E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 6 No 1 2021

RESEARCH ARTICLE

Hydrothermal Alteration and Ore Metal Mineralisation at Temon, Pacitan, East Jawa, Indonesia.

Yoyok Ragowo Siswomiharjo Sukisman[1], Sri Mulyaningsih[2*], Radhitya Adzan Hidayah[3]
[1,2,3]Geological Engineering Institut Sains & Teknologi AKPRIND, Yogyakarta, 55222, Indonesia.

* Corresponding author : sri_m@akprind.ac.id
Tel.:+62-821-362-93027; fax: +62-274-563847
Received: Feb 2, 2021; Accepted: March 17, 2021.
DOI 10.25299/jgeet.2021.6.1.6368

Abstract

Pacitan area is known as Tertiary volcanic arc in Java, as the result of subduction zone of the Indian-Australian Plate beneath the Eurasian Plate since Oligocene. It was superimposed volcanism which formed a wide area of hydrothermal alteration zone, resulting potential ore metals mineralization, such at Temon and its vicinities, Pacitan Regency, East Java Province, Indonesia. The aim of study was to analyze hydrothermal alteration and ore metal mineralization zones. Method was surface mapping, thin section analyses, mineragraphic analyses and X-Ray Diffraction (XRD) analyses. Field study observed denuded and deformed volcanic crater geomorphology. There are ore placer deposits within the sand dunes of Grindulu River, which it consists of andesitic lava and breccia of Early Oligocene Mandalika Formation; Early Miocene lithic and vitric tuffs; and dacitic intrusion. The dikes of dacite as the last of volcanism was the host rock controlling the zonation of alteration and mineralization stages. Oblique normal faults and shear faults were cross over dilating formed fractures, which were as bodies to depositing the ore metals. There are (zone 1st) the argillic clay consists of quartz+alunite+dickite+kaolinite±illite with vuggy structures, (zone 2nd) the argillic clay consists of quartz+montmorillonite±illite zone with quartz vents, brecciated and sulfide massive, and (zone 3rd) as the chloritized zone with low grade and supergene on the edge of hydrothermal alteration. It was fluid overprinted that very acid to the core of zone 1st (pH2-4) into more netral pH 4-6 (zone 2nd) and (pH5-6) in the edge zone 3rd. The potentials ore metal mineralization are Fe and Cu by pyrite, chalcopyrite, hematite, and covellite. Other potential ore metal mineralization was also from enargite by the supergene alteration.

Keywords: zonation, alteration, hydrothermal, mineralization, ore, and Cu-Fe

1. Introduction

Study area is located at Temon and its vicinities, Pacitan Regency, East Java Province (Fig. 1). The range of Pacitan, Ponorogo and Wediombo have been widely known as the PT Aneka Tambang concession area since the late 20th century. This area is located in the eastern part of the Southern Mountains, the oldest Tertiary magmatic arc in East Java, due to the subduction of the Indian-Australian plate beneath the Eurasian plate since Oligocene (Sukisman, 2021). The impact is a superimposed volcanic range (Mulyaningsih, 2016). Superimposed volcanoes can potentially produce ore metal mineralization, such Au, Cu and Fe (Prihatmoko & Idrus, 2020). A superimposed volcano is complex volcanoes by periods of repeated volcanic activities that takes place in the same area (narrow), with the same or adjacent volcanic craters or vents, in a long time / era, by magmatism pathways of millions to tens millions years old (Mulyaningsih, 2015; Bronto, 2013). Magmatic activities touched subsurface water (could be water-table or connate water or fossil water) formed hydrothermal water in a very long period. It then altered all of the mineral/host rock around, then releasing heavy minerals from the host rock body that has been altered. The heavy minerals / ore metals then accumulated along cracks (structural geology) through which the hydrothermal water flows / passes. The results were hydrothermal alteration zones, which able to precipitate metal sulfide minerals (Bronto, 2016; Mulyaningsih, 2015).

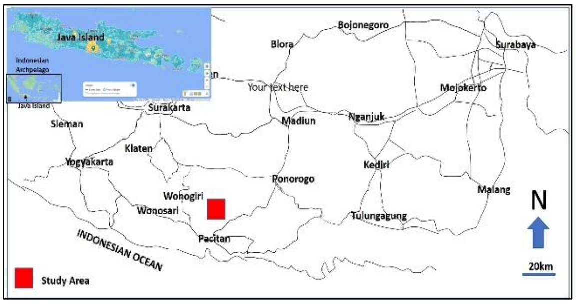

Fig. 1. Situation map of study area (8.030844313005346 S, 111.17895119106147 E)

Altered volcanic rocks are widespread in the study area, which is located in Temon and its surroundings, Pacitan Regency, East Java Province, Indonesia (Sukisman, 2021; Fig. 2). These altered rocks are associated with basaltic, andesitic and dacitic compositions; sequentially as Early Oligocene-Early Miocene of Mandalika Formation and the Early Miocene of Arjosari Formation and covered by Middle Miocene of Punung carbonate rocks (Samodra et al., 1992). Initial assumption was superimposed volcanoes with circular deeply deformed morphologies as results of the repeated liftings of Java Island from sea to land in post volcanism. Regionally, southern Java was formed by three main structural patterns: northeast-southwest of Cretaceous-Paleocene (Meratus) Pattern, north-south Upper Eocene-Upper Oligocene (Sunda) Pattern and east-west of Miocene (Javanese) Pattern, which is thought still active (Sribudiyani et al., 2003). These patterns of geological structurs are thought to had influenced the filling of sulfide minerals in study area.

