Identification of Altered Minerals Based on Synthetic Aperture Radar (SAR) For Mineral Exploration in a Tropical Area

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Abstract: Geological investigation by remote sensing using surface physical properties in tropical regions is challenging. To minimize the effects of atmosphere and vegetation in the obtained optical images, we used the synthetic aperture radar (SAR) images. The phased array L-band synthetic aperture radar (PALSAR) onboard the advanced land observing satellite (ALOS) was selected due to ability of the L-band to penetrate clouds and canopy vegetation. The polarimetric decomposition method based on Cloude–Pottier classification was used as the basis for backscattering analyses. The Ciseuti area in West Java, Indonesia was selected as the study site due to the existence of mining activities, including gold and galena mines. The identification is focused on the spatial distribution of prospected minerals regardless of cloud and vegetation canopy. The classified prospect zones could be extended using the Cloude–Pottier polarimetric decomposition into moderate random entropy and alpha double bounce scattering at argillic alterations, moderate random entropy and alpha surface scattering at intermediate argillic alterations, and highly moderate random entropy and alpha volume diffusion at advanced argillic alterations. The entropy and alpha extracted from ALOS PALSAR data based on Cloude–Pottier decomposition were very useful for identifying alteration zones.
Keywords: mineral exploration, synthetic aperture radar, alteration, polarimetric decomposition, entropy, alpha.

1. Introduction

Various remote sensing methods have been developed to obtain the most accurate geological information possible. The optical remote sensing is used frequently for mineral mapping because it can provides large amounts of spectral information in the visible, near-infrared, and shortwave infrared regions. This method effectively identifies minerals based on their reflectance spectra. However, optical images are affected by atmospheric conditions and the presence of vegetation can interfere with the reflectance spectra used to analyze the target materials (soils, rocks, or minerals). Synthetic aperture radar (SAR) is advanced to detect geological targets on the ground based on

physical properties of the soil surface in the tropics because of its ability to minimize the atmospheric and vegetation effects [1].

Full polarimetric SAR data can be used to discriminate the target from the earth's surface by measuring the type of scattering generated by the surface [2]. While decomposition techniques have been widely used in the environmental field to classify polarimetric radar data of target surface scattering, its application to geosciences is still rare [3]. Saepuloh et al. (2012) [4] used the polarimetric decomposition techniques of Cloude and Poittier to extract the geomorphology and structure of active volcanoes by using surface roughness at the volcanoes. From the surface roughness they were able to distinguish between surface alterations, hot mud, and hot springs. The level of acidity (pH) in the surface will cause its roughness [5].

Hydrothermal alteration is a complex process that includes changes in mineralogy, chemistry, and textures of rocks. Alterations are generated from the interaction of hydrothermal solutions with rocks in its path under certain chemical-physical condition [6]. Studying alterations is one way to identify a mineral deposit in an area. Using polarimetric Cloude–Poittier decomposition technique and surface roughness enables the classification of alteration zones in the study area.

2. Study Area
The research area focused on the mineral prospects in Ciseuti, Purwakarta. At the coordinates 756345-765375 Em and 9275275-9266245 Nm UTM Zone 48 S (Figure 1). The island of Java was affected by the subduction zone between the Indo-Australian plate and the Eurasia plate, called the Sunda-Banda Magmatic Arc [7]. The presence of volcanic activity in the subduction zone resulted in the mineralization of precious metals and base metals. Geologically, Ciseuti is located in the Bogor zone, where the morphology is generally hilly with rocks predominantly volcanic rocks and sedimentary rocks [8]. The oldest rock formation in this area is the Rajamandala formation. A sedimentary rock formation, Jatiluhur, is also well exposed in the study area. Younger igneous rocks such as andesite hornblende and porphyry diorite hornblende intrude into this formation [9].

3. Data
Data used in this study was collected using the phased array type L-band synthetic aperture radar (PALSAR) onboard the advanced land observing satellite (ALOS) in ascending orbit mode with full polarization (HH, HV, VV, VH) level 1.0. Fieldwork was carried out to collect alteration from ten different locations around the study area.

