

# Texture and Chemical Properties of Two Depth Soils in a Toposequence of Anak Krakatau Before December 2018 Eruption

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## ABSTRACT

Anak Krakatau volcano is one of the famous volcanic mountains located in the sea to the south part of the Province of Lampung, Indonesia. The volcano was derived from the active Krakatau caldera that first appeared on the surface in 1930 or 47 years after the eruption of Krakatau in 1883. The materials produced by the Anak Krakatau eruption were very interesting related to soil forming materials, especially their physical and chemical properties. The objectives of this study were to present information about the texture and chemical properties of soil from Anak Krakatau Mountain taken at the southeast slope before the December 2018 eruption at two different depths. This study was conducted in March to September 2019 which consisted of two parts: (1) soil survey in the field and (2) soil analysis in the laboratory. Soil samples were taken from a toposequence at seven points with an interval about 15m above sea level (asl) on the southeast slope (approaching northeast) of the Anak Krakatau in July 2018 at the depth of 0-20 cm and 20-40 cm. The soil texture of Anak Krakatau mountain before eruption in December 2018 was sandy with the percentage of sand 98.82 - 99.59%; silt 0 - 0.59%; and clay 0.41 - 0.74%. The soil chemical properties of Anak Krakatau mountain were soil pH (H<sub>2</sub>O) 4.95 - 6.27; soil pH (KCl) 4.75 - 5.89; Cation Exchange Capacity 0.41 - 2.02 cmol(+) kg<sup>-1</sup>; Base Saturation 117.24 - 514.63%; CaO 2.63 - 6.34%; MgO 3.06 - 6.13%; K<sub>2</sub>O 0.019 - 0.034%; Na<sub>2</sub>O 0.035 - 0.080%; P-retention 82.10 - 84.74%; and organic carbon 0.06 - 0.72%. The SEM-EDX analysis showed that the amounts of Mg and Na were more than 1% and there were several trace elements present in Anak Krakatau soil, namely Sb (Stibium), Nb (Niobium), Y (Yttrium), F (Flour), Co (Cobalt), and Ba (Barium).

**Keywords:** Anak Krakatau volcano, soil chemical properties, soil texture

## ABSTRAK

Gunung Anak Krakatau merupakan salah satu gunung vulkanis penting di Indonesia. Gunung ini berasal dari kaldera Krakatau yang masih aktif dan pertama kali muncul di permukaan pada tahun 1930 atau 47 tahun setelah erupsi Krakatau 1883. Material hasil erupsi Anak Krakatau merupakan bahan pembentuk tanah yang sangat menarik untuk dipelajari terutama mengenai sifat fisika maupun kimianya. Penelitian ini bertujuan untuk menyajikan informasi mengenai tekstur dan sifat kimia tanah Gunung Anak Krakatau pada lereng tenggara sebelum erupsi Desember 2018 pada dua kedalaman yang berbeda. Penelitian ini dilakukan pada bulan Maret hingga September 2019 yang terdiri dari dua bagian: (1) survei tanah di lapangan dan (2) analisis tanah di laboratorium. Sampel tanah diambil secara *toposequence* pada tujuh titik dengan selang ketinggian ±15 m di atas permukaan laut (dpl) pada lereng tenggara Gunung Anak Krakatau pada Juli 2018 pada kedalaman 0 - 20 cm dan 20 - 40 cm. Tanah Gunung Anak Krakatau sebelum erupsi Desember 2018 memiliki tekstur pasir dengan persentase pasir 98,82 - 99,59 %, debu 0 - 0,59%, dan liat 0,41 - 0,74%. Tanah Gunung Anak Krakatau sebelum erupsi memiliki sifat kimia yaitu pH (H<sub>2</sub>O) 4,95 - 6,27; pH (KCl) 4,75 - 5,89; Kapasitas Tukar Kation 0,41 - 2,02 cmol kg<sup>-1</sup>; Kejenuhan Basa 117,24 - 514,63%; CaO 2,63 - 6,34%; MgO 3,06 - 6,13%; K<sub>2</sub>O 0,019 - 0,034%; Na<sub>2</sub>O 0,035 - 0,080%; retensi-P 82,10 - 84,74%; dan C-organik 0,06 - 0,72%. Berdasarkan analisis SEM-EDX diketahui bahwa kandungan Mg dan Na > 1% dan terdapat beberapa *trace element* pada tanah Anak Krakatau sebelum erupsi Desember 2018 yaitu Sb (Stibium), Nb (Niobium), Y (Yttrium), F (Flour), Co (Cobalt), and Ba (Barium).

**Kata kunci:** Gunung berapi Anak Krakatau, sifat kimia tanah, tekstur tanah

## INTRODUCTION

Indonesian archipelago is part of very active volcanic and dynamic Pacific Ring of Fire. Van Bemmelen (1970) recorded about 129 active volcanoes in the Indonesian archipelago. The Krakatau volcanic complex lies in the Sunda Strait (Indonesia) between Java and Sumatra islands and belongs to the volcanic arc related to the subduction of the Indo-Australian plate beneath the South-East Asian plate (Deplus *et al.* 1994). Within the Krakatau complex, there are four islands: Sertung, Panjang, Rakata, and Anak Krakatau. Anak Krakatau meaning “Child of Krakatau” emerged from the caldera in the 1930s or 47 years after Krakatau eruption in 1883 and is composed of lava and pyroclastic deposits from the late Krakatau mountain. Since its emergence from the sea, Anak Krakatau has progressively grown and considered as one of the fastest growing volcano in Indonesia (Fiantis 2019). Anak Krakatau erupted on 22<sup>nd</sup> December 2018, expelling tons of ashes and causing a collapse of South-West slope of the island and loss of 70% – 80% of its volume in 2018 (Pusat Vulkanologi dan Mitigasi Bencana Geologi 2019).

