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Ore Mineralization Characteristics in Hydrothermal Alteration at Mangunharjo and Surrounding Area, Pacitan, Indonesia

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ABSTRACT

The research area is located in Mangunharjo-Grindulu, Pacitan (Indonesia), as part of the Southern Mountain Tertiary Volcanic Arch. Outcrops of quartz veins-riched volcanic rock associated with sulfide minerals are found in this area. The Southern Mountain Oligo-Miocene magmatic arc is known as the potential area that contains precious metal deposits. The study aimed to determine the characteristics of the mineralized zone in this area. The research methods are geological surface mapping, thin-section observation, mineragraphy, and X-Ray Diffraction (XRD). The results show that the constituent lithologies were andesitic lava, breccia, and tuff; co-ignimbrite breccia, dacitic pumice and tuff, and dacitic dike; and pyroxene-rich andesitic volcanic rocks. The geological structure is dominated by oblique normal faults, strike-slip faults, and upward oblique faults associated with shear joints filled with quartz veins. Fieldwork observation, thin-section analyses, and mineragraphic and XRD observations identify three alteration zones in the hydrothermal system: the advanced argillic zone, the intermediate argillic zone, and the chloritized zone. By the mineral's association, it is interpreted that the advanced argillic zone was formed at a temperature of 220-330^{o}C and pH 3-6 due to dissemination with side rocks located near the hydrothermal flows; the intermediate argillic zone and the chloritized zone were formed at a temperature of 150-300^{o}C and a pH of 5-6 due to chloritized alteration of the hydrothermal fluid carrying the ore. This alteration zone has no economic potential for precious metal minerals so it is better to be developed for education, conservation, and natural laboratories.

Keywords: Geology, Ore Mineralization, Hydrothermal Alteration

INTRODUCTION

Mangunharjo Village, Pacitan, East Java, is the western end of the Oligo-Miocene eastern part of the Southern Mountain Range, as a Tertiary volcanic pathway [1] (Fig. 1). The lithology is dominated by volcanic rocks of the Mandalika Formation, Arjosari Formation, and the Early Oligocene-Miocene intrusive rocks [2]-[3]. Regionally, the geological structural trends are horizontal slip faults trending to the southwest-northeast [1]-[2]. So, those are theoretically more related to tectonics than volcanism [2]. The joints formed are known to be filled with quartz and sulfide veins [4]-[7], especially along the Grindulu Fault with a west-east pattern [8].

Quartz veins associated with sulfide minerals in the Tertiary magmatic pathway of the Southern Mountains indicate the potential for precious metals [16]-[17]. Research on mineralization and hydrothermal alteration in the Pacitan-Ponorogo area has been carried out; produce various versions of the study [16]-[17]. Many detailed studies on its characteristics and sustainability have also been carried out. A wiser policy is needed in its development to not damage or eliminate the existing potential. For this reason, a comprehensive study of its characteristics is still needed, so that its economic potential is known.

This study aims to determine the characteristics of sulfide mineralization in the Mangunharjo area and its surroundings so that the results can also describe the geological conditions of the research area for wiser development. Hydrothermal alteration is a complex process of changes in mineralogy, chemistry, and rock textures due to the interaction of hydrothermal solutions with the rock body they pass through under certain chemical and physical conditions [9]. Hydrothermal solutions require fluids, heat sources, fractures/fissures, and volcanic source rocks, so they are usually located in superimposed volcanism, such as the Tertiary Volcanoes of Southern Mountain (Java, Indonesia) [14]. Ore mineralization, in the process of depositing metals with economic values, such as gold (Au), copper (Cu), Lead (Pb), zinc (Zn), and silver (Ag) [10], is often related to hydrothermal alteration [11].