4. Methodology
Decomposition methods have been introduced in the analysis of two or full polarimetric radar images to interpret the physical characteristics of an object through reflection. One of the latest techniques in decomposition of polarization data is to use eigenvalue analysis to obtain the physical attributes. One of the decomposition algorithms that widely used is Cloude–Pottier decomposition [2] for polarimetric data (covariance matrix or coherence shape). Cloude–Pottier decomposition can be used to convert the highly complex full polarimetric data into three simpler units of analysis, namely entropy, alpha angle, and anisotropy.

$$H = \sum_{i=1}^{3} -P_i \log n \ P_i; \quad P_i = \frac{\lambda_i}{\sum \lambda_i} \qquad (1)$$

Entropy (H) has a range of values between 0 and 1; it shows the degree of randomness object scattering on an object in the Earth's surface and can be referred to as the relative intensity of the scattering i-process. $H = 0$ indicates a single object, a unique, or an object with a low surface roughness. $H = 1$ indicates a random process of backscattering with no dominant object or a surface with high roughness in the coverage area. Thus, when an object on the Earth's surface is single, unique, or has a low surface roughness, the entropy values will tend to be close to zero.

$$\bar{\alpha} = \sum_{j=1}^{3} \alpha_j P_J \tag{2}$$

Another important parameter is the angle alpha, which shows the type of backscattering (of any type of object) that is the most dominant in the observed pixels. The value varies between 0° and 90°. Zero degrees indicates odd-bounce scattering from a flat surface. Even-bounce scattering can be observed around $\alpha = 90°$, while $\alpha = 45°$ indicates dipole scattering.
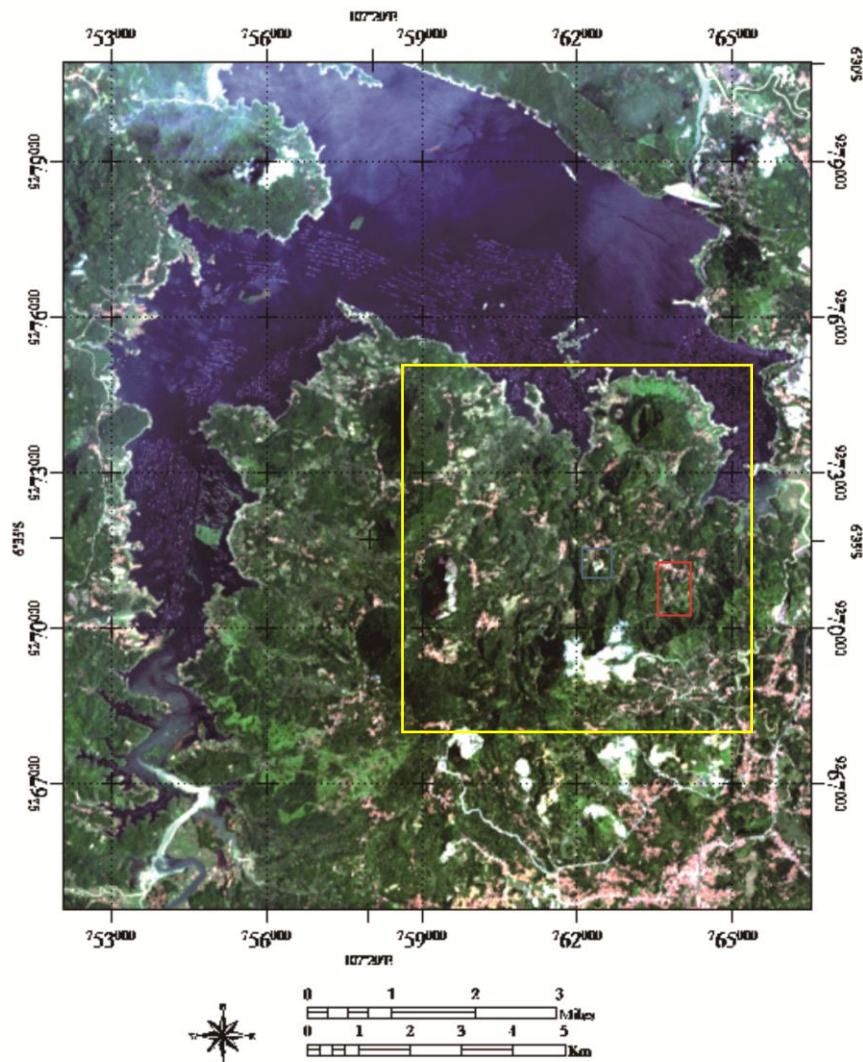

Figure 1. The yellow box denotes the study area, the image was captured from the Landsat 8 (band 4, 5, and 6 in RGB composition).