The Anak Krakatau volcano can be a natural laboratory for all of the pedogenic processes. Texture and chemical properties of soils of Anak Krakatau are very important to study. It will explain the general characteristics of volcanic soil. Materials from the eruption of the Anak Krakatau is very important to study the soil forming processes. Weathering of the erupted materials will determine the texture and chemical properties of the soil that will be formed. Soil formation will begin shortly after the deposition of volcanic ash (referred to as starting point of soil genesis) (Fiantis *et al.* 2010). The volcanic eruption (Tephra) spewed by the Anak Krakatau is rich in primary minerals, which contain relatively high base cations. Fiantis (2019) reported that the Ca content in the Anak Krakatau soil sample was higher than that of in the soil samples from Panjang, Rakata and Sebesi islands, reaching 6.4%, Mg 5%, and P 1%, and the sulfur level was also higher than that in the surrounding area. In addition, the Anak Krakatau soil also has a lower weathering index compared to the soil samples from Panjang, Rakata, and Sebesi Islands. The low weathering index indicates that the weathering of primary minerals is still at an early stage and there are many macro nutrients contained in the soil or, in other words, the weathering rate of the volcanic materials is still going very slowly. However, the chemical and physical properties of the soil (especially the texture of the

soil) can be very interesting since it will show the properties of andic soil formed and the rate of weathering of the soil in the southeast slope of the Anak Krakatau.

Andisols (IUSS Working Group WRB 2015) develop from volcanic ashes or other volcanic materials. Andisols are characterized by the presence of short-range order minerals, such as allophane, imogolite and ferrihydrite, and frequently Al (Fe)-humus complexes (Shoji *et al.* 1993; Arnalds 2004; Auxtero *et al.* 2008. Non crystalline minerals such as allophane and imogolite as products of weathering of volcanic ashes can fix phosphate, which is difficult to be replaced by other ions (Wada 1985). However, the development of andic properties through genesis processes other than volcanic ash weathering cannot be excluded (Van Ranst *et al.* 2019). Soil observation through toposequence will make it easier to see the changes of soil characteristics that are not only influenced by the soil parent materials but also the topography of the study area. Therefore, the main objective of this study was to understand the texture and chemical properties of soils along the southeast of Anak Krakatau Mountain.

## MATERIALS AND METHODS

### Environmental Setting and Soil Sampling

This research was conducted in March to September 2019, which consisted of two parts: (1) soil survey in the field and (2) soil analysis in the laboratory. The study area is located in the southeast slope of Anak Krakatau mountain, where a toposequence was sampled along the southeast slope ( $\pm 5$  m to  $\pm 105$  m above sea level (asl), seven elevation with interval of  $\pm 15$  m asl) (Figure 1). Disturbed soil samples were collected at depth of 0 - 20 cm and 20 - 40 cm. The samples were immediately packed in a plastic bag that was tightly closed, then samples were air-dried and crushed to pass a 2-mm sieve.

### Physico-chemical Analyses

Most of physico-chemical analyses were performed at Laboratory of Soil Science, University of Lampung. Scanning electron microscopy and energy-dispersive analyses (SEM-EDX) were carried out at Integrated Laboratory and Center for Technology Innovation, the University of Lampung using ZEISS/EVO MA 10 software. Particle size distribution or soil texture was determined by recovery of clay, silt and sand fractions after sieving

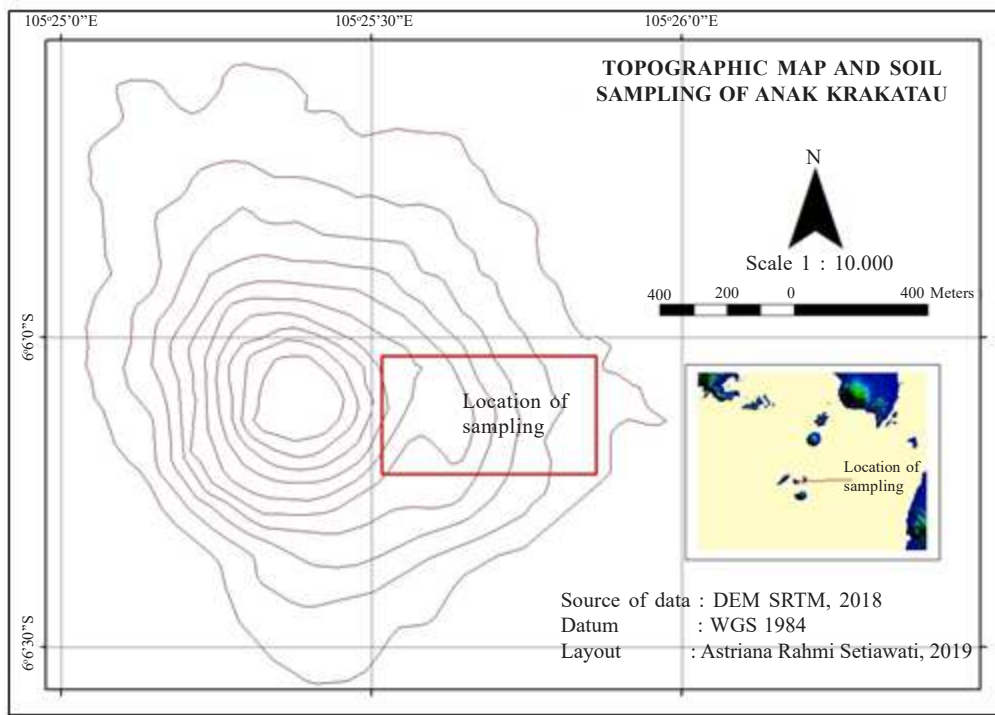


Figure 1. Topographic map and soil sampling of Anak Krakatau.

and dispersion with Na – hexametaphosphate (pipette and sift method) (Sudjadi *et al.* 1971).

The pH of soil was determined potentiometrically in both deionized water (H<sub>2</sub>O) and 1 M potassium chloride (KCl) with a 1:2.5 solid/solution ratio using a combined glass-calomel electrode (Tan 2005). Cation exchange capacity (CEC) and exchangeable base cations (Ca, Mg, K, and Na) were determined by leaching with 1 M-ammonium acetate solution (pH 7), followed by leachate analysis using atomic absorption spectrophotometry (AAS) (Tan 2005). Base saturation (BS) was calculated from the sum of contents of exchangeable base cations, relative to CEC determined with 1 N NH<sub>4</sub>OAc at pH 7 (Anda 2012). Phosphate retention (P-ret.) was determined by the method of Blakemore *et al.* (1987). Determination of soil organic carbon by entering the soil samples into the furnace at a temperature of 600°C for 4 hours (Association of Official Agriculture Chemists 2002). For SEM-EDX analysis, samples were prepared by adhering the tephra grain samples onto an Al sample holder with double-sided tape and coated with gold (Fiantis *et al.* 2016). The behavior of chemical elements in tephra can be inferred by determining the total element analysis (Fiantis 2010). Total alkaline earth elements (Ca, Mg, K, and Na) were removed by leaching with HCl 25%, followed by leachate analysis using atomic absorption spectrophotometry (AAS).