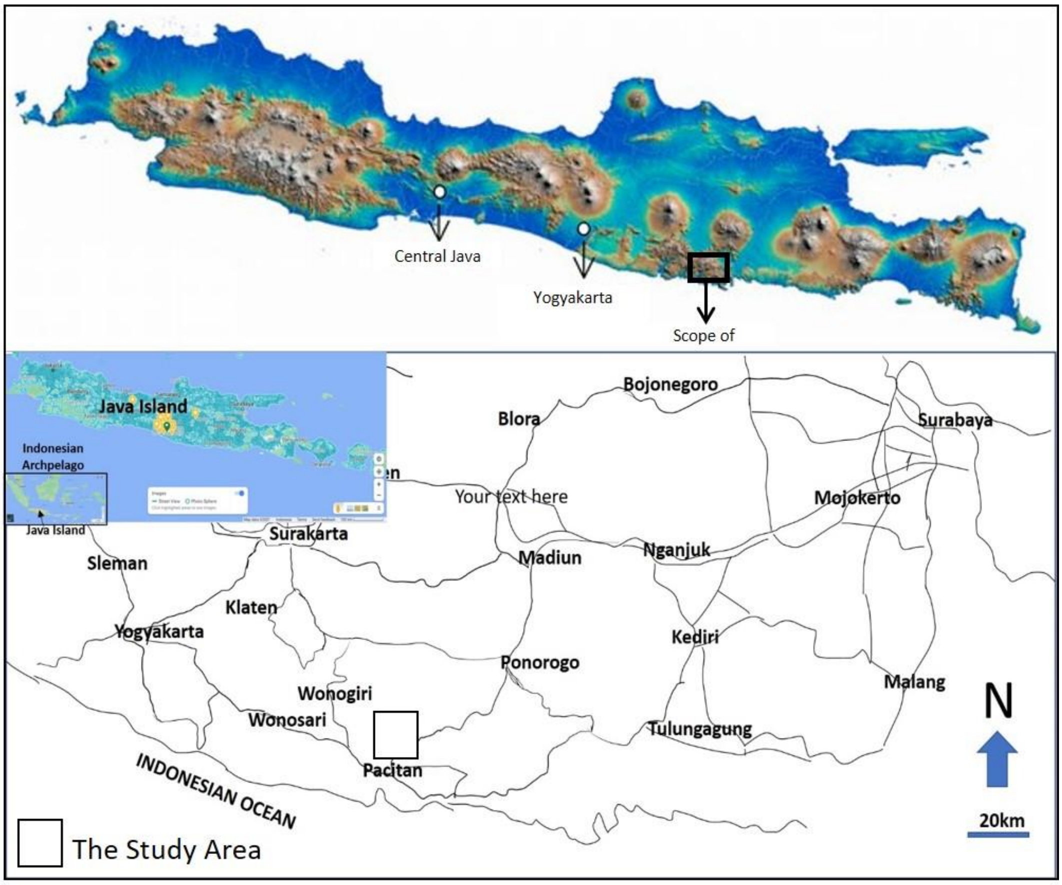

Figure 1. Situation map of the study area

METHODS

This research began with a literature study and the Digital Elevation Model (DEM) interpretation for the nature and geology of the paleo-volcanoes, followed by a surface geological mapping that consisted of identification, interpretation, and recording of the data. The collected field data comprised petrology, geomorphology, geological structures, and the nature of the alteration/mineralization. During the fieldwork, rock samplings and temporary alteration zoning identification was done.

The rock samples taken from the field were prepared for thin-section observations, mineragraphy, and XRD. Observation of thin sections using a polarizing microscope, while mineragraphy using a reflection polarization microscope. XRD analysis used the principle of X-ray diffraction to determine the type of clay and oxide minerals. Identification of clay minerals aims to determine the temperature and acidity (pH) of the hydrothermal fluid that formed the clay minerals. Fluid temperature and pH were used to determine alteration paragenesis and hydrothermal deposit type. The presence of clay minerals and oxides were used as parameters to reconstruct their relationship with hydrothermal mineralization. A total of 12 samples were made of thin-section covering all rock types that support the geology of the research area. Three different rock samples were prepared for mineragraphic analysis and powdered for X-ray Diffraction. The samples were powdered, then reacted with HCl to remove the carbonate content. The next step was the clean samples were dissolved with NaOH, then prepared and shot by X-rays. The results of X-ray diffraction were measured for their intensity. The x-rays intensity and the angle were displayed in the form of diagrams that were analyzed using the Match® software to determine the type of clay minerals present.

RESULTS AND DISCUSSION

The geomorphology of the study area is dominated by a circular dome with steep slopes ranging from 10º-40º, an elevation of 100-750m above sea level, and surrounded by a circular valley. The southern valley is the Grindulu River, which consists of varying altered volcanic rocks, ranging from argillic to zeolite. The circular dome is very strongly cut found in Borang, Kalikuning, Kedungbendo, Ngile, and Gedangan. Generally, it shows trellis till sub-trellis flow patterns; comprises subsequent streams connected by resequent. The geomorphological features are interpreted as controlled by Tertiary superimposed volcanism due to the magmatic arc [1] and tectonism.

Based on the Digital Elevation Model (DEM) that has been clarified during the field mapping, four main fault systems are identified, i.e. (1) The Grindulu oblique sinistral normal fault is trending southwest-northeast; (2) The Pronggo sinistral fault is relatively trending east-west; (3) The Kuniran normal fault is trending northwest-southeast; and (4) The Ngepoh dextral fault is relatively trending north-south (Figure 2). These faults were developed during and after the volcanism as the results of superimposed volcanism triggered by tectonics.