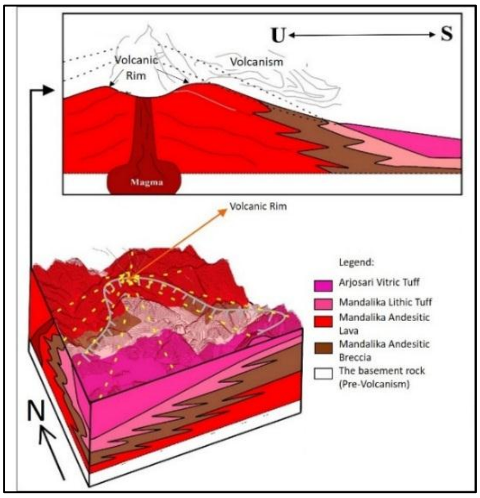

Fig. 2. Block diagram of geological map of the study area that showing the wide-distributed Mandalika and Arjosari Volcanic Formations (Sukisman, 2021)

Aim of study was to analyze zonation of hydrothermal alteration and ore metal mineralization that formed the potentials of Au, Cu, Fe and sulfide minerals. It was approached by surface geological mapping. Hydrothermal alteration is the replacement of minerals and chemical composition due to the interaction between the hydrothermal fluids and wall rocks in maintaining the equilibrium process (White, 1996). Alteration occurs simultaneously with the formation of fractures and filling of veins or gangue along the fractures. The alteration zone is the physical and chemical appearance of a regularly patterned within the altered rock body. Hydrothermal alteration is an initial mineralization process which describes the alteration zoning and mineralization to produce economical ore minerals, although not always. Nguimatsia et al. (2017) argue that hydrothermal deposits are one of the major sources of base metals and precious metals; metal deposits in hydrothermal alteration accounted for 65% of the world's gold from 1984-2006. Ore minerals are minerals containing metals or metal aggregates, which can be processed with economic value; ore minerals can be extracted to produce metals, such as chalcopyrite with Cu and Ag metals, galena with Pb, and argentite and silvanite with Au metal. Metallic minerals that cannot be extracted are not categorized as ore minerals.

Corbett and Leach (1996) classified hydrothermal alteration zone based on the geological environment into 7 groups, i.e: groups of silica, alunite, kaolinite, illite, chlorite, calcilicate and fedspar. **The silica group** formed at pH <2 are associated with titanium seeds, for example: rutile; at temperatures <100°C it forms opal, cristobalite and tridymite; at temperatures of 100-200°C it forms chalcedony, and at temperatures >200°C it forms amorphous silica. **The alunite group** is formed at pH >2 to form quartz, andalusite and corundum at a temperature of 300-350°C, consisting of steam heated alunite from H_2S evaporation at a depth of <1.5km to form filamentous and needle-like minerals, supergene alunite by weathering massive sulfide deposits rich in feroxides. The volatile, magmatic alunite precipitation from the intrusion into the wall rock (the vein and breccias zone) forms the prismatic radier crystals of the porphyry system. **The kaolinite group** formed at pH ~4 form kaolinite at temperatures 150-200°C and propylitics at 200-250°C is limited by dyckite in the transition zone. **The illite group** is formed at a pH of 4-6, a temperature of 150-200°C forms smectite, at a temperature of 100-200°C it forms inter-layering illite-smectite, at a temperature of 200-250°C forms an illite, at a temperature of 200-250°C forms fine sheet mica, at a temperature of 250-300°C it forms larger sheet white mica. **The chlorite group** is formed at neutral pH chlorite-carbonate, at low temperature it forms smectite and at higher temperature it forms chlorite. **The calcsilicate group** is characterized by the appearance of zeolite-chlorite-carbonate at low temperatures and neutral pH and actinolites at high temperatures, at temperatures <150°C hydrous zeolite (natrolite, kabazite, mordenite, stilbit, and heulandite) is formed, at a temperature of 150- 200°C laumontite is formed, at a temperature of 200-300°C it forms wairakit, zeolite zones can form prehnite and pumpellite replacing epidote (Elders et al., 1982) at 180-220°C with poor granular shape, and at temperatures 220-250°C forms good mineral grains, the active hydrothermal system actinolite is stable at 280-300°C (Leach et al., 1983), at 300-325°C the porphyry environment forms biotite , the active porphyry system is characterized by clinopyroxene (>300°C) and garnet (325-350°C). **The feldspar group** is characterized by the presence of carbonate minerals at pH>4 associated with illite, kaolinite and chlorite; and calc-silicate associated with feldspar and chlorite. Albite is formed at neutral pH with high Na^+/K^+ ratios while K-feldspar was at low Na^+/K^+ ratios. Sulfide minerals are formed over almost all temperatures and pH ranges. Alunite is formed at low pH 3-4 and anhydrite at higher pH with temperature 100-150°C, gypsum is formed at lower temperature.

2. Method

This research begins with literature study, followed by surface mapping to identify, analyze and record field data. The geological data included geomorphology, petrology and stratigraphy, geological structures, and alteration / mineralization zones. By surface geological mapping, zoning and identification of alteration and mineralization were also carried out. The field data was also supported by test pit of ~10m depth to observed the fresher altered materials and collect the base metals.