## RESULTS AND DISCUSSION

### Particle Size Distribution or Soil Texture

Particle size distributions are presented in Table 1. The textural classes of the soil samples are grouped into sand. The soil samples taken from seven locations in one top sequence showed the same sandy soil textural classes (> 98% sand) and indicated the very low content of clay (< 0.75%). This result indicates that the weathering process of the volcano materials is still very slow. Changes in the percentage of particle sizes: sand (50 - 2000 µm); silt (2 - 50 µm); clay (0 - 2 µm) at each depth at each observation location are presented in Figure 2.

Furthermore, Figure 2 showed that the sand fraction (particle size > 50 µm) in the 0-20 cm layer (except at observation point 6) is higher than that in the 20-40 cm layer. In addition, it appears that the fraction of sand will be higher with increasing altitude. The high sand fraction in the 0-20 cm depth might be caused by the addition of new materials from the eruption of the Anak Krakatau. Figure 2 also showed that in general the fraction of silt (20 µm - 2 µm) and clay (0 - 2 µm) in the depth of 20 - 40 cm are higher than those in 0 - 20 cm depth. In addition, the texture of the soil is finer as the sampling location reaches the lower places. This might be caused by the influence of elevation and soil erosion from the upper slope to the lower slope of the

Table 1. Soil texture of Anak Krakatau.

No Profil	Depth (cm)	Particle sizes* (%)			Class USDA
		sand	silt	clay	
P1	0 – 20	99.47	0.11	0.42	sand
	20 – 40	99.31	0.23	0.46	sand
P2	0 – 20	99.59	0.00	0.41	sand
	20 – 40	98.89	0.37	0.74	sand
P3	0 – 20	99.33	0.11	0.56	sand
	20 – 40	99.14	0.32	0.54	sand
P4	0 – 20	99.35	0.11	0.54	sand
	20 – 40	99.31	0.18	0.51	sand
P5	0 – 20	98.84	0.59	0.57	sand
	20 – 40	98.82	0.54	0.64	sand
P6	0 – 20	99.16	0.33	0.51	sand
	20 – 40	99.33	0.26	0.41	sand
P7	0 – 20	99.35	0.17	0.48	sand
	20 – 40	99.10	0.30	0.60	sand

\*Particle sizes: sand (50 – 2.000  $\mu\text{m}$ ), silt (2 – 50  $\mu\text{m}$ ), clay (0 – 2  $\mu\text{m}$ ).

mountain. The elevation difference in the toposequence of the Anak Krakatau can bring the finer soil fractions from the higher location washed down to the lower location. The effect of the eruption of the Anak Krakatau that is often repeated resulting in the fine ashes will fall farther away from the source of the eruption due to the wind, while the coarse fraction will fall closer to the source of the eruption. The soil texture that is formed from volcanic materials produced by volcanic activity will be finer if it moves away from the center of eruption where the volcanic materials exit, and will be coarser when it approaches to the center of eruption (Hardjowigeno 2003). The formation of clay is indicated that the weathering process of the Anak Krakatau soil has newly been begun.

#### Soil Chemical Properties of Anak Krakatau Soil Reaction (Soil pH)

The soil pH ( $\text{H}_2\text{O}$ ) of the Anak Krakatau soil is classified as acidic to slightly acidic (4.95 - 6.09) (Table 2). The higher pH value indicates that the primary minerals of the soil are still high. Changes in the acidity of the soil from acid to slightly acidic to near neutral, which are indicated by pH values, cause the soil negative charges are increasing. The difference between pH KCl and pH  $\text{H}_2\text{O}$  values ranges from -0.02 to -0.56. The pH value represents the colloidal surface charge condition of the soil with positive, zero or negative charges (Tan 1998). At high soil pH (near neutral or alkaline), the surface of the soil will be dominated by negative charges, so that the soil has the ability to bind base

cations, whereas at low pH the surface of the soil will be dominated by positive charges (Fiantis 2006). Changes in the soil pH  $\text{H}_2\text{O}$  and KCl at each observation and soil depth are presented in Figure 3.

Figure 3 shows that the pH of the soil generally decreases with decreasing altitude, and the pH is increasing with soil depth. However, the changes in pHs at each soil depth are not significant. It appears that there is extremely significant pH difference between P1 ( $\pm 105$  m asl) and P7 ( $\pm 50$  m asl). This phenomenon can be caused by weathering that is getting faster with decreasing altitude, then the weathering process of the soil has also been begun and accelerated by plant root activity (noted that the lower the sampling location approaching to the beach, the more vegetation density grown).

#### Soil Cation Exchange Capacity (CEC) and Total C

The CEC of Anak Krakatau soil is very low (0.41 - 2.03  $\text{cmol}(+) \text{kg}^{-1}$ ) (Table 2). The low CEC of the Anak Krakatau soil can be attributed to the very low content of clay and organic-C of the soil. Clay and organic-C contents determine the soil CEC. This is caused by the clay and organic-C are being as soil colloids, where all forms of cation exchange reactions occur on the surface of soil colloids. The changes in CEC and organic-C content of the soil at each depth and sampling locations are presented in Figure 4. Farmer *et al.* (1985) reported that allophane soil made from volcanic ash provides unique characteristics because it has high variable charge and has CEC between 20 - 50  $\text{cmol}(+) \text{kg}^{-1}$ .