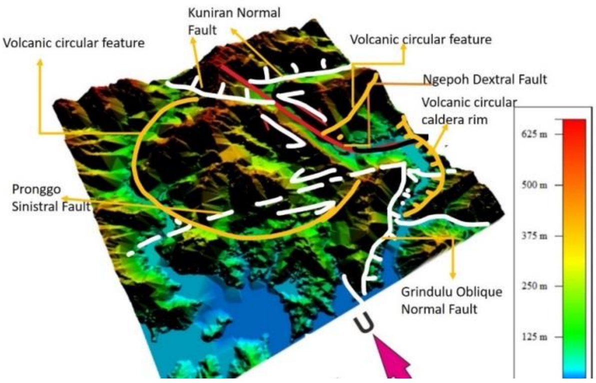

Figure 2. The Digital Elevation Model (DEM) of the research area, shows the geomorphology of circular hills of volcanic origin that have been strongly slashed.

The field mapping identified volcanic rocks, from the bottom to the top, are andesitic lavas, breccias, and tuff; unconformably above them are co-ignimbrite breccias, beds of the lapilli-stone, tuff, and dacite (dike). There are two sequences of andesitic volcanic rocks; one below the dacitic volcanic sequence and the other is above the dacitic volcanic sequence. The lower sequence is deeply altered, while the interpreted upper sequence is less altered. The less altered volcanic rocks mainly compose the circular dome (Kuniran-Jetis Kidul). In comparison, the deeply altered andesitic rocks are exposed along the Grindulu River, Ngile, Ngepoh, and Kalikuning (composing the circular valley). A radiometric dating method is necessary.

As described above, the altered andesitic lavas and breccias are light gray to green color (by containing chlorite), massive, some saw sheeted and porphyritic. The andesitic tuffs are strongly altered forming argillic clay with quartz veins and pyrites within so that the ndesitic breccias. The co-ignimbrite breccias are massive structures, poorly sorted with very angular shape fragments that are composed of andesite, dacite, and pumice in a medium-coarse tuff matrix. Increasingly upward, it is covered by very thick beds of alternating dacitic pumice and tuff that gradually upwards is dominated by the layers of dacitic tuff (Figure 3). Referring to the regional geological map of Pacitan and Ponorogo sheets with a scale of 1;100,000, this volcanic rock is Late Oligocene [2] or from K/Ar dating is 8-42.73 million years ago [12]. Bordered by the Kuniran normal fault, there are less altered until fresh andesitic volcanic rocks. Those are characterized by light grey color, massive structures, and porphyritic, and consist of andesine (as the major phenocryst), amphibole, and aegirine as the mafic minerals grounded within the glass (Figure 4). Some grains of pyrite are common within the dikes.

The thin section observations for the lower andesitic lava identify vesicular, hypocrystalline, porphyritic, inequi-granular, anhedral-subhedral, and composed of andesine, hornblende, ore minerals, and glass; mostly minerals are altered (Figure 5). Some of them have fragment alignments. The dacitic thin section shows K-feldspar, quartz, and albite as the phenocryst, a little bit of biotite and amphibole, and glass as the groundmass (Figure 6).

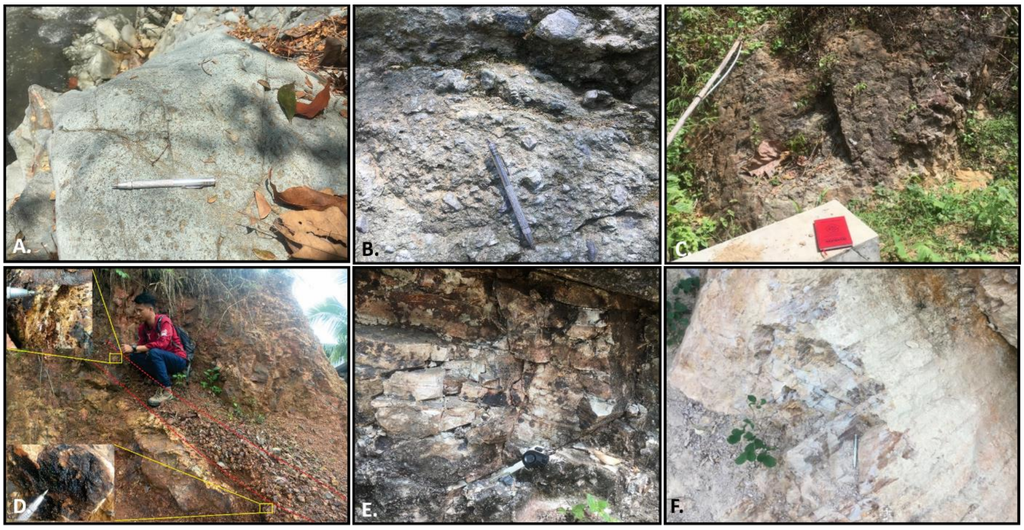

Figure 3. Outcrops of volcanic rocks in the study area. A. Altered andesite. B. Andesitic breccia with chlorite. C. Dacite. D. Upper andesitic lava. E. Andesitic tuff. F. Dacitic tuff.