About 10 rock samples were collected for thin section preparations, mineragraphy and X-Ray Diffractions (XRD). Thin section used 0.003mm thick of the rock samples then observed under polarized microscope with 40x magnificent. Those purposed to identify optical properties, textural and mineral composition, especially to the altered minerals. Mineragraphic analyses were done in the laboratory of mineral resources Gadjah Mada University, Yogyakarta. The results were polishing incision with 25x25mm^2 of a very smooth and polished plates. Observations used reflected-ray microscope with 499x magnificent. The result data was photomicrograph of both thin section and polished incisions. X-ray diffraction (XRD) was addressed to identifying clay minerals that exposed at study area, especially for clay minerals formed by hydrothermal alteration. It was did in the laboratory of mineral resources Gadjah Mada University - Yogyakarta.

Rock samples that have been taken were prepared for the purposes of thin section, mineragraphy, and XRD observations. Total samples were 7; have been observed including basaltic-andesitic volcanic rocks, dacitic volcanic rocks and younger andesitic volcanic rocks. Three different rock samples were prepared for the clay mineral analysis using X-ray diffraction method.

All data was collected then compiled as A-Z system, and synthesized using overlay system. Field data record helped the zoning. Each zone was divided based on the presence of key clay minerals that formed within the interpreted zone. Synthesis data used Corbett and Leach (1996).

3. Geological Setting, Magmatism and Alteration Zone

Geomorphology of study area is dominated by hills to mountains with a slope of 14°-42°, elevated 50-700 asl. Structural lineaments with steep slopes on high resistance hills are generally featuring the landform. It's characterized by a semicircular depression with horseshoe landform. There are at least 3 circular features covering three domes (Fig. 3). The circular basins are looked as caldera rims, while the domes looked as volcanic domes. Lithologically, it's composed by volcanic rocks, which are very strongly cut and deformed. Based on the geomorphological features and the composing lithology, this area is interpreted as ancient volcanoes, probably in 6 periods within the same area.

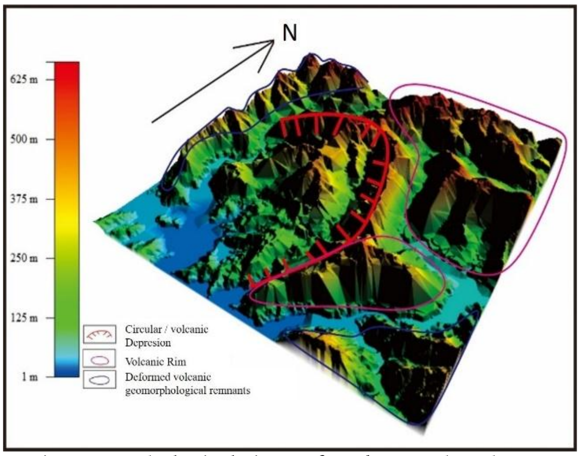

Fig. 3. Morphological views of study area that shows circular feature that interpreted as central of volcanic activities during the Oligocene Mandalika paleo-volcano, the lineaments of the hills around it and the main Grindulu River

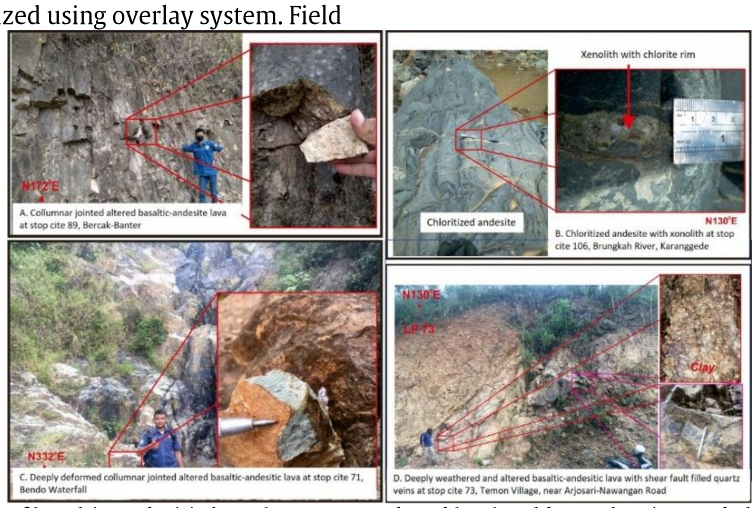

Fig. 4. Some outcrops of basaltic-andesitic lava that were produced by the oldest volcanism and altered rocks in various grade, i.e., xenolith with chloritized rim at Karanggede (low grade alteration) and quartz veins ass the high grade at Nawangan

The interest thing that should be attended is the subdendritic to subtrellis drainage pattern; with the main streams are Grindulu River and Ngepoh River. Those rivers are meandered and contain ore metal placer deposits. The rivers flow along structural lineaments with the circular features, so that looked deformed caldera rims. Mass movements are presenting as long as the cliffs over the rivers. It's seem deformations responsible dominated the paleo-geomorphological processes.

Lava and dikes are characterized by less till deeply altered to form chloritized lava till argillic clay (Fig. 5a-b). Some of them are deeply deformed and filled quartz veins, sulfide minerals such as pyrite, chalcopyrite and clay minerals with fuggy structures. Massive igneous rocks are not known exposed at study area. Thin section observation identified vesicular to amygdaloidal structures in the basaltic-andesitic lava and dike; porphyritic to poikilitic that composed by subhedral to anhedral of fine grains of labradorite, augite, and ore phenocrysts. The polish section identified pyrite, chalcopyrite, enargite, covellite and strong oxidation of hematite, goethite and jarocyte.