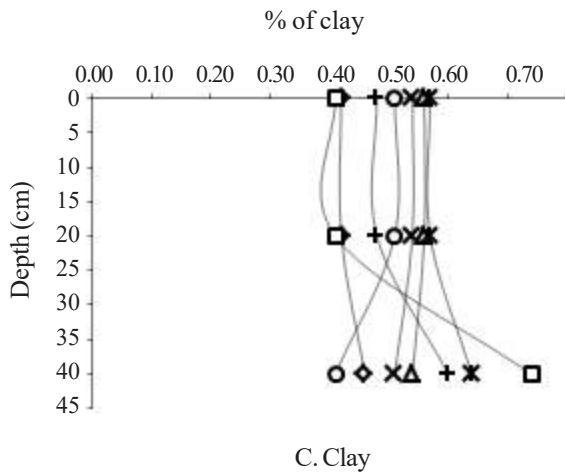
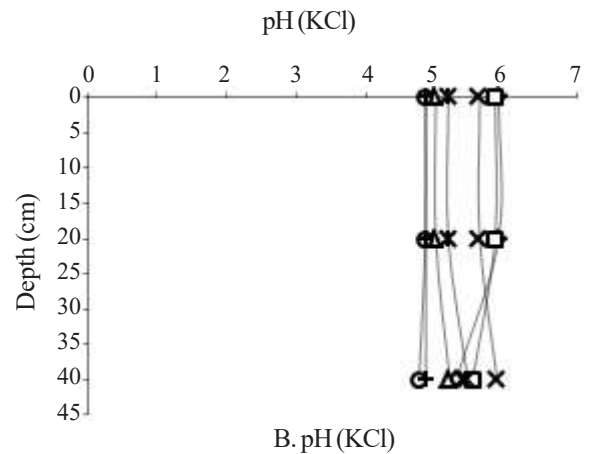
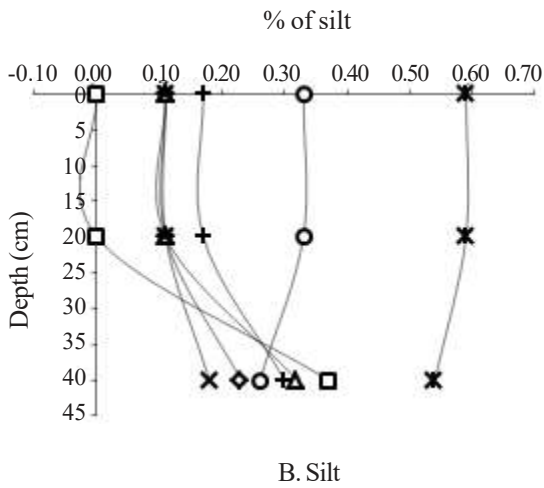
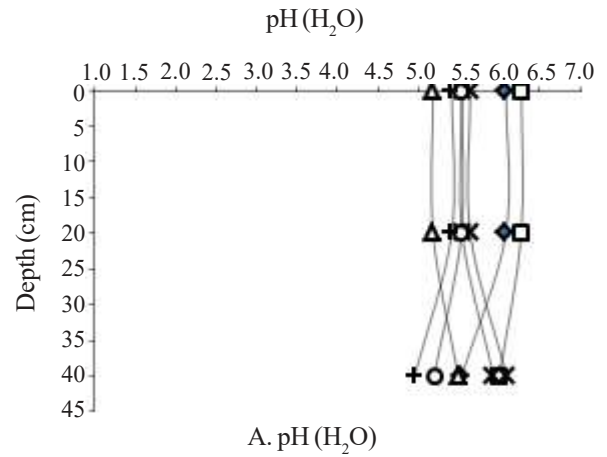
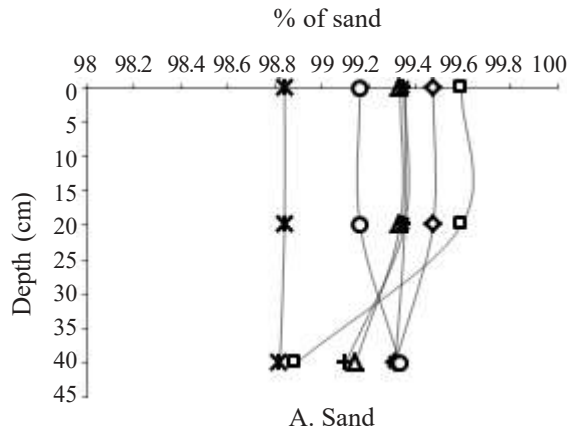


Figure 2. Changes of percentages of sand (A), silt (B), and clay (C) in every depth at seven altitude. —○— : P1, —□— : P2, —△— : P3, —×— : P4, —\*— : P5, —○— : P6, —+— : P7.

Figure 3. Changes of soil pH (H<sub>2</sub>O) (A) and pH (KCl) (B) in every depth at seven altitude. —○— : P1, —□— : P2, —△— : P3, —×— : P4, —\*— : P5, —○— : P6, —+— : P7.

Figure 4 shows that the CEC of the soil is increasing with increasing the soil depth. The CEC of the soil shows a positive correlation to soil clay contents which are also relatively increasing with the soil depth. In addition, with the lower location of the sampling, the values of the CEC are increasing. This phenomenon is also related to the higher clay

and organic-C contents at lower locations. At lower locations, the soil has experienced more weathering than that at higher locations. In addition, the lower the sampling location, the more density of vegetation was found, so that the more vegetation in the lower location, the higher the soil CEC may occur. Fiantis (2019) reported that the organic-C content of the Anak Krakatau soil ranged from 1.3% to 1.7%. The soil organic-C content determined using the dry ash method (dry burning) is about 0.06% to 1.28% (Table 2). The dry combustion method will result in a lower organic-C content in comparison to that using the wet ash method (oxidation by K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>). Dry burning is conducted by burning the soil samples on the furnace, then measuring the CO<sub>2</sub> released. The results are quantitatively more precise than wet combustion method (Hardjowigeno 2003). Figure 4 showed that the organic-C contents in the 20-40 cm layer at some observation points are higher than in the 0-20 cm layer. This is most likely due to organic matter leaching from layer 0-20 cm to layer 20-40 cm.