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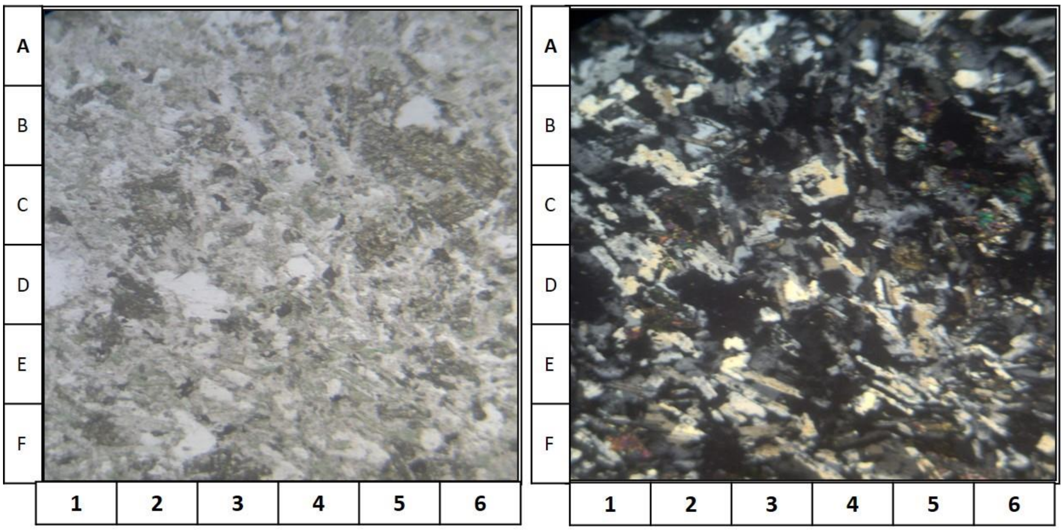
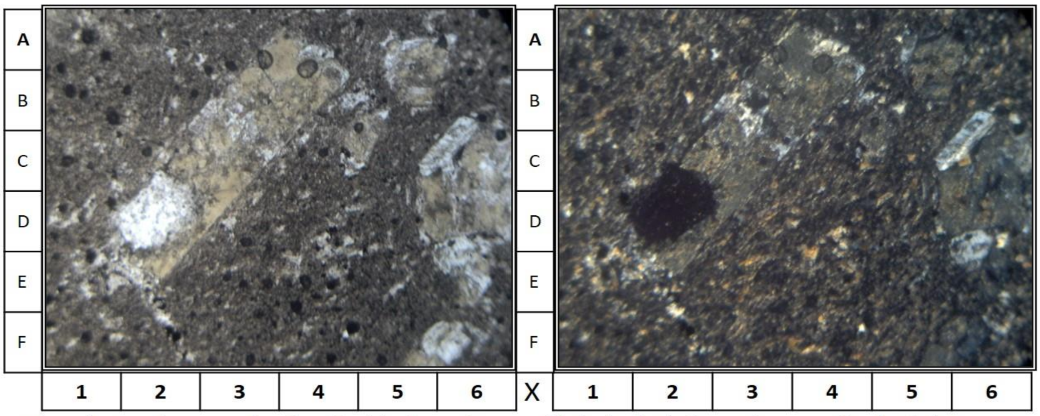
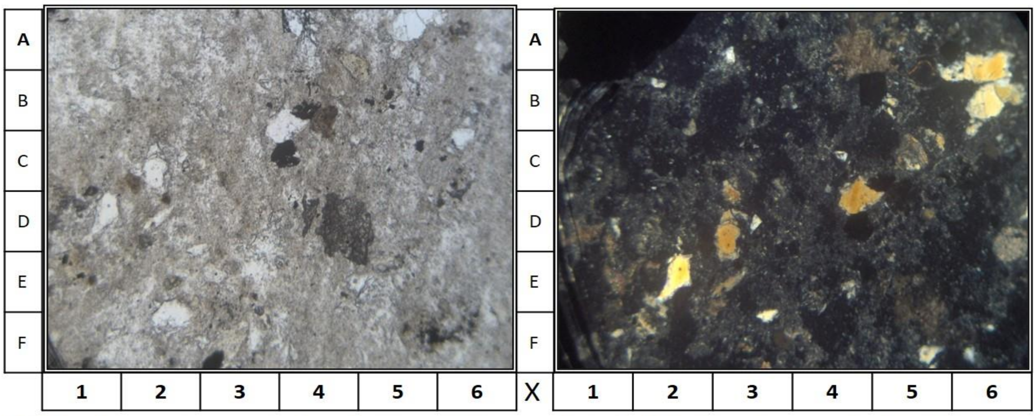