The lithology consists of basaltic-andesitic lava and breccia with so many-many andesitic dikes and thin layers of basaltic to andesitic lithic tuff. Those are described as members of Mandalika Formation, age Early Oligocene-Early Miocene. Above them are beds of dacitic-pumicitic lapillistone, tuff, lava and dikes of Arjosari Formation, age Early Miocene. Some of them had been altered forming zeolite and other argillic clays. Above dacitic volcanic rocks are basaltic to andesitic volcanic rocks, by Samudro et al (1992) were grouped as Nglanggeran Formation, age Early to Middle Miocene. Volcanic rocks of the Nglanggeran Formation are described interfingering with rhyolitic pumice, tuff and polymix breccia of Semilir Formation, age Early to Middle Miocene. The Semilir Formation is thickening to the west (Wonogiri). Andesitic-basaltic breccia is characterized by brown color caused by supergene alteration of rich-ores volcanic rocks. Mostly are altered, very rich sulfide deposits especially within the matrix. The breccia often intersects with lava. It's massive but often un-distinct with lava and dikes (Figure 5). Some outcrops show backing effect formed by the repeated dikes. The dikes are characterized by planar columns structures, contain sulfide minerals (pyrite and chalcopyrite), with quartz veins, and some of them looked altered with chlorite minerals (Fig. 7.b). Thin layers of lithic tuff often insert in the beds of breccia.

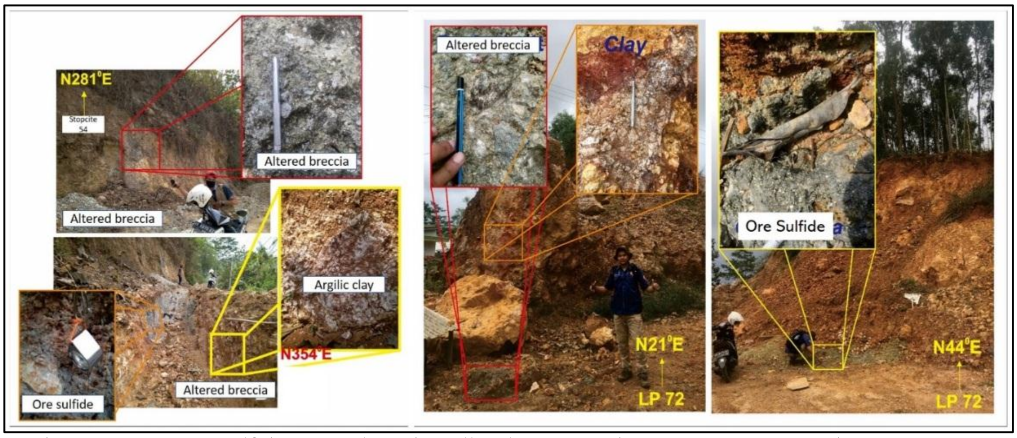

Fig. 5. Altered breccia with ore sulfide minerals and argillic clay exposed at stop cite 53-54 and 101 Ngramen and Temon-Sendang

Polymix breccia with very angular lapilli and block fragments consist of basalts, andesites, dacites, dense-pumice, lithified tuff and cherts in poorly sorted volcanic rocks (Fig. 6) are exposed in the caldera basin (see Fig. 3). The deposits are intersecting with pumice breccia; thinning and finning to the top and the adjacent. These volcanic rocks are also cut by dacitic dikes. These dikes are interpreted as the heat sources that triggering the hydrothermal alteration in the basaltic to andesitic volcanic rocks.

Shear and oblique normal faults are working in those volcanic rocks (both basaltic-andesitic and dacitic materials). Those are the northeast-southwest sinistral normal faults of Grindulu, Karangtengah and Kuniran, north-south dextral normal faults of Brungkah and Pronggo, north-south sinistral faults of Banaran, and northwest-southeast dextral normal faults of Ngepoh. The structure formations of study area were controlled by tectonism after volcanism. These tectonic periods were during Late Oligocene-Early Miocene deforming basaltic-andesitic volcanic rocks of Mandalika Formation and Arjosari Formation which were formed due to volcanism controlled by the subduction zone of the Indo-Australian Plate beneath the Eurasian Plate in the southern part of Java Island. Tectonism controlled in the development of shear faults and reactivated the previous normal faults to be oblique faults, which initially formed downward lines or faults, so that hydrothermal fluid flowed and triggered the mineralization. It complies with the fault formations based on comparability of the previous study (Abdullah et al., 2003), so that five phases of fault formation are obtained. Those were volcanic structures forming normal and oblique faults of Grindulu, Kuniran and Karangtengah; some normal faults were reactivated by younger volcanism forming oblique normal faults of Ngepoh and Grindulu; the next volcanism was followed by tectonism that uplifted Southern Mountain, reactivated Karangtengah Fault, Grindulu Fault, Ngepoh/Kuniran Fault so that oblique near central facies and shear faults on the lower stream; the last phase was north-south shear faults of Brungkah, Pronggo and Banaran.