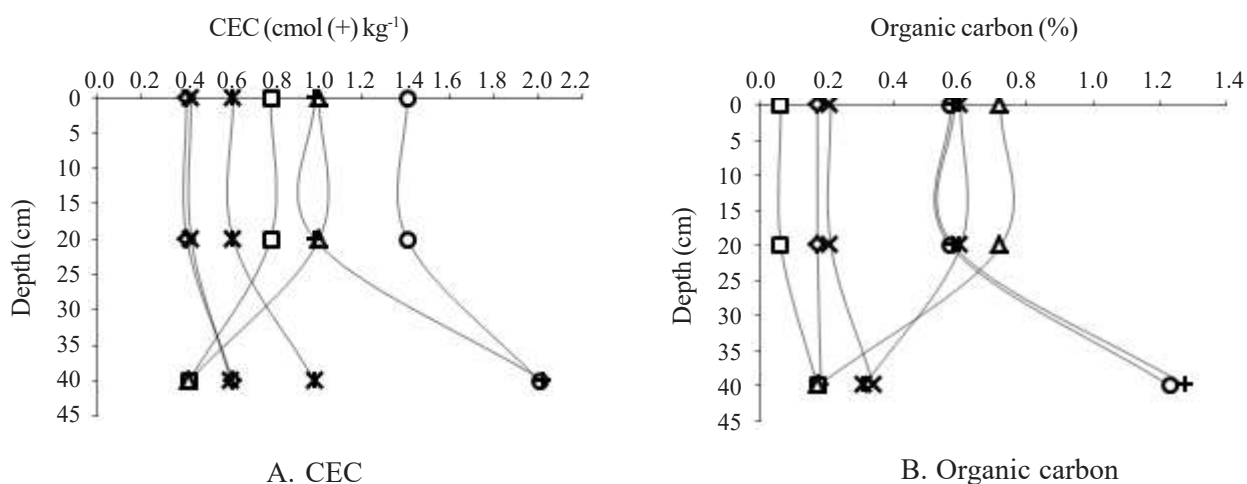


Figure 4. Changes of CEC (A) dan soil organic carbon (B) in every depth at seven altitude. —○— : P1, —□— : P2, —△— : P3, —\*— : P4, —\*— : P5, —○— : P6, —+— : P7.

### Exchangeable Ca, Mg, K, Na and Base Saturation

The amounts of exchangeable-Ca and -Mg as well as other cations of soils are very low. These amounts can also be an indication of the low weathering process of primary minerals. Figure 5 shows that at each observation location the amount of exchangeable-Ca was higher than that of exchangeable-Mg. At the observation site 3, the amounts of exchangeable-Ca (1.01 cmol(+) kg<sup>-1</sup> soil) and exchangeable-Mg (0.67 cmol(+) kg<sup>-1</sup> soil) in the 0-20 cm depth are higher compared to those at the other observation locations. Meanwhile, the amounts of exchangeable-Ca (0.52 cmol(+) kg<sup>-1</sup> soil) and exchangeable-Mg (0.42 cmol(+) kg<sup>-1</sup> soil) in the 20-40 cm depth are lower than those in other observation locations. The trend of exchangeable-Ca and -Mg at location 3 are similar to the trend of soil CEC in which the CEC values are high in the 0-20 cm depth. Meanwhile, the amounts of exchangeable-K are classified as low, and the amounts of exchangeable-Na of the Anak Krakatau soil are classified as medium. In general, the amounts of exchangeable-Na in the layers 0-20 cm are higher than those in the 20-40 cm depth. Meanwhile, the amounts of exchangeable-K at each location show no regular patterns (Figure 5).

Base saturation (BS) of the Anak Krakatau soil in every sampling location in the 0-20 cm depth is higher than that of in the 20-40 cm depth (Figure 6). The amounts of base cations range from 1.4 up to 2.43 cmol(+) kg<sup>-1</sup>, and the trend of the total base cations is increasing with decreasing the altitude of the sampling location. Similarly, the CEC values are higher in the upper location compared to those in

the lower altitude of the sampling location, but the change in the total base cations with the decrease of the altitude is not significant. The soil BS in the upper altitude sampling location (P1) is significantly higher than that in the lower location (P7).

### P-retention

The P-retention of the Anak Krakatau soil in each depth for the seven locations ranges from 82.10% up to 84.74%. These amounts do not meet the requirements for andic soil properties. The requirements for andic soil properties are Bulk Density (BD) < 0.9 Mg m<sup>-3</sup>; P-retention > 85%;  $Al_0 + \frac{1}{2} Fe_0 > 2\%$  (Soil Survey Staff 2014; IUSS Working Group WRB 2015). Figure 7 shows that the amount of P retention in the soil observed in the 0-20 cm depth of the location point 3 (P3) is higher than that of the other observed points (P1, P2, P4, P5, P6 and P7). In general, the amounts of P-retention in the 0-20 cm depth are higher than those in the 20-40 cm depth, except for the amount of P-retention observed in P6 and P7, which shows that the P-retention in the 0-20 cm depth is lower than that in the 20-40 cm depth. However, the difference in the amounts of P retention of the two layers are not significant.

Shoji *et al.* (1993) indicated that the amount of phosphate that could be retained is influenced by soil pH and free Al and Fe content. The presence of quite a lot of active Al / Fe compounds that are positively charged in the soil causes P to be strongly adsorbed in the mineral structure of allophane or bound to the functional groups of OH- or H. This results in allophane being very strong in binding P compared to the ability of organic acids to release P

Table 2. Soil chemical characteristics of Anak Krakatau.