Figure 4. The thin section photomicrograph for the upper andesitic volcanic rocks exposed at Kuniran (left: parallel nicol; and right: cross nicol); is composed of andesine (D1, F4, etc), clinopyroxene (C2, B-C 5-6, and F3)

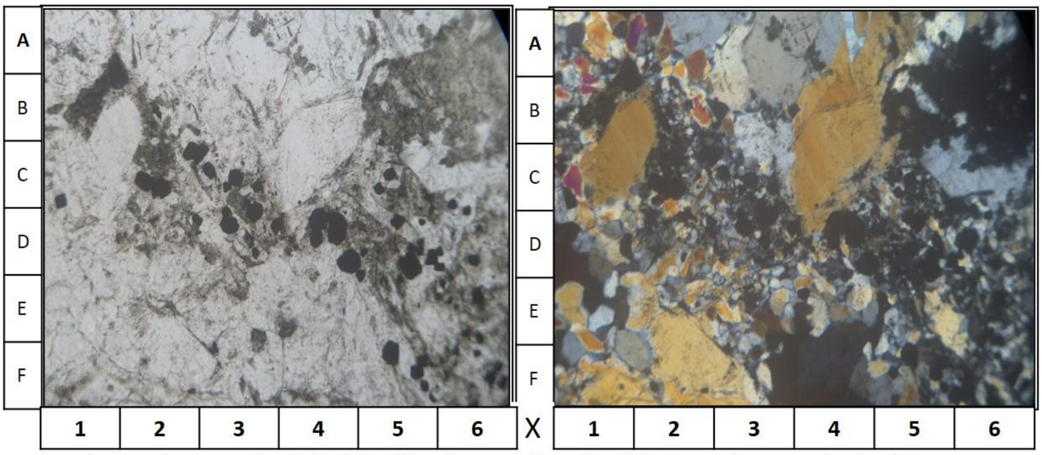


a. The photomicrograph of andesitic lava for parallel nicol (left) and cross nicol (right)

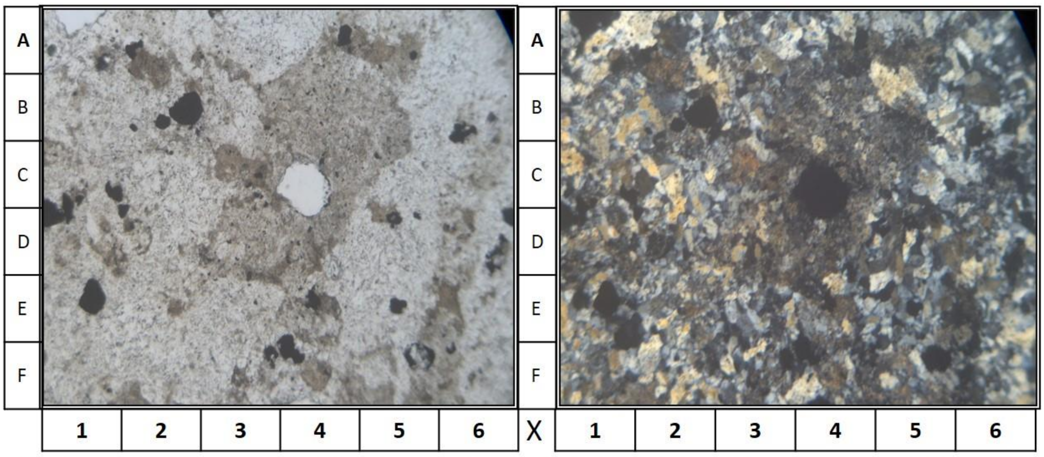


b. The photomicrograph of andesitic tuff for parallel nicol (left) and cross nicol (right)

Figure 5. Thin section analyses for the andesitic volcanic rocks; it is andesitic lava (a) that consists of andesine (A-D1-4), orthopyroxene (E4) (altered), and clinopyroxene in a vesicular structure and porphyritic texture. (b) is showing poorly sorted altered andesitic tuff that consist of altered lithic ash (C-F1-3) and A-B4-5.



a. The photomicrograph of dacitic dike for parallel nicol (left) and cross nicol (right)



b. The photomicrograph of dacitic tuff for parallel nicol (left) and cross nicol (right)

Figure 6. Thin section analyses for the dacitic volcanic rocks; consist of quartz (A-B2-4 and BC-4), albite (B-C1 and E-F1-2), and amphibole (A-B5-6) as the phenocryst of the dacitic dike with massive structure and porphyritic texture (a); the tuff is mostly altered with sericite and chlorite (b).