Fig. 6. Dacitic volcanic rocks exposed at study area; consist of dacitic dike, lava, co-ignimbrite breccia, pumice rocks and vitric tuff

Under the microscope (Fig. 7a-b), the matrix of volcanic breccia is in the form of crystal glass tuff, which can be divided into three types, i.e. chlorinated tuff, fresh tuff (clear) and scoria tuff (blackish brown). The first tuff is pale green; volcanic glass and some crystals have begun to change, generally into chlorite and a little iron oxide (Fig. 8.b). The crystals here are generally plagioclase and pyroxene-clino as well as small micro phenocrysts of opaque minerals. The second tuff is clear in color with a plagioclase phenocryst and pyroxene- clino (Fig. 7d). The third tuff is dark brown in color with a rounded hole structure, as a microscopic appearance of scoria.

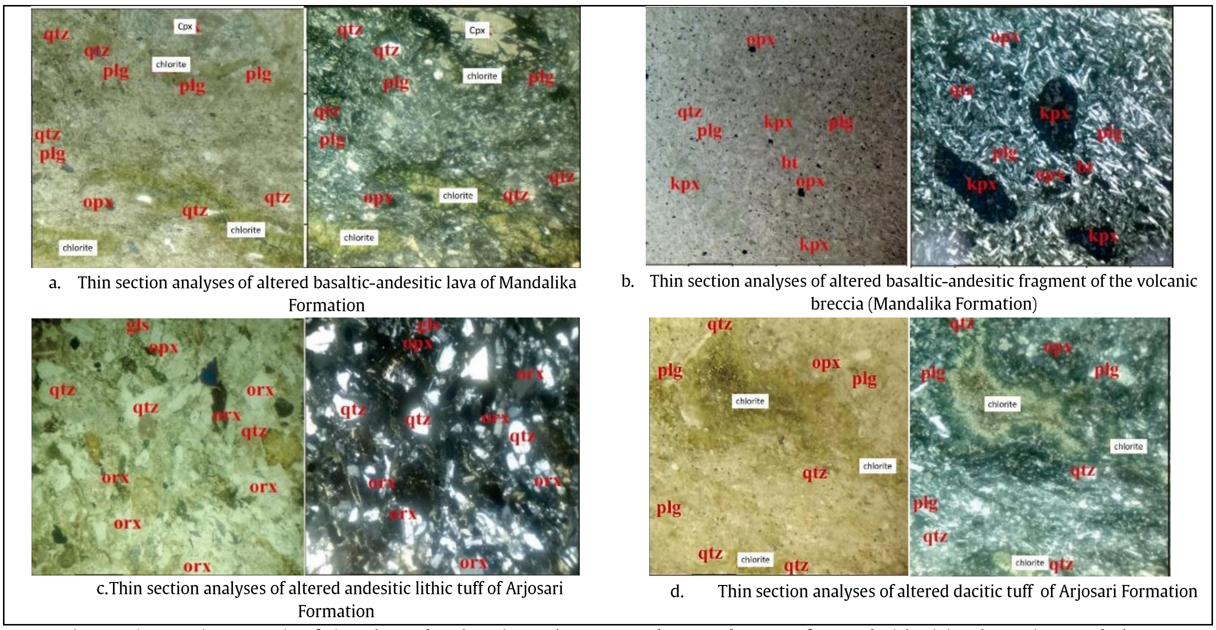

Fig. 7. Photomicrograph of the altered volcanic rocks exposed at study area, formed chloritic alteration and clay.

Further argillic alteration was pervasive; all of consisting minerals were replaced by sulfides, which were existed as dissemination filling in the vuggy zone by pyrite, chalcopyrite, enargite, covellite and the strong oxidation of hematite, goethite and jarocyte (Fig. 8.b). This alteration zone is composed by quartz and alunite with silica vuggy. Based on X-Ray Diffraction (XRD) with 3° shots read clay mineral of alunite, kaolinite, illite and dickite (Fig. 8.a). Overprinting was identified based on the mineragraphic analyses of the altered clay; shows quarts + alunite + kaolinite + dickite as the first alteration or the central mineralization caused by the dominated fluid and vapor with pH<3 (acid fluid; Corbett & Leach, 1997; Hedenquist et al, 1996). It was more fluid dominated system on the adjacent forming illite by the next higher acidic fluid (pH 4-6) (Corbett & Leach, 1997; Hedenquist et al., 1996).

Fig. 8. Fe and Cu base metals in hand spacemen (a), and the photomicrograph of polish incision for altered breccia (b) and quartz vein (c)

Based on field data recorded deeply altered rocks, medium altered rocks and un-altered rocks. The deeply altered rocks were identified around Grindulu and Ngepoh Rivers, located at Temon area. This area is described as massive altered, as zone of intersection and dilation of Grndulu Fault, Ngepoh Fault and Pronggo Fault (Fig. 2). In this area, pervasive argillic alteration was found shown by all minerals are replaced by clay minerals and sulfide minerals, which are present in dissemination filling within the foggy texture, such as pyrite, chalcopyrite, enargite, and covellite as well as the oxidation of hematite, goethite and jarocytes which are quite strong. Quartz was commonly found as foggy residual and massive. The XRD graphs (Fig. 9-11) show quartz + alunite + kaolinite + dickite mineral set.

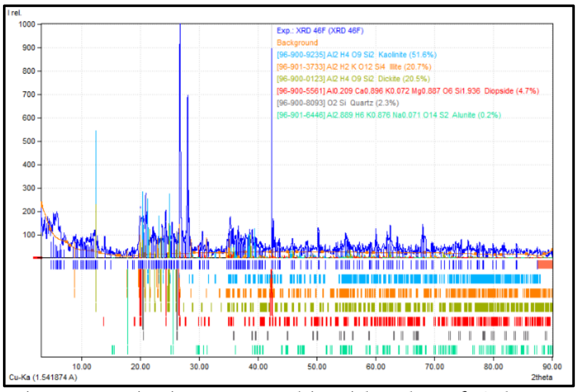

Fig. 9. Quantitative XRD graphic with a shot of 3° shows clay minerals of alunite, kaolinite, illite and dickite.