5. Result and discussion

Before the decomposition classification the data must pass through several processes including focusing and multilooking, followed by geocoding and terrain correction. The process of geocoding and terrain correction requires digital elevation model (DEM) data, in this case we used shuttle radar topographic mission which is available online The geocoding process, the projection map is entered according to the location of the research area, Ciseuti areas is located in UTM 48S zone in the WGS84 datum.
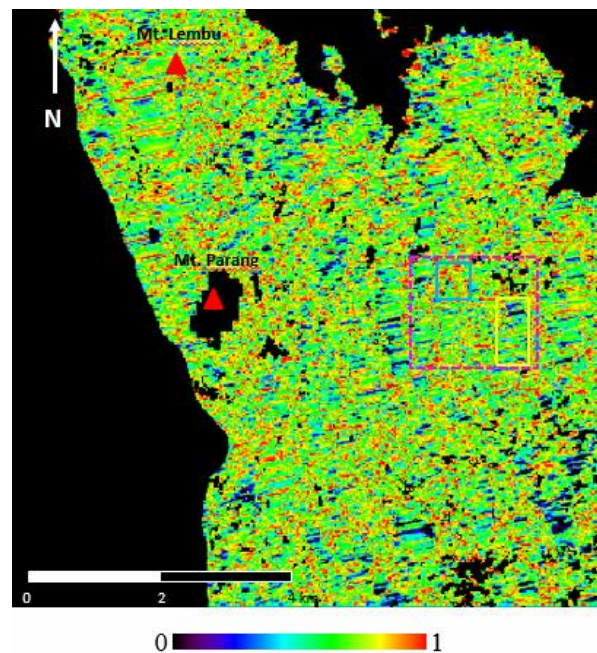
3

Figure 2. Entropy map; Ciseuti area, gold mining site, and galena mining site presented by purple, yellow, and blue rectangles, respectively.
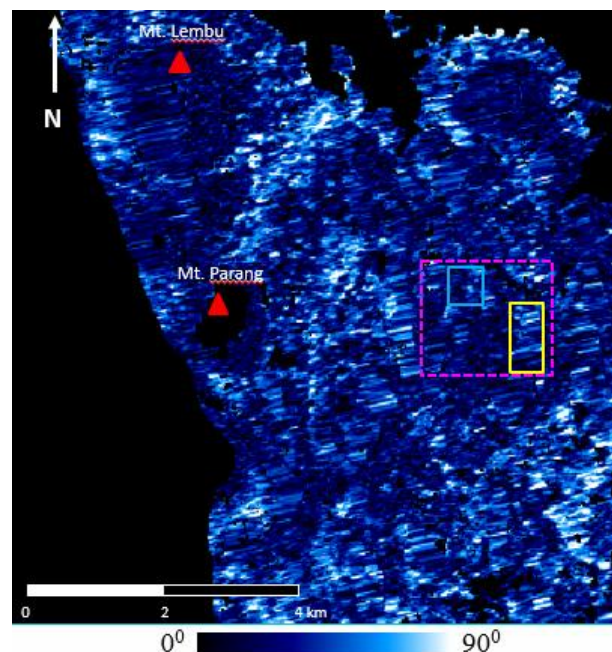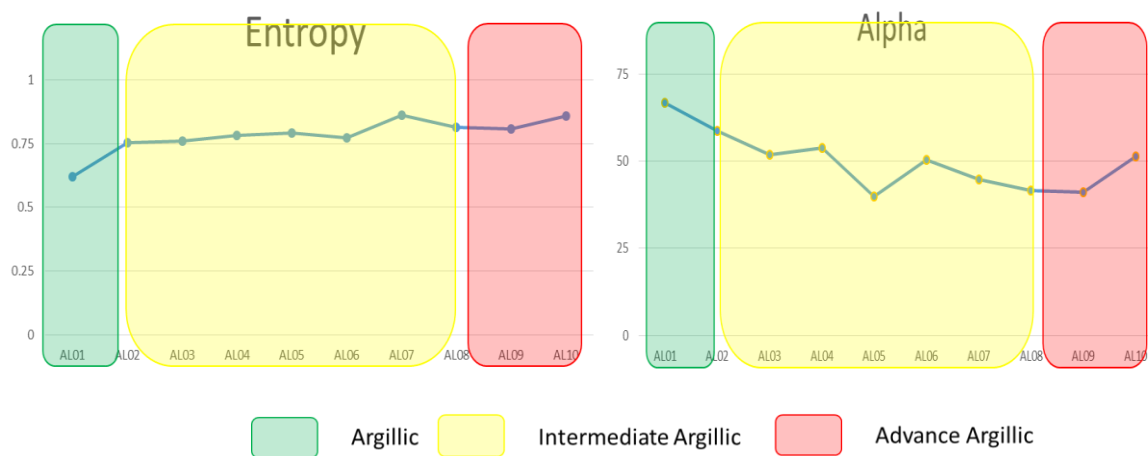

