Detecting Coastal Atmosphere Weathering Process on Andesite Rock Using Magnetic Susceptibility and Fe_3O_4/Fe_2O_3 Ratio

Pendeteksian Pelapukan Batuan Andesite pada Atmosfer Pantai Menggunakan Suseptibilitas Magnetik dan Rasio Fe_3O_4/Fe_2O_3

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(Received 04 March 2020; in revised form 09 March 2020; accepted 21 May 2020)

ABSTRACT: Weathering is a geological phenomenon that is often an important considered because of its destructive properties, mainly in subsurface. Many parameters are used to measure the presence of weathering indications. This study focuses on testing of magnetic susceptibility (χ), compound oxide content and Fe_3O_4/Fe_2O_3 ratio that have been selected as an indicators of weathering process. This study explains in detail the quantitative analysis of weathering based on these parameters in basaltic andesite rocks found in coastal atmospheric areas. The results obtained for weathered rocks, magnetic susceptibility, compound oxide content such as CaO and the Fe_3O_4/Fe_2O_3 ratio has decreased significantly. In the coastal atmosphere, the weathering of basaltic andesite rocks also marked by the distribution of magnetic minerals which tend to be in the domain of pseudo single domain (PSD) or single domain (SD). Thus it can be concluded that both of low frequency magnetic susceptibility (χ_{lf}), CaO and Fe_2O_3 content and also the Fe_3O_4/Fe_2O_3 ratio can be used as weathering level indicators.

Keywords: weathering, andesite, magnetic susceptibility, Fe_3O_4/Fe_2O_3 ratio, coastal atmosphere.

ABSTRAK: *Pelapukan merupakan fenomena geologi yang sering menjadi pertimbangan penting karena sifatnya destruktif terutama pada bawah permukaan. Banyak parameter yang digunakan untuk mengukur adanya indikasi pelapukan. Penelitian ini berfokus pada pengujian suseptibilitas magnetik (χ), kandungan senyawa kimia dan rasio Fe_3O_4/Fe_2O_3 yang dipilih menjadi parameter sebagai indikator pelapukan. Penelitian ini menjelaskan secara rinci analisis kuantitatif pelapukan berdasarkan kedua parameter tersebut pada batuan beku basaltik andesit yang terdapat pada area atmosfer pantai. Hasil penelitian didapatkan untuk batuan lapuk, suseptibilitas magnetik, kandungan senyawa kimia CaO dan rasio Fe_3O_4/Fe_2O_3 mengalami penurunan. Pada atmosfer pantai batuan basaltik andesit yang mengalami pelapukan juga ditandai oleh distribusi mineral magnetik yang cenderung berdomain pseudo single domain (PSD) maupun single domain (SD). Dengan demikian dapat disimpulkan bahwa baik suseptibilitas magnetik low frekuensi (χ_{lf}), kandungan senyawa kimia CaO dan Fe_2O_3 maupun rasio Fe_3O_4/Fe_2O_3 dapat dijadikan sebagai indikator tingkat pelapukan.*

Katakunci: *pelapukan, andesite, suseptibilitas magnetik, rasio Fe_3O_4/Fe_2O_3, atmosfer pantai.*

INTRODUCTION

Weathering is an important phenomenon because related to geological processes. The weathering indication have been investigated by various methods such as using ground penetrating radar (GPR) (Hynek *et al.*, 2017), who specifically study the effects of fractures on weathering igneous and volcanic sedimentary rocks in the Puerto Rico tropical rainforest. Weathering can also be characterized in different ways by using elastic waves on a laboratory scale. Many ways that can be developed to detect the level of weathering in a rock, which quantitative analysis relating to the level of weathering in rocks is needed. This study aims to quantitatively analyze weathering of andesite rocks in coastal atmospheric areas based on magnetic properties mainly magnetic susceptibility, oxide compound content CaO and Fe_2O_3 and also analyze of Fe_3O_4/Fe_2O_3 ratio. The coastal atmosphere is considered as an area which triggers weathering faster compared to other areas such as mountainous areas. The speed of weathering in this area is also triggered by the rapid corrosion process of magnetic minerals deposited.

In some previous studies, magnetic parameters also used as an indication of chemical and physical weathering intensity. Magnetic properties especially magnetic susceptibility have been used in detecting weathering in the core layers indicated by geothermal alteration (Pandarinath *et al.*, 2014). Magnetic susceptibility also can detect weathering that occurs in igneous rocks in China (Su *et al.*, 2015). Tracing the origin of weathering on the loess-paleosol deposition sequence and its implications for paleoclimate in Gosoeng area on the east coast of South Korea using magnetic susceptibility and geochemistry also have been performed (Hwang *et al.*, 2014).