Loca tion	m asl	Depth (cm)	pH		CEC cmol (+) kg <sup>-1</sup>	Ex Cation				BS (%)	Total cation extract HCl 25 %				P retention (%)	Org-C (%)
			H <sub>2</sub> O	KCl		Ex-Ca cmol (+) kg <sup>-1</sup>	Ex-Mg cmol (+) kg <sup>-1</sup>	Ex-K cmol (+) kg <sup>-1</sup>	Ex-Na cmol (+) kg <sup>-1</sup>		CaO (%)	MgO (%)	K <sub>2</sub> O (%)	Na <sub>2</sub> O (%)		
P1	± 105	0-20	6.08	5.89	0.41	0.74	0.54	0.22	0.61	514.63	3.52	6.07	0.024	0.042	83.04	0.17
		20-40	5.53	5.28	0.62	0.62	0.46	0.18	0.36	261.29	5.92	3.37	0.032	0.058	82.56	0.18
P2	± 90	0-20	6.27	5.84	0.79	0.67	0.44	0.15	0.42	212.66	2.63	5.42	0.020	0.035	82.84	0.06
		20-40	6.00	5.52	0.42	0.73	0.48	0.23	0.41	440.48	6.34	3.31	0.034	0.080	82.66	0.17
P3	± 75	0-20	5.18	4.99	1.01	1.01	0.67	0.29	0.40	434.65	4.56	4.29	0.028	0.048	84.74	0.72
		20-40	5.49	5.19	0.42	0.52	0.42	0.14	0.33	335.71	4.00	3.66	0.020	0.045	82.50	0.17
P4	± 50	0-20	5.64	5.62	0.43	0.57	0.41	0.16	0.40	358.14	3.74	6.13	0.020	0.042	83.04	0.21
		20-40	6.09	5.87	0.61	0.62	0.45	0.18	0.38	267.21	4.53	4.76	0.019	0.048	82.10	0.34
P5	± 35	0-20	5.54	5.17	0.62	0.93	0.65	0.38	0.47	391.94	5.93	3.06	0.037	0.080	83.70	0.60
		20-40	5.93	5.45	0.99	0.79	0.53	0.28	0.54	216.16	5.94	4.44	0.032	0.080	83.60	0.31
P6	± 20	0-20	5.53	4.84	1.41	0.88	0.64	0.26	0.52	163.12	5.84	4.76	0.025	0.053	82.66	0.57
		20-40	5.19	4.75	2.02	1.01	0.66	0.24	0.50	119.31	4.39	4.87	0.026	0.049	83.94	1.23
P7	± 5	0-20	5.41	4.85	0.99	0.81	0.60	0.25	0.51	219.19	4.41	4.71	0.024	0.048	83.26	0.58
		20-40	4.95	4.85	2.03	0.92	0.62	0.33	0.51	117.24	5.54	4.68	0.032	0.055	84.28	1.28

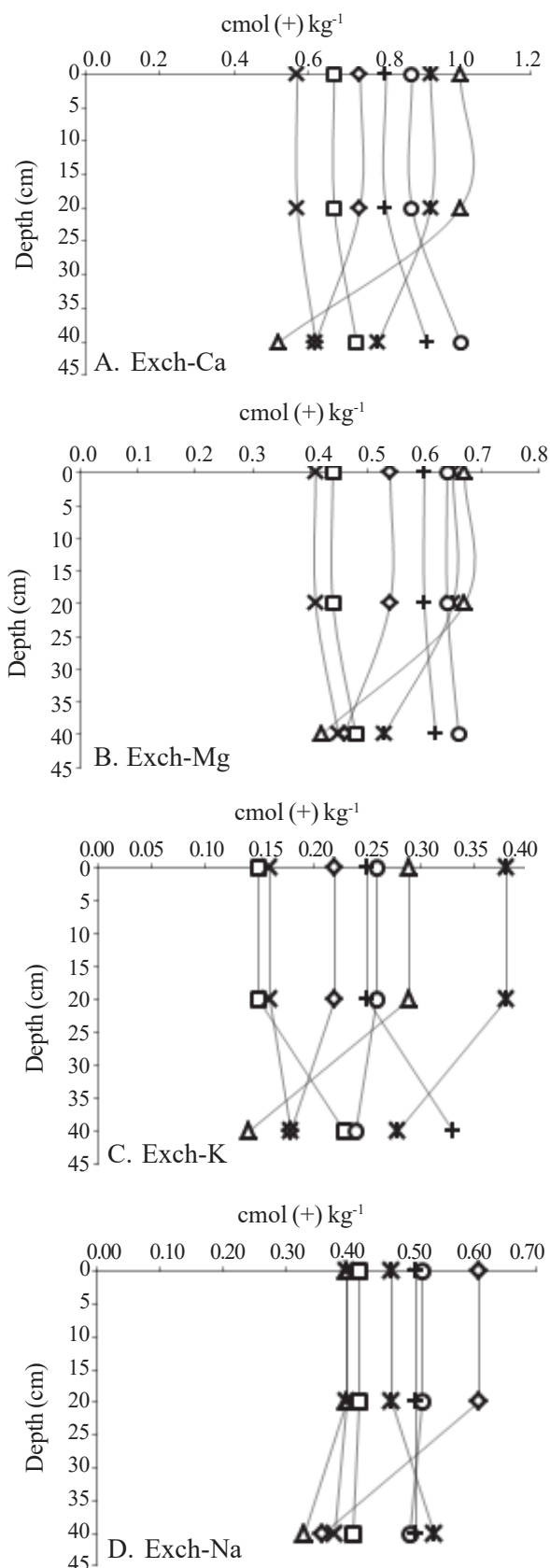


Figure 5. Changes of exchangeable-Ca (A), exchangeable-Mg (B), exchangeable-K (C), and exchangeable-Na (D) in every depth at seven altitude. —◇— : P1, —□— : P2, —△— : P3, —\*— : P4, —●— : P5, —○— : P6, —+— : P7.

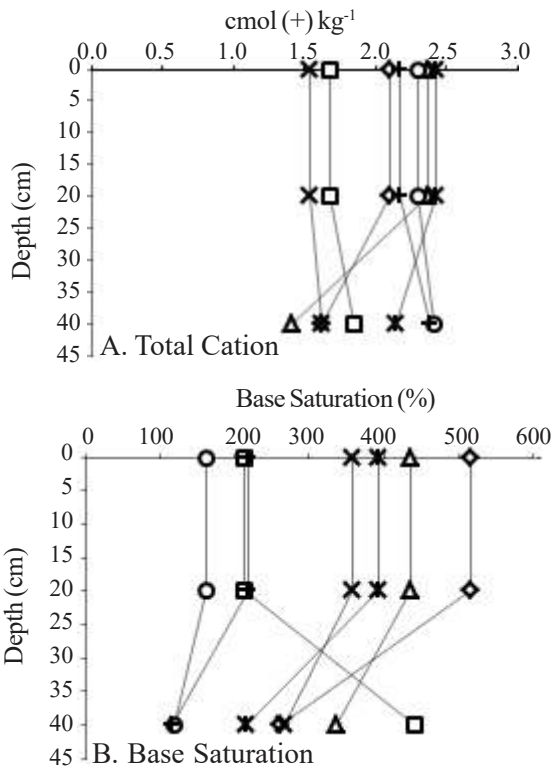


Figure 6. Changes of total cation and base saturation in every depth at seven altitude. —○— : P1, —□— : P2, —△— : P3, —×— : P4, —\*— : P5, —○— : P6, —+— : P7.