The mineragraphic analyses of the fluid inclusion of quartz veins taken from Petungsinaran showed the replacement by pyrite, covellite, chalcopyrite, and malachite (Figure 7. a). Samples that were taken from Kebondalem show replacement pyrites, a little bit of covellite that replaced chalcopyrites, and hematite (Figure 7. b). The last samples that were taken from Gedangan showed chlorite, pyrite, a little bit of chalcopyrite, and hematite (Figure 7. c). The X-Ray diffraction (XRD) for the sample that was taken from Mangunharjo-Kebondalem (near Grindulu River) shows quartz, alunite, kaolinite, and dickite (Fig. 8.a), while the sample that was taken from the foot-slope of Gunung Plawangan shows the presence of quartz, montmorillonite, and illite (Figure 8. b).

The results of field observation, thin section analyses, mineragraphy, and XRD, regarding Meyer and Hemley (1967), Rose and Burt (1979) in [15], identified 3 alteration zones with three alteration mineral groups that have different abundances of sulfide minerals, namely the advanced argillic zone, intermediate argillic zone, and chloritized zone.

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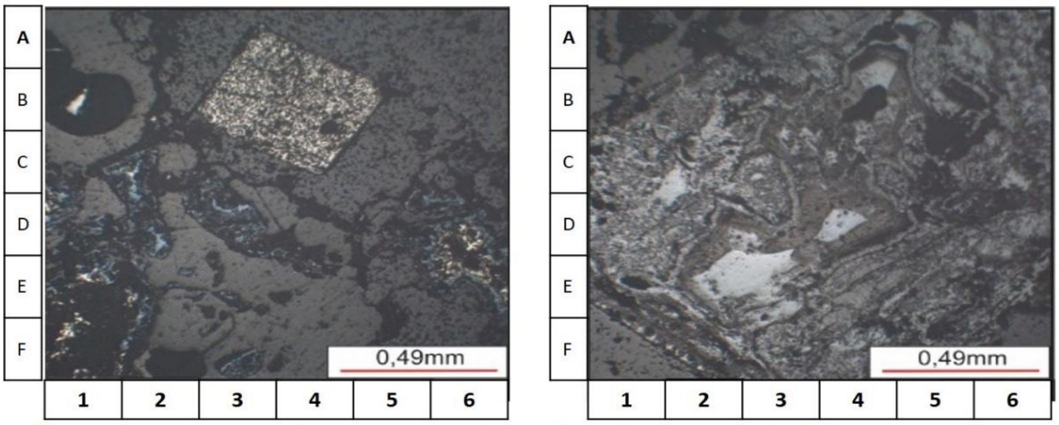
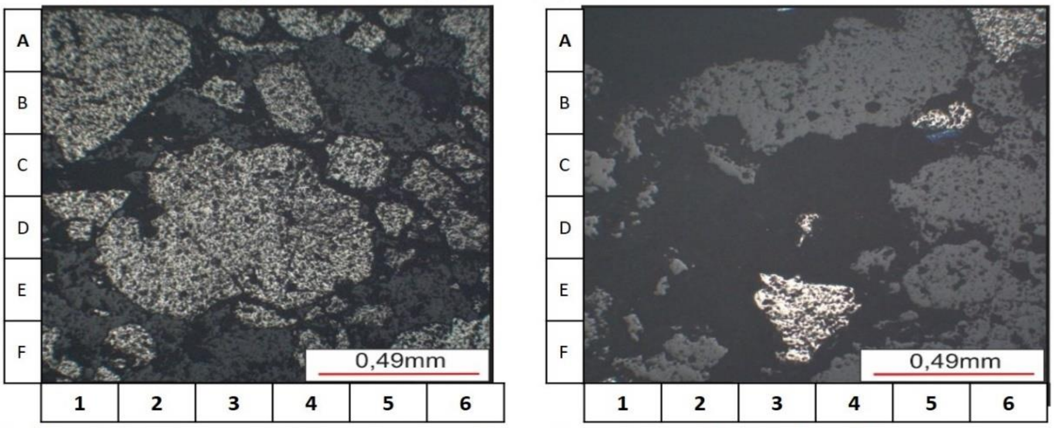
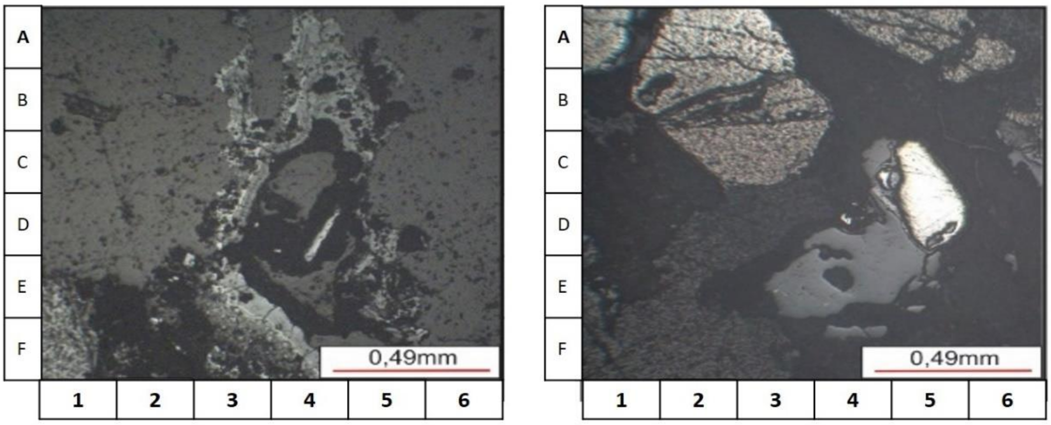