In the weathering process, magnetic minerals can act as recorders of the weathering, diagenesis and paleoclimate processes, so this process can be tested with changes in magnetic susceptibility, isothermal remanent magnetization (IRM) and anhysteretic remanent magnetization (ARM) as well as other magnetic parameters, (Maxbauer *et al.*, 2016). Study of weathering effects on soil originating from volcanic rock decomposition by scanning electron microscope (SEM) and x-ray diffraction (XRD) has also been carried out (Okewale and Coop, 2017). Magnetic mineralogy tracking from weathering has also been carried out on tropical basalts in the South China Hainan Island (Ouyang *et al.*, 2015). The relationship between magnetic properties and weathering also indicated in basaltic rocks (Dam and Velbel, 2009). The relationship between magnetic properties and reddening of tropical soils due to alteration as weathering indicators has also been detected in laterite soils that contain a lot of hematite (Preetz *et al.*, 2017). The weathering effects on physical and mechanical properties of igneous rocks and metamorphic saprolite has been studied (Rocchi *et al.*, 2017). For soils that have experienced strong weathering, there is a weak relationship between the magnetic properties and the total of iron (Fe) content.

The location of the weathering process is also an important part to consider due to chemical and physical properties of weathering. (Ietto *et al*,, 2018), characterize weathering in coastal areas. Rocks are generally degraded or weathered due to the results of the hydrological cycle including fresh water and sea water (Lee and Yoon, 2017). This research also studies the basaltic andesite weathering in coastal atmospheric areas, which in the future can be used for comparison with mountainous or other areas.

Geological Setting

Samples in this study were taken at the Pasir Putih beach area in Prigi Bay, Trenggalek. The geographical location of the sample is 8^{o}17’56.65”S and 111^{o}44’23.96”E. Samples were taken on the east side of the beach. Based on the geological map, the area is marked by the appearance of intrusive rock consisting of diorite, dacite and andesite (Tomi). These intrusive rock affects the Arjosari, Mandalika and Campurdarat Formations. The intrusive rocks are scattered in a dispersal manner especially around the Prigi bay (Samodra *et al.*, 1992). Description of the sampling location shown in Figure 1 and description of the geological map listed in Figure 2.

METHODS (AND MATERIALS)

The sample in this study was andesite basaltic igneous rock taken from the Prigi coast area, Watulimo sub-district, Trenggalek regency (Figure 1). Samples taken in the form of hand specimens of rocks that are indicated from the change in color of the rock body from inside to the outside. If the hand specimens of rock are broken down, the change in colour due to weathering is very clear. The inner part is blackish gray, the middle is brown and the outer is light brown. This rock is thought to be experienced weathering which detected from its hardness is getting more soft to outer part. In the sampling to be measured, the sample is divided into three part, inner, middle and outer rocks. The outermost rock was thought to have undergone an almost perfect to perfect weathering process. This illustration shown in Figure 3.