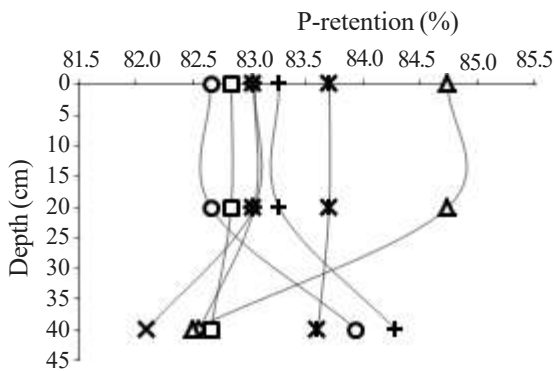


Figure 7. Changes of P-retention in every depth at seven altitude. —○— : P1, —□— : P2, —△— : P3, —×— : P4, —\*— : P5, —○— : P6, —+— : P7.

from sorption complexes. Non-crystalline minerals allophane and imogolite resulting from the weathering of volcanic ashes can fix phosphate, making it difficult to be replaced by other ions (Wada 1985). A high P-retention in the soil indicates the high amount of short range order minerals in the Anak Krakatau soil. The nature of the surface charges of Andosols is influenced by the relative amounts of short range order minerals (mainly, allophane and

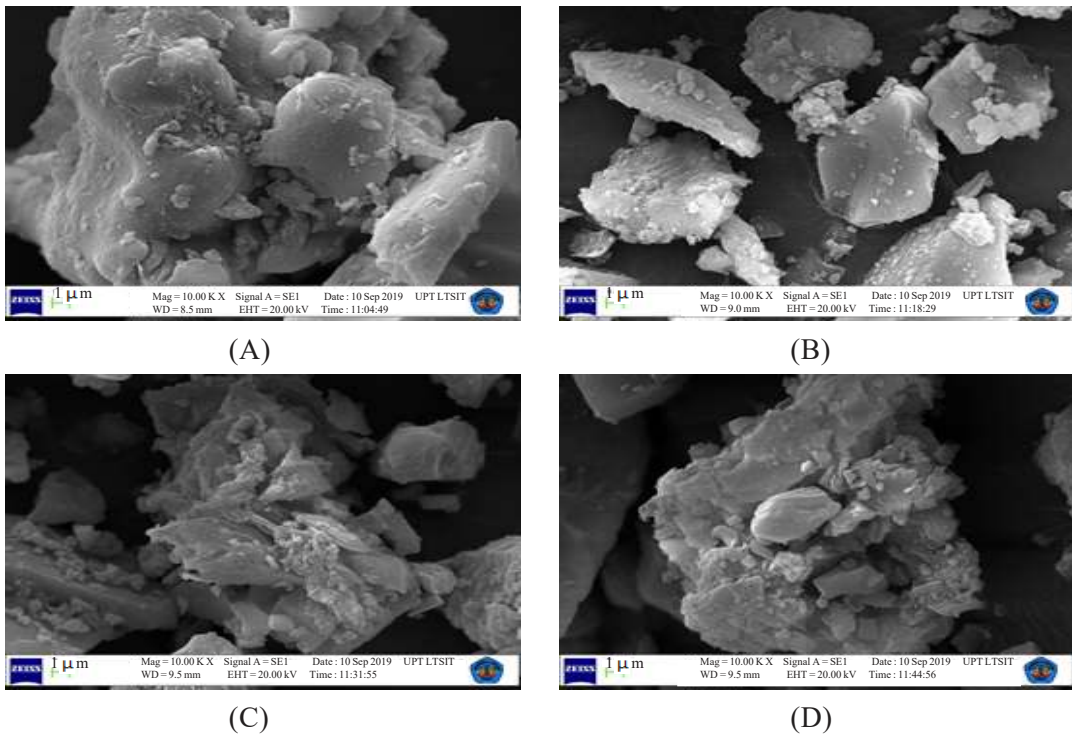
ferrihydrite), organic matter (especially Al- and Fe-humus complexes), crystalline Fe oxides, gibbsite, and silicate clay layers (smectites, halloysites, kaolinites) (Dahlgren *et al.* 2004; Qafoku *et al.* 2004; Theng and Yuan 2008; Parfitt 2009; McDaniel *et al.* 2012; Xu *et al.* 2016; Van Ranst *et al.* 2017; Utami *et al.* 2019).

### Mineralogical Characteristics of Anak Krakatau

Morphological analysis of the Anak Krakatau soil and identification of its elemental contents were carried out using scanning electron microscopy and energy-dispersive analysis (SEM-EDX). From the seven observation sites, only two observation locations were taken: observation location 1 (P1 with altitude  $\pm 105$  m asl) and observation location 7 (P7 with altitude of  $\pm 5$  m asl). Figure 8 shows that the mineral form P1 layer 0-20 cm has an irregular shape compared to that in the layer 20-40 cm. The mineral surfaces in the P7 at layer 0-20 cm and 20-40 cm look more crystallized compared to the mineral surfaces in P1. This irregular mineral form is caused by the non-crystalline clay mineral content in the soil of Mount Anak Krakatau. Minerals with irregular crystal structures are called non-crystalline clay minerals (Van Ranst *et al.* 2008).

The amount of Si (Figure 9) at P1 at the 0-20 cm layer is lower (4.74%) than that in the 0-20 cm layer at P7 in which the Si content reaches 42.40%. Meanwhile, for the 20-40 cm layer, the Si content at P1 is higher (57.83%) compared to that at the 20-40 cm layer at P7 (14.83%). Inorganic carbon in P7 layer 20 - 40 cm is higher (15.16%) compared to that at location P1. The total Na and Mg at P1 were detected higher than the total Mg and Na at P7. The results show that the nutrient reserves in P1 are relatively higher compared to those in P7. The behavior of chemical elements in tephra can be inferred by conducting the total element analysis (Fiantis 2010). The alkaline earth elements of Ca (2.63 – 5.93%) and Mg (3.06 – 6.07%) contents found in the Anak Krakatau soil samples under investigation are higher than the alkaline elements of K (0.019 – 0.034 %) and Na (0.035 – 0.080 %) (Table 2). In the depth 0 – 20 cm, the content of Mg > Ca > Na > K. However, in the depth of 20 - 40 cm, the content of Ca > Mg > Na > K. The elements of K, Ca and Na are present in feldspar, pyroxene and hornblende, while Mg originates from hornblende. It is known that some major elements, such as Ca in basaltic and andesitic rocks are easily mobilized during weathering. Calcium is mobilized out of the system in the early stages of alteration. Small amounts of





Gambar 8. (A) SEM micrograph of Anak Krakatau soil at location 1 (P1) at 0 - 20 cm layer, (B) SEM micrograph of Anak Krakatau soil at location 1 (P1) at 20 - 40 cm layer, (C) SEM micrograph of Anak Krakatau soil at location 7 (P7) at 0 - 20 cm layer, (D) SEM micrograph of Anak Krakatau soil at location 7 (P7) at 20 - 40 cm layer.