a. The photomicrograph of the mineragraphic analyses for the identified advanced argillic zone



b. The photomicrograph of the mineragraphic analyses for the identified argillic zone



c. The photomicrograph of the mineragraphic analyses for the identified chloritized zone

Figure 7. The mineragraphic photomicrograph of the altered volcanic rocks exposed in the study area. a. The presence of pyrite (B1-3 left), covellite (E1 left), and hematite (D1 right). b. Pyrites are dominant (left), while a bit of covellite starts to replace the chalcopyrite (B5 right). c. Massive quartz (left) with chlorite and pyrite (A-C2-3 right).

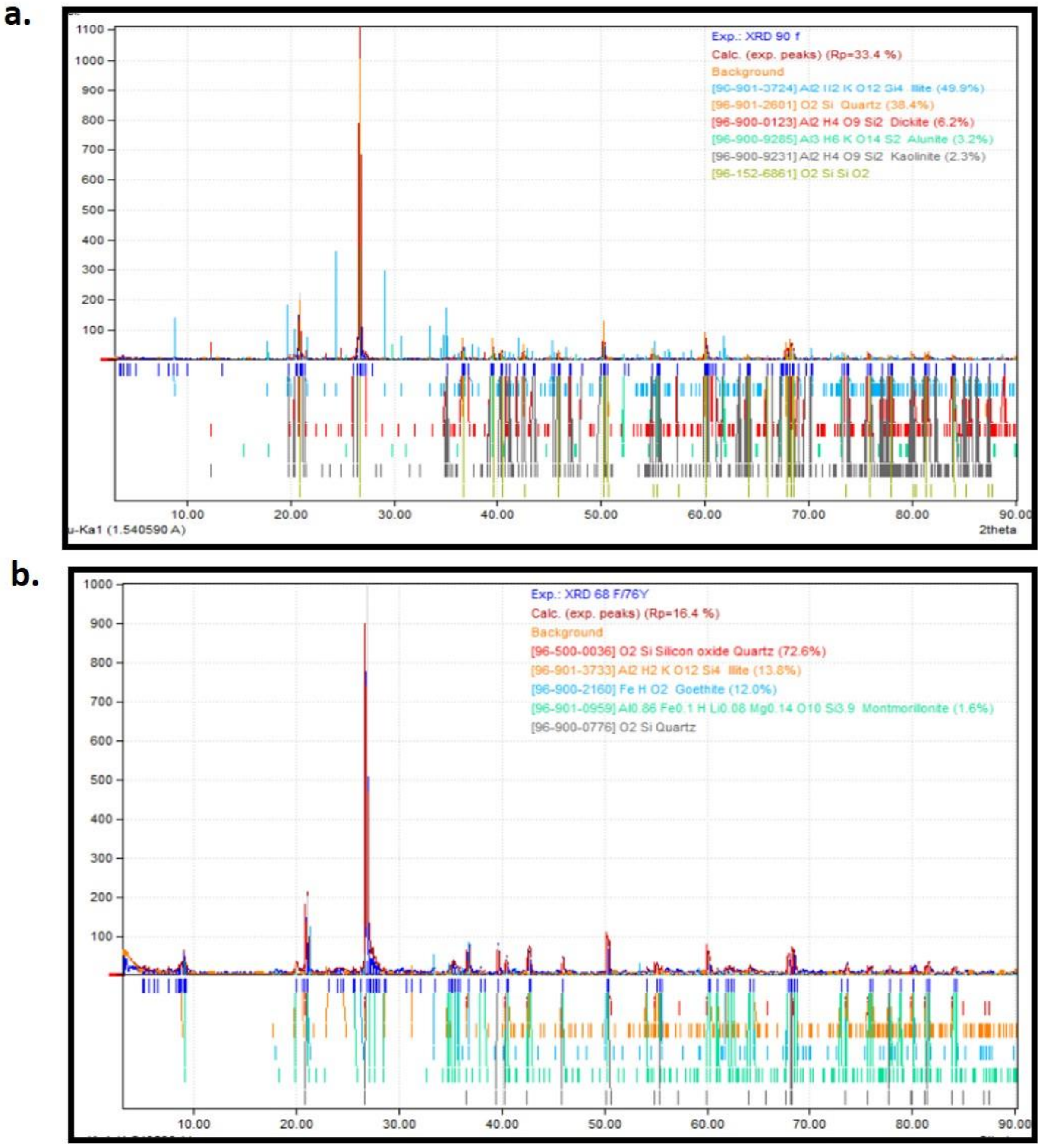


Figure 8. The XRD chart of the altered volcanic rocks exposed at (a) Kebondalem; the graphic shows quartz, alunite, kaolinite, and dickite, and (b) lower Gunung Plawangan; the graphic shows quartz, illite, and montmorillonite.

The advanced argillic alteration zone is characterized by the presence of quartz, alunite, kaolinite, illite, and dickite. The ore minerals are pyrite, chalcopyrite, covellite, and hematite. This zone consists of brown-white-red color andesitic breccia, with pervasive alteration pattern and strong enough intensity, shown by the almost completely replaced minerals. According to Corbett and Leach [13], it was developed within the temperature of about 220°-330°C with a pH range of <3-6. The ore mineralization was disseminated in the wall rocks undergoing a hydrothermal alteration of the advanced argillic zone. In addition to dissemination, mineralization also occurs in quartz veins with a vuggy texture. Pyrites are the most dominant mineral present in this alteration, as disseminated body in the quartz veins. Meanwhile, chalcopyrite is present locally and is being replaced by covellite (Figure 5). This alteration is influenced by the structure (by the vuggy nature) and the permeable andesite breccia lithology as the passage of the hydrothermal fluid.