Figure 3. Alpha map; Ciseuti area, gold mining site, and galena mining site presented by purple, yellow, and blue rectangles, respectively

The next process is H/alpha decomposition, which produces the entropy (H) and alpha values. After obtaining these two of parameters, the next process is polarimetric classification based on H / alpha. In the results shown in Figure 2, the minimum alpha value of 24 is shown with a dark blue and the maximum value of 87 is shown in light blue, while the black color represents areas for which there is no data. The minimum entropy value 0.06 is indicated by blue and the maximum value of 0.96 is shown in red; purple represents areas for which there is no data (Figure 3).

Table 1. Values of entropy and alpha, and hydrothermal alteration zone at the observation point.

Code	Easting (Em)	Norting (Nm)	alpha	entropy	Hydrothermal Alteration Zone [10]
AL01	763856	9270696	66.5936	0.6217	"Adularia" — sericite, sericitic, argillic
AL02	763955	9270531	58.6789	0.7537	"Adularia" — sericite, sericitic, argillic
AL03	763855	9270456	51.8378	0.759	Argillic, intermediate argillic
AL04	763749	9270311	53.8481	0.7811	Argillic, intermediate argillic
AL05	762601	9271548	39.9066	0.792	Argillic, intermediate argillic
AL06	762535	9271247	50.3473	0.7735	Argillic, intermediate argillic
AL07	762531	9271296	44.7217	0.8624	Argillic, intermediate argillic
AL08	762475	9270860	41.4975	0.8146	Advanced argillic — acid sulphate
AL09	762392	9270689	41.1937	0.8085	Advanced argillic — acid sulphate
AL10	762484	9271120	51.251	0.8563	Advanced argillic — acid sulphate

Figure 4. Graph entropy value (left) and alpha value (right) at the observation point.

When the entropy value obtained at a point of observation (show in Figure 5) is paired with alteration zones identified by Thompson (1996) [10], then argillic zones, intermediate argillic zones, and advanced argillic zones show different patterns (Figure 4). AL01 and AL02 are argillic zones. AL03, AL04, AL05, AL06 and AL07 are intermediate argillic zones. AL08, AL09, and AL10 are advance argillic zones.

The Cloude–Pottier polarimetry decomposition analysis generates the H (entropy) and α (alpha) values. The value of H, as previously noted, indicates the level of randomness of surface scattering of an object, where the surface roughness is a function of H. The surface of altered rock will be rougher than the surface of unaltered rocks. More acidic rock surface, with a pH value less than 7, will have a higher surface roughness than rocks with a neutral pH or pH close to 7 [5].