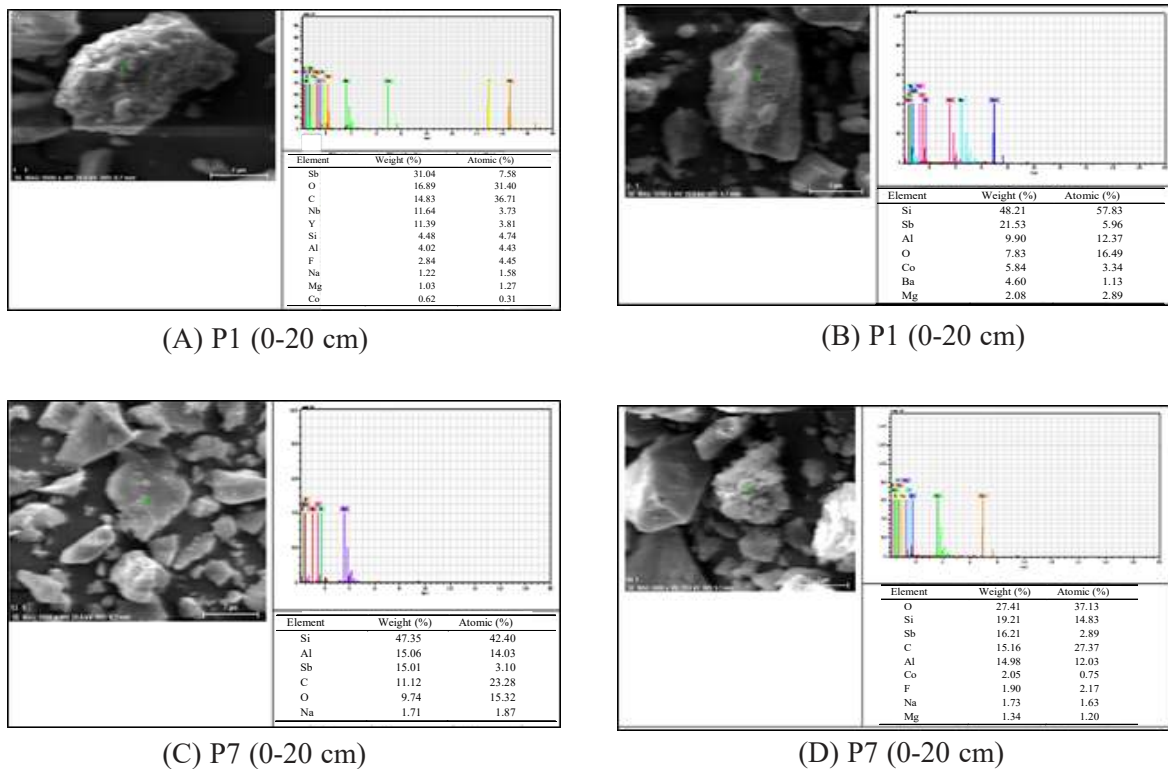


Figure 9. Surface characteristics and elemental composition of Anak Krakatau soil.

soluble K and Mg are supplied by the volcanic ashes. These provided significant additions to the soil exchangeable cation pool (Fiantis 2010).

There are 6 trace elements present in Anak Krakatau materials (Figure 9), namely Sb (Stibium), Nb (Niobium), Y (Yttrium), F (Flour), Co (Cobalt),

and Ba (Barium). The identification and quantification of these elements in volcanic ash deposit are important for defining whether the volcanic ash contains some micronutrient elements, rare earth elements, heavy or toxic metal elements that can pollute the environment. These trace elements occur as trace constituents of primary minerals of the volcanic ash, *i.e.* olivine, hornblende, augite, apatite, anorthite and andesine. Olivine, hornblende and augite contain nickel (Ni), zinc (Zn), vanadium (V), scandium (Sc), lead (Pb) and copper (Cu); anorthite and andesine are the source for strontium (Sr) and Cu, apatite is the source for rare earth elements Pb and Sr. The presence of Y and Zr can be explained by the abundance of plagioclase feldspar and apatite. Among the trace elements identified in the volcanic ash, Zn, Cu and Ni are essential micronutrients. Trace elements like yttrium (Y), zirconium (Zr), niobium (Nb), scandium (Sc), and thorium (Th) are considered as rare earth elements and immobile elements (Fiantis 2010).

## CONCLUSIONS

The texture of Anak Krakatau soil before eruption in December 2018 was sandy with the percentage of sand 98.82 - 99.59%; silt 0 - 0.59%; and clay 0.41 - 0.74%. The chemical properties of Anak Krakatau soil were pH (H<sub>2</sub>O) 4.95 - 6.27; pH (KCl) 4.75 - 5.89; Cation Exchange Capacity 0.41 - 2.02 cmol(+) kg<sup>-1</sup>; Base Saturation 117.24 - 514.63%; CaO 2.63 - 6.34%; MgO 3.06 - 6.13%; K<sub>2</sub>O 0.019 - 0.034%; Na<sub>2</sub>O 0.035 - 0.080%; P-retention 82.10 - 84.74%; and organic carbon 0.06 - 0.72%. The SEM-EDX analysis showed that the amounts of Mg and Na were more than 1% and there were several trace elements present in Anak Krakatau soil, namely Sb (Stibium), Nb (Niobium), Y (Yttrium), F (Flour), Co (Cobalt), and Ba (Barium).

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