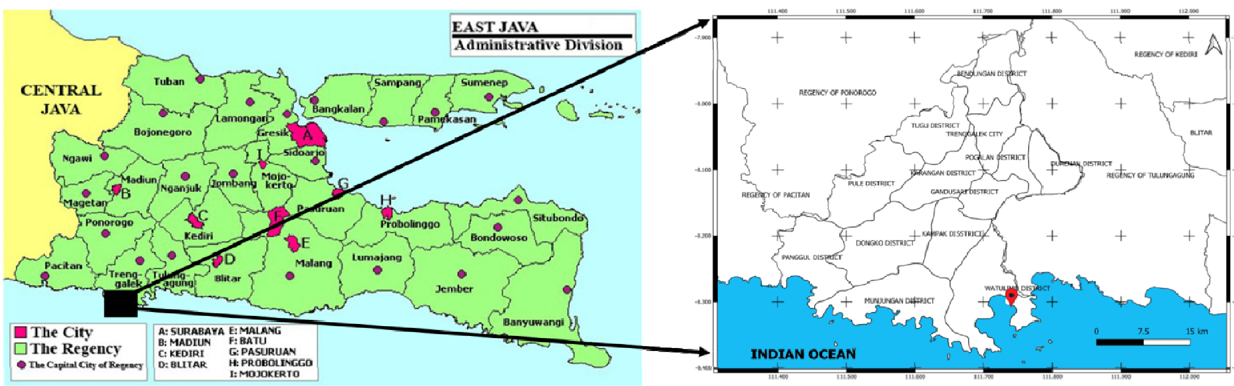
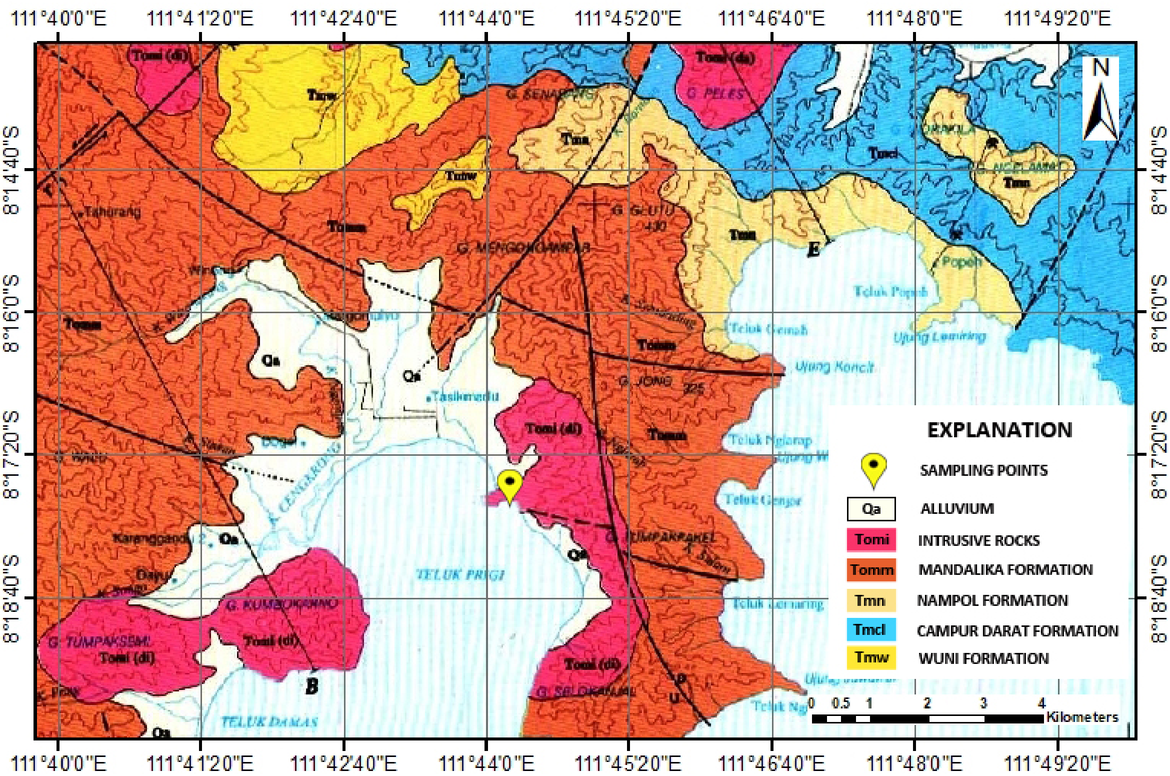


Figure 1. Location of sampling in a whole map of east Java (left) and the frame of Trenggalek regency (right). Map Source: http: //www.syncOnConnect_time=1177956727



Map Source: 38-1507-5-Tulungagung

Figure 2. Geological map and location of sampling that marked by yellow point that precise in intrusive rock area

Three pieces of hand specimens were taken and nine sub samples were assumed to be representative for magnetic susceptibility measurements. The sub-sample is then crushed to be powders and insert it in a standard plastic holder for magnetic measurement. Measurement of magnetic susceptibility was performed by Bartington susceptibility meter MS2B. Some representative sub-samples were tested for their elements and oxide compound content such as CaO using XRF (X-Ray fluorescence) and XRD (X-Ray diffraction), that to be used to determine the Fe_3O_4/Fe_2O_3 ratio. The entire set of sample preparation, and measurements were carried out in the central laboratory Universitas Negeri Malang (UM).