It was overprinting by difference fluid properties. Originally, it was a set of mineralization stage of quartz + alunite + kaolinite + dickite as the first (in the central fractures) with acidic vapor dominated system (pH <3) (Corbett and Leach, 1997 and Hedenquist et al, 1996). Meanwhile, the edge of the dominant fluid formed illite by a neutral fluid (pH 4-6) (Corbett and Leach, 1997 and Hedenquist et al, 1996). It was in a temperature of 200°-300°C (Fig. 9-10) and pH 3-6 (Corbett and Leach, 1997 and Hedenquist et al, 1996).

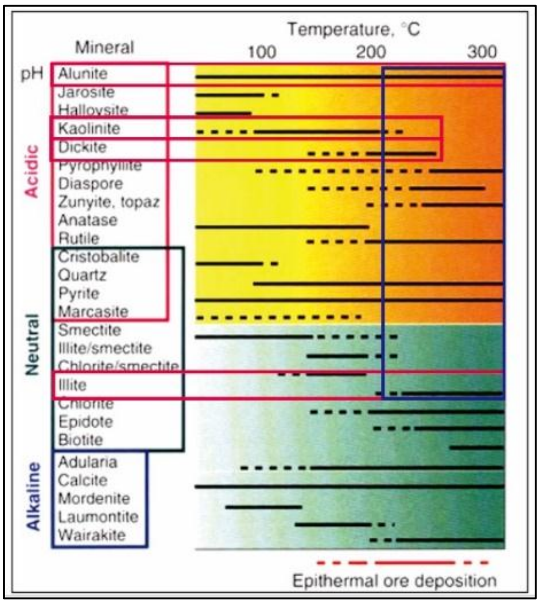

Fig. 10. Estimated temperature range of the advanced argillic alteration zone in the study area (modification from Hedenquist et al., 1996)

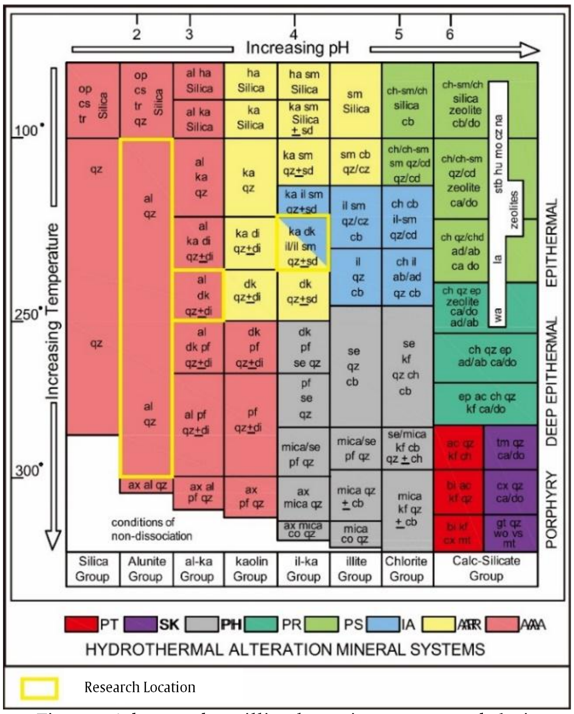

Fig. 11. Advanced argillic alteration zones and their mineral assemblages (refers to Corbett and Leach, 1997)

Middle stage alteration was controlled by two types of quartz + montmorillonite ± illite group. The first type associated with the deeply argillic alteration zone; and the second type was not. The main properties of the altered rocks are grayish-brownish-red and tough or smooth like soap when exposed to water. The deeply altered zone was pervasive; all minerals consisting the wall rocks were replaced by clay and sulfide minerals, by dissemination to fill in quartz veins and in rocks such as pyrite, chalcopyrite, covellite and sufficient oxidation of hematite, goethite and limonite.

Based on the results of the X-Ray Diffraction (XRD) analysis with a shot angle of 3°, clay minerals were found in the form of montmorillonite and illite (Fig 12). This alteration zone is characterized by the mineral assemblage of quartz + montmorillonite ± illite and belongs to the argillic-medium alteration zone according to Corbett and Leach, 1997 (Fig. 13). This alteration forms at a temperature of 185°-220°C (Fig. 14) and a pH range of 4-6 (Corbett and Leach, 1997 and Hedenquist et al., 1996).

Overprinting's by difference fluid characteristics formed quartz+montmorillonite as the first fractures zone that filled by a nearly neutral acidic fluid (pH 4-5) of the temperature of 185°-220°C (Corbett and Leach, 1997 and Hedenquist et al., 1996). It was liquid dominate system forming illite by neutral (pH 5-6) and temperatures around 200°-220°C (Corbett and Leach, 1997 and Hedenquist et al, 1996).

