbsite in moderate quantity (Table 4). Based on this condition, the main processes of soil development that mainly characterize the soil body on the footslope (P3) are cumulation, eluviation, illuviation, leaching, and synthesis of secondary minerals, desilication, and ferrallization.

Level of Soil Development:

The development of the soil body on the serpentinite bedrock can be identified in terms of the sequence of the levels of development on the basis of the intensity of leaching, the quantity of sand minerals that easily weather, and the accumulation of ions with low mobility (Fe and A1). The intensity of leaching is based on the combination of the quantity of base cation, BS and the quantity of Si leaching. The sequence of the quantity of base cation and BS from the highest to the lowest is P2 (1) > P1 (2) > P3 (3) (Table 2); and the sequence of Si leaching from the lowest to the highest is P2 (1) < P1 (2) < P3 (3) (Table 3). The sequence of the quantity of sand minerals that easily weather from the highest to the lowest is P2 (1) > P1 (2) > P3 (3) (Table 4). The sequence of the accumulation of Fe from the lowest to the highest is P2 (1) < P1 (2) < P3 (3), and the sequence of the accumulation of A1 from the lowest to the highest is P1 (1) < P2 (2) < P3 (3) (Table 3). Based on this sequence, the total of the combination sequence is obtained; the higher the total of the combination, the more advanced the soil development. The sequence of the levels of soil development from the highest to the lowest is P3 (18) > P1 (11) > P2 (7). This shows that the soil that has a high development is the soil that formed on the footslope (P3), followed by the soil on the summit (P1) and the soil on the backslope (P2).

Soil Classification:

The soils on the summit (P1) and the backslope (P2) have the characteristics of the surface horizon as mollic epipedon. Horizon B as horizon under the surface (endopedon) has the characteristics as a diagnostic horizon of Kandic. Besides the Kandic horizon, all the horizons have BS of > 50% except horizon A1 (Table 2) so that they are better classified as belonging to order Alfisols. Profiles P1 and P2 have the Ustic soil moisture regime so that they are classified as suborder Ustalfs and group Kanhaplustalfs. The horizon under the surface has the hue of 2.5 YR-10 R and value 3 so that it is classified as subgroup Rhodic Kanhaplustalfs.

The soil on the footslope (P3) has the surface characteristics of horizon as Umbric epipedon. Horizon B as horizon under the surface (endopedon) has the characteristics like clay content of 66.8%, a clay texture (Table 1), sand mineral content that easily weathers < 10%, there are no rock fragments, CEC of 2.46 cmol(+).kg^{-1}, and effective CEC of 6.39 cmol(+).kg^{-1} (Table 2) so that it is better classified as oxic diagnostic horizon. The soil that has oxic horizon that is situated in the depth is better classified as order Oxilsols. Profile P3 has an Ustic soil moisture regime so that it is classified as suborder Ustox and great group Haplustox. In the depth about 125 cm from the soil surface there is a petroferric contact (Bm) so that it is classified as subgroup Petroferric Haplustox.

Conclusion:

The processes of formation of the soil on the serpentinite bedrock on Bohusimale Mountain are desilication and ferrallization. The soils that formed in the three topographical sequences contain clay minerals dominated by goethite and magnetite, Fe_d (13.91-22.28%), Fe_t (17.80-25.81%), and high Fe_d/Fe_t ratio (0.75-0.91). The soils that have the highest development are the soil on the footslope, then the soil on the summit and the soil on the backslope. The soils that formed on the serpentinite bedrock on the summit and the backslope are classified as Rhodic Kanhaplustalfs whereas the soil on the footslope is classified as Petroferric Haplustox.

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