The second zone is the intermediate argillic zone, characterized by the presence of quartz + montmorillonite + illite; formed around massive and permeable textured quartz veins in the form of andesite breccia (Figure 6). This alteration is controlled by the geological structure and porous rock andesitic breccia. In the field, the alteration is found massive; yellowish white-red, pervasive with moderate to strong intensity; all minerals are replaced. The ore mineral is dominated by pyrite, a little covellite replaces chalcopyrite and hematite.

The chloritized zone is characterized by the presence of chlorite; scattered around the uartz stock and veins; controlled by weak to medium intensity selectively patterned lithology. This alteration is colored green by chlorite. The thin-section analyses and the mineragraphic photomicrograph show that chlorite begins to replace primary minerals; interpreted to form at a temperature of 150°-300°C with a pH of 5-6 [13]. Ore minerals are found in the form of pyrite, a little chalcopyrite, and hematite. This alteration zone is thought to be at the very edge of the hydrothermal fluid source with ores.

It can be synthesized that ore mineralization in the study area was more intensive in the advanced argillic alteration zone, which forms quartz + alunite ± kaolinite + illite ± dickite. It is interpreted to occur due to differences in hydrothermal fluid temperature during the alteration and ore mineralization. In addition, the advanced alteration zone is closer to the hydrothermal fluid outlet than the others. This is inversely proportional to the chloritized zone which is at the very edge of the fluid source, so its ore mineralization is significantly less.

CONCLUSION

All three alteration zones in the study area are related to the hydrothermal system. The innermost alteration produced an advanced argillic zone located in the outer intrusion closest to the hydrothermal fluid flows, followed by the intermediate argillic zone, and the outermost intrusion formed the chloritized zone. The hydrothermal alteration that took place in the study area has unexpected potential for metallic minerals. Its presence, which is more dominated by pyrite, indicates that the alteration process has been advanced so most of the ore of the precious metal has been replaced. As result, there will be no economic potential. This area is more likely to be used as a natural laboratory and education in further use.

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