Magnetic susceptibility measurements were performed at low (χ_{lf}) and high (χ_{hf}) frequencies. From the magnetic susceptibility data of the two frequencies, we can obtain the dependency frequency susceptibility by using the following formula:

$$\chi_{fd(\%)} = (\chi_{lf}-\chi_{hf})/\chi_{lf} \times 100\% \quad \text{(Dearing, 1999)} \qquad (1)$$

$\chi_{fd(\%)}$ describe the distribution of magnetic mineral domains in samples. The range of χ_{fd} from 0 to 2% indicates that the magnetic mineral domain is in the multi domain (MD) range. Meanwhile, for χ_{fd} from 2% to 4% are single domain (SD) to pseudo single domain (SSD) and above 4% are classified as superparamagnetic (SP) (Dearing, 1999). Multidomains (MD) signify coarse grains, while pseudo single domain (PSD), single domain (SD), and SP signify relatively fine grains.

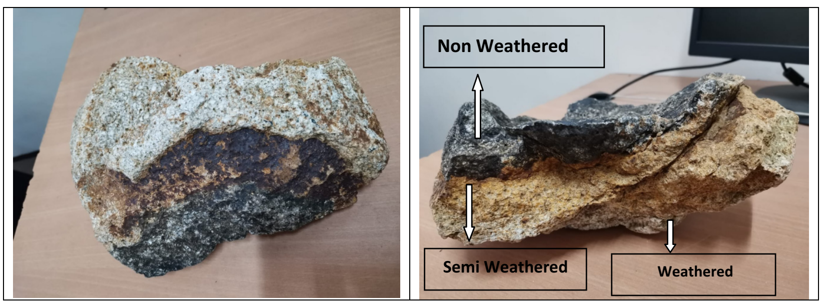


Figure 3. Illustration of sample position distribution in hand specimens of basaltic andesite rock. The black-gray one is the inner sub-sample which has not been weathered, the next layer, the brownish middle is the sub-sample which is half-weathered and the whitish-brown outer part has been weathered.

XRD test is carried out at an angle (10 – 90) to identify the iron oxide content (Fe_3O_4 and Fe_2O_3) as a step to determine changes in the value of Fe in rocks that have not weathered with the rock that have weathered. According to (Zhao *et al.*, 2011), the highest peak of relative intensity in magnetite minerals (Fe_3O_4) is at the angle of 2θ approximate to 30°; 35° ; 42°; 57°; 62° and for the hematite minerals (Fe_2O_3) is at the angle of 2θ approximate to 25°; 32°; 35°; 40°; 50°; 55°; 57°; 60°; 62° .

Table 1. Magnetic susceptibility and compound oxide of basaltic andesite (Wt%) sample from Prigi coast.

coast.

Sample	χ_{lf} ($10^{-8}m^3kg^{-1}$)	χ_{fd} (%)	CaO (%)	Fe_2O_3 (%)	Al_2O_3 (%)	SiO_2 (%)
Inner	637.55	0.40	14.2	11.3	15	52.1
Middle	4.28	9.60	4.98	12.8	16	56.9
Outher	5.72	5.51	4.88	32.86	12	43.2

*Inner = non weathering sample
*Middle = semi weathered sample
*Outer = weathered sample

RESULTS

The type of the samples, had already determined in the previous work based on the element content using the Le Meitre method, it was found that the rock type in this sample is basaltic andesite which contains more andesitic content (Pujiastuti *et al.*, 2020). The XRF test results the dominant of oxide composition in the measured sample listed in Table 1.

There are four dominant oxide compounds analyzed in this study: CaO, Fe_2O_3, Al_2O_3 and SiO_2. Weathering process can be detected from the content of certain compounds, such as Fe_2O_3, and CaO. There was a decrease in the quantity of CaO and conversely an increase in Fe_2O_3 in rocks that experienced weathering process. This shows that both minerals are susceptible to weathering and changes of its amount in a rock can be used to understand the physical condition of the rock. The amount of CaO value in weathered rocks has decreased very significant. The CaO compounds in rocks that not yet weathered to perfect weathering have a value from 14.2% to 4.88% respectively. The value of Fe_2O_3 experienced a significant increase, from inner part to outer part was from 11.3% to 32.86%. Fe_2O_3 compounds also correlated with magnetic susceptibility that have decreased from inner part to outer part of rock, where the weathered rock is completely estimated contain maghemite minerals. This is due to during the weathering process the elements content of the rock undergoes a reduction-oxidation chemical reaction. Meanwhile other minerals such as Al_2O_3 and SiO_2 are not affected by the weathering process so they are not representative as weathering indicators. Al_2O_3 and SiO_2 compounds cannot be used as indicators of the weathering process, because of their resistance to oxidation. Sodium silicate can be used as a barrier to the rate of chemical oxidation reactions (Adziima *et al.*, 2013).