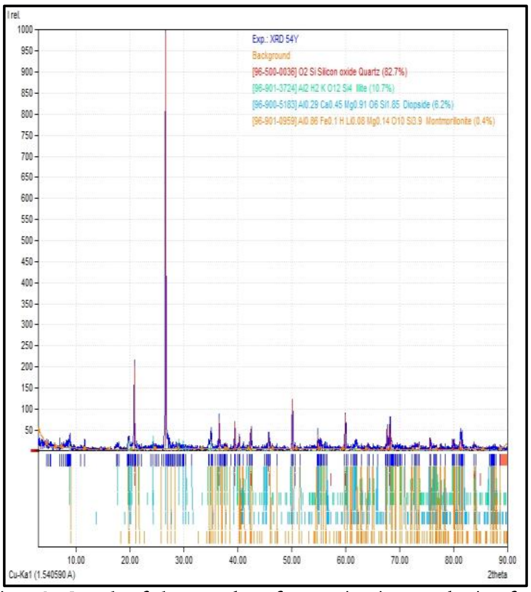

Fig. 12. Graph of the results of quantitative analysis of X-Ray Diffraction (XRD) on LP 54

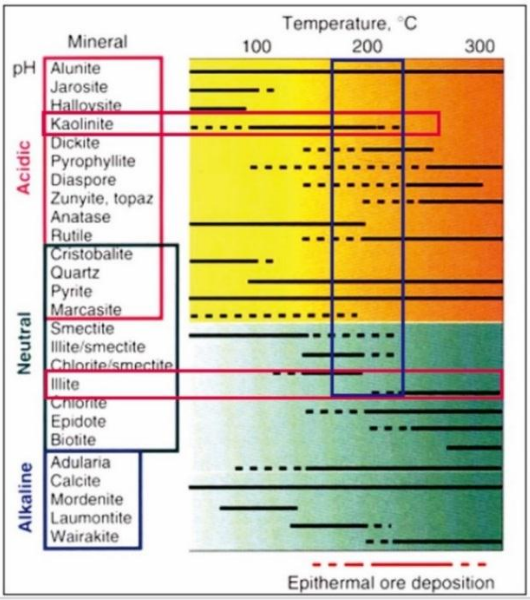

Fig. 13. Estimated temperature range of the alteration zone of quartz + montmorillonite ± illite in the study area (modified from Hedenquist et al., 1996)

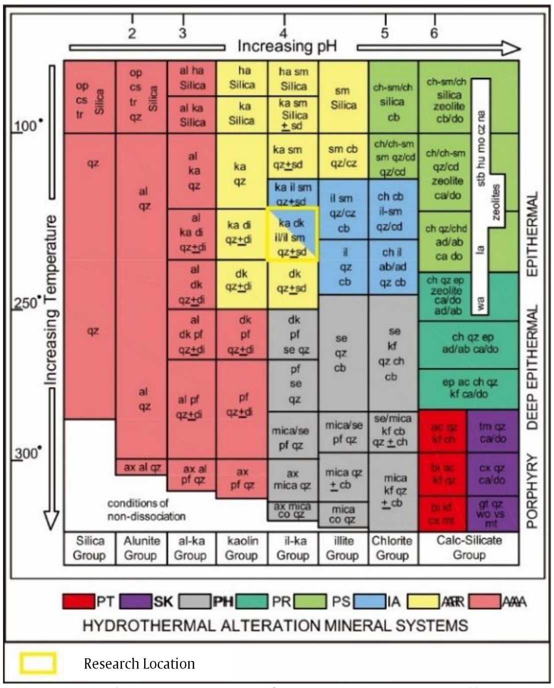

Fig. 14. Alteration zone of quartz + montmorillonite mixed with illite by the argillic to intermediate argillic alteration and their mineral assemblages (refers to Corbett and Leach, 1997)

The last zone of the alteration is chlorinated zone; it formed green-greenish gray rocks. These primary minerals were replaced by selected pervasive elements (Fig. 15). The intensity of alteration varies from moderate to strong. Sulfide minerals presented as filling dissemination by pyrite substitution. It locally intense and increased by moderate oxidation of hematite near quartz + montmorillonite ± illite alteration zone and the advanced argillic alteration zone (Fig. 16). it is interpreted that this alteration zone was formed at a temperature of 135-300°C and pH of 5-6 (Corbett and Leach, 1997).

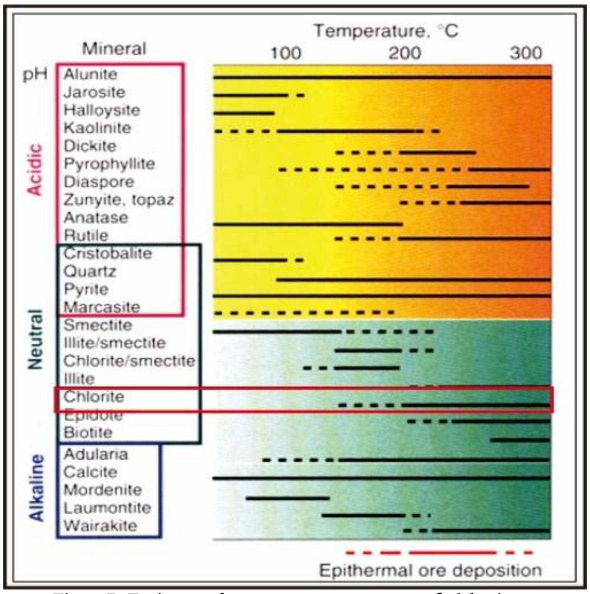

Fig. 15. Estimated temperature range of chlorite alteration zones in the study area (modified from Hedenquist et al., 1996)