The argillic alteration zone is characterized by the presence of clay minerals such as illite, kaolinite, and montmorillonite. This alteration is caused by the process of cations are widely leached in acidic conditions, transforming plagioclase into kaolinite and into montmorillonite at the outer areas. The intermediate argillic zone shows presence of minerals such as montmorillonite, illite, chlorite, hydromicas, and locally kaolinite. The formation of these minerals is related to the availability of limited amounts of K, Ca, and Mg. Advanced argillic alteration refers to complete acid attack with the formation of the mineral kaolinite-dickite and a number of diaspore, alunite, amorphous silica, slightly corundum, and pyrophyllite minerals [6].
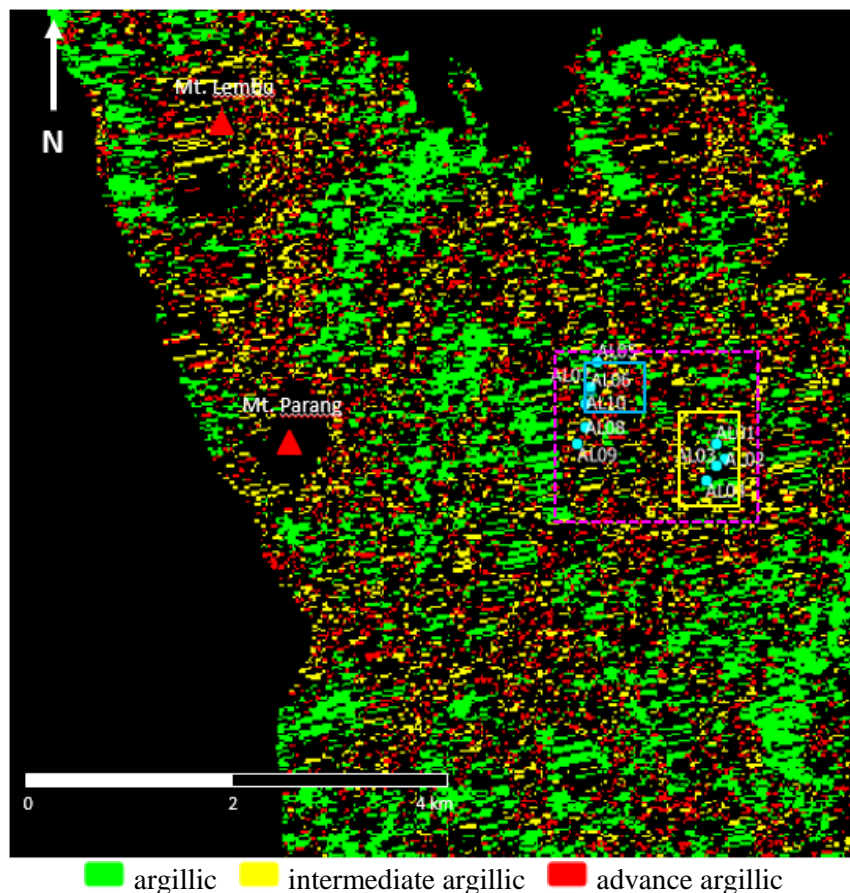

Figure 5. Map of the distribution of alteration zones; Ciseuti area, gold mining site, and galena mining site presented by purple, yellow, and blue rectangles, respectively; blue dots are observation point.

The entropy value of argillic zones AL01 0.6217 and AL02 0.7537 are moderate random entropy. Intermediate argillic zones AL03 0.759, AL04 0.7811, AL05 0.792, AL06 0.7735 and AL07 0.8624 are moderate random entropy. Advanced argillic zones AL08 0.8146, AL09 0.8085, and AL10 0.8563 are highly random entropy. This is because advanced argillic zones have the highest acidity (lowest pH), which causes the surface of altered rocks to be more rugged or rough. Argillic and intermediate argillic zones have lower acidity so that the surface are more smooth then advance argillic. Because higher entropy value causes more rough the surface.

Alpha value based on the number of reflections before the signal received by the sensor. The alpha value of argillic zones AL01 66.59 and AL02 58.68 are double-bounce scattering. Intermediate argillic zones AL03 51.84, AL04 53.85, AL05 39.91, AL06 50.35 and AL07 44.72 are volume diffusion. Advanced argillic zones AL08 41.50, AL09 41.19, and AL10 51.25 are volume diffusion. It's because

on the surface argillic zones little backscatter specular reflection, whereas on intermediate argillic and advance argillic zones moderate backscatter. The backscatter of the signal influence the number of signal reflection before reach sensor.

From the map of the distribution of alteration zones shown in Figure 5, it appears that the area around Ciseuti area is dominated by advanced argillic alteration zones. This is in agreement with the results of research conducted by Dewangga (2014) [8] which also showed that the Ciseuti region is dominated by advanced argillic alteration.

6. Conclusion

Full polarization data obtained from ALOS PALSAR was deconstructed to the distribution of entropy and alpha values. With entropy and alpha values can describe alteration zones base on physical properties of the surface. The advance argillic with strong acid have rougher surface than argillic and intermediate argillic zone, cause rougher surface higher entropy value. Alpha value base on backscatter of the signal from the surface.

Areas of argillic alteration have moderate random entropy and alpha double-bounce scattering. Intermediate argillic zones have moderate random entropy and alpha volume scattering. Advanced argillic zones have highly moderate random entropy and alpha volume diffusion. Ciseuti area is dominated by advanced argillic alteration zones.

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