Figure 4. shows that the distribution of magnetic mineral domains in samples that have not experienced weathering based on χ_{fd} is in the range below 2% where the magnetic grains are still dominated by MD. For samples that undergo weathering process, χ_{fd} tends to be in the range of 2% to 10% which indicates the magnetic minerals domains from MD are transformed into PSD, SD or SP.

In Table 1 it is also shown that there is a very significant decrease in the value of low frequency magnetic susceptibility χ_{lf} from rocks that have not yet weathered become weathered. Decreasing in magnetic susceptibility in weathered rocks to less than 10% of the initial susceptibility.

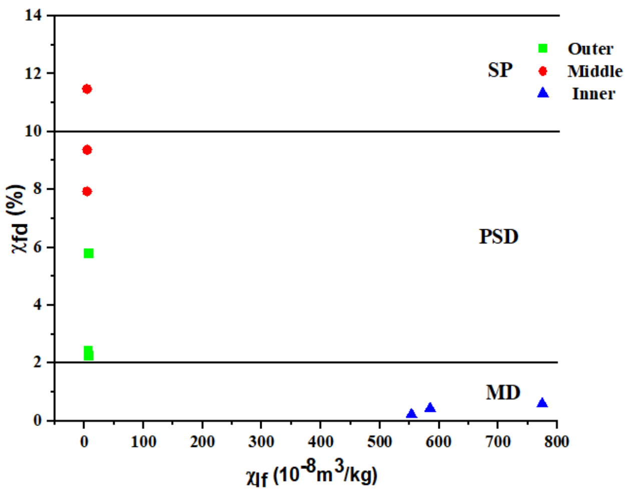


Figure 4. Domain magnetic distribution due to χ_{fd}

The results of the XRD show a peak angle at a relatively high intensity. From Figure 5, described that the basaltic andesite rocks in coastal area contain magnetite and hematite minerals based on angles at the highest peak intensity. The non weathered rocks have magnetite minerals at the highest peak with the angle of 2θ appoximate 30°; 37°; 40°; and 50° , while hematite minerals have the highest peak at the angle of 2θ approximate 23°; 37°; 41°; and 49° . For weathered rocks there are magnetite minerals found at the angle of 2θ are about 30°; 37°; 40°; and 50 ° while hematite minerals are at the angle of 2θ are about 24°; 30°; 41°; and 49° .

The ratio of magnetite (Fe_3O_4) and hematite (Fe_2O_3) on the rock that is not weathered yet and undergo weathered shown in Table 2. Ratio of Fe_3O_4 and Fe_2O_3 from coastal rocks that undergo weathered

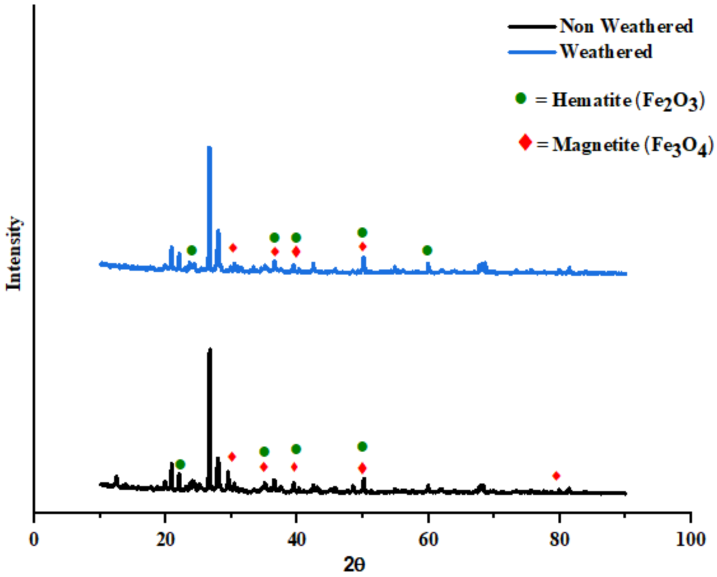


Figure 5. XRD analysis for detecting magnetite and hematite minerals in non weathered and weathered sample of basaltic andesite rock.

Table 2. Percentege of magnetite and hematite minerals and Fe_3O_4/Fe_2O_3 ratio

Location	Sample	Wt (%)		Ratio
		Fe_3O_4	Fe_2O_3	
Pasir Putih Beach	inner	75.5	24.5	9 : 3
Prigi Trenggalek	outer	43.2	56.8	5 : 7

has decreased. Magnetite minerals (Fe_3O_4) are ferrimagnetic. Ferrimagnetic material has a high magnetic susceptibility (Dearing, 1999). The rock that has been weathered completely contain large Fe_2O_3 (hematite), this occurs because of oxidation reaction. The presence of hematite phase is a natural phase that happen because in the principle of iron oxide particles (Fe_3O_4) will quickly undergo oxidation (Gubin *et al.*, 2005).

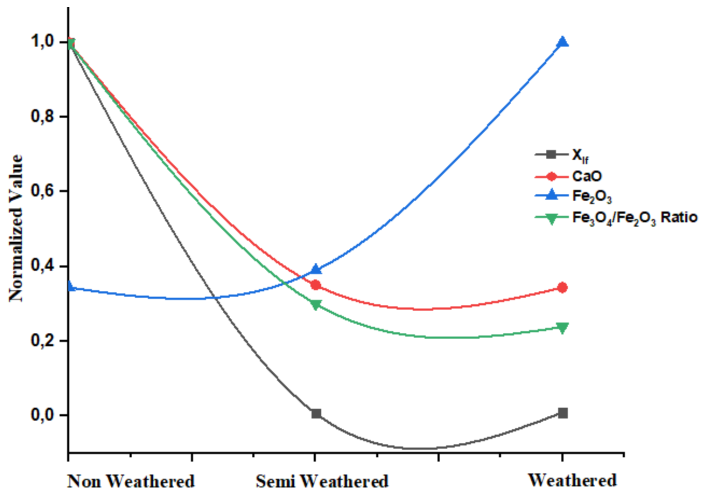


Figure 6. Weathering indicators such as χ_{lf}, CaO, Fe_2O_3 and Fe_3O_4/F_2O_3 from non weathered to weathered samples

DISCUSSIONS

Based on the data analysis obtained in this study, there are three parameters that can be used as indicators of the weathering process, i.e. magnetic susceptibility, the content of CaO and Fe_2O_3 oxide compounds and the Fe_3O_4/Fe_2O_3 ratio. The content of CaO compounds has decreased in basaltic andesite rocks which experienced weathering process up to 30% from non weathered rock. This can also compared with general continental crust data where the average of CaO content is 4.2% down to 1.3% and 2.3% respectively on sedimentary mudrock and suspended load (Allen, 2009). The decrease in value also occurs in magnetic susceptibility, along with decreasing grain size which is marked by the change in magnetic mineral domain from MD to PSD or SD. Decreasing in magnetic susceptibility also occurs in sediment cores that experience weathering due to geothermal alteration (Pandarinath, 2014) and also in igneous rock (Su *et al.*, 2015). Conversely, in rock which undergo weathered has an increase in the amount of Fe_2O_3 due to oxidation of magnetic minerals from ferrous iron to ferric iron as well as the presence of hydration reactions that cause the transformation of iron oxide hematite into hydrated iron hydroxide limonite (Allen, 2009). The increase in the amount of Fe_2O_3 at the same time causes a decrease in the ratio of Fe_3O_4/Fe_2O_3 in weathered rocks. Figure 6 shows a description of decreasing and increasing of these parameters.

CONCLUSSIONS

This study conclude there are two content of oxide compounds, CaO and Fe_2O_3 which can be used as indicators of rock weathering and make it possible to represent weathering levels. The weathering process of andesite basaltic rocks in the coastal atmosphere clearly indicated from the change in the content of CaO compounds which has decreased and Fe_2O_3 which has increased. In addition, weathering of basaltic andesite rocks indicated by decreasing the value of low-frequency magnetic susceptibility, χ_{lf} or increasing of magnetic susceptibility frequency dependence, $\chi_{fd(\%)}$. The decreasing in Fe_3O_4/Fe_2O_3 ratio also occurs in basaltic andesite rocks which undergo weathering processes. These parameters have been tested and thus can be re-tested for other types of rocks or the same rock in different atmospheres.

ACKNOWLEDGEMENTS

Outhors gratitude to thank to DRPM High Educational Ministry through Hibah Thesis Magister 2018 with contract number 19.3.13/UN32.14.1/LT/2019, where the first author become a principal researcher. We also thanks to magister student, Arif Juliansyah, Eka Yuliana Agustine and Moch. Bagas Setya Rahman due to their assistance during sampling and preparation process.

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