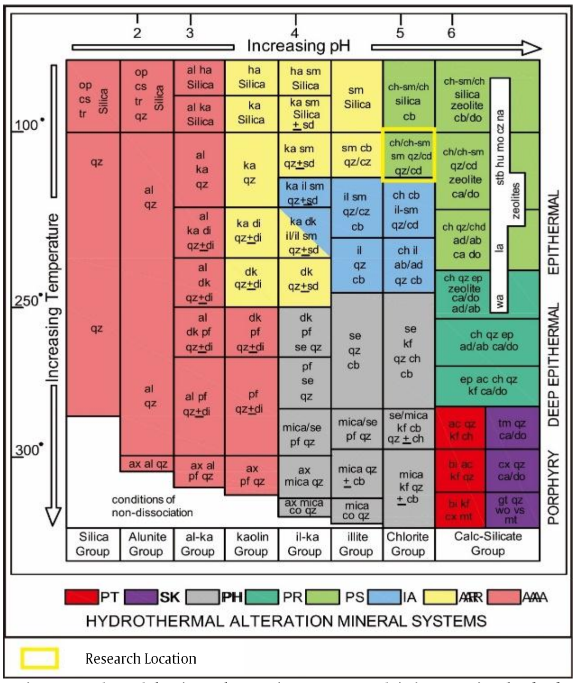

Fig. 16. The chlorite alteration zone which was included in the propylitic zone mineral association in the study area (modification from Corbett and Leach, 1997)

4. Discussion

Field data recorded volcanological phenomenon, happening during Oligocene till Middle Miocene. Some data tend to lead that there was superimposed volcanism. Three periods of constructive volcanism and two periods of destructive volcanism were occured. By repeating tectonism and magmatism, those periods of volcanism developed hydrothermal fluids within shears and the opening faults deposited ore minerals, such as sulfides, oxides, and metals in a long time. By endogen and exogen energy, those ore minerals were alternately accumulated, replaced, substituted, and disseminated into secondary mineral deposits. Southern Mountain superimposed volcanism was also proposed by Mulyaningsih et al. (2019), Mulyaningsih (2016), Bronto et al. (2009), and Hartono et al. (2008). Recording secondary economic minerals (i.e gold, ore, titanium and cooper) in Southern Mountain were also proposed by Idrus et al. (2009), Widodo & Simanjuntak (2002) and Ismadji et al. (2015). It's made sense that study area has economic ore minerals potentials related to the hydrothermal controlled volcanism.

Mineragraphic study and thin section observations show altered rocks and mineralized sulfide and quartz as secondary replacement minerals. Corbet & Leach (1990) argued that alteration can perform in 7 type conditions within certain temperature and pH resulted different types of altered clays, as discussed above. Based on the study of altered clays, there are three stages of alteration have been described. It's correlated with the results of the volcanism. The firm contact between chlorinated green tuff and clear tuff (as shown in Fig. 7 photomicrograph) was thought to be the result of hydrothermal alteration to chlorinated green tuff at the time of rising magma to form clear tuff. Meanwhile, the gradual contact between clear tuff and scoria tuff (Fig. 8) indicates a change in the composition of magma at the beginning of the activity with a relatively acidic composition of dacitic Arjosari volcanic formation, then to alkaline at the next stage resulted andesitic volcanic formation of Nglanggeran Formation.

In addition to containing acid gas, such as sulfuric acid (H_2S) and hydrochloric acid (HCl) in chlorinated phase of alteration at study area, the magmatic volatile might also contained water vapor (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), and metal elements as vapor dominated system. As a result of this interaction, the affected rocks (the wall rocks) gradually undergo hydrothermal alteration, ranging from low level (pyrophyllite) to high level which produced various kinds of argillic clay minerals. In the low sulfidation zone, illite and smectite clay were formed followed by adularia (feldspar type). In the high sulfidation zone, the clay minerals that are formed are illite, smectite, kaolinite and alunite. Meanwhile, free silica oxide (SiO_2) will crystallize into cristobalite type quartz. Metal elements react with sulfuric acid gas or sulfur dioxide to form metal sulfide compounds which are deposited more and more so that mineralization of metal ore deposits in high sulfidation areas and ore veins in low sulfidation areas was formed. In general, areas of high sulfidation mineralization were located in conduits below volcanic craters or caldera (Bronto, 2016), while low sulfidation areas are located far outside the volcanic center facies. In some cases, if the supply of hot water vapor was so large that it was able to dilute sulfuric acid in the central facies of the volcano, low sulfidation metal mineralization were formed. Furthermore, in the volcanic center facies, mineralization can develop from the vein / epithermal system to porphyry, both in the mesothermal and hypothermic groups.

Metal sulfide ore minerals were very diverse at study area; one that was commonly found in nature was the pyrite (FeS_2) and chalcopyrite ($CuFeS_2$). For the basic metal groups (Cu, Pb and Zn), the minerals that are generally formed were chalcopyrite / galena (PbS) and sphalerite (ZnS).

5. Conclusions

Study area was volcanic central facies with superimposed volcanism. There were three periods of construction phases and two periods of destruction phases. Those implied to the hydrothermal alteration zones, varying in levels. The highest and moderate levels were mineralized and deposited base metals and sulfide minerals that might potential to economic ore deposits. It needs further studies.

The heat sources of the mineralization were andesitic volcanism since Oligocene (Mandalika Formation), then realtered by the dacitic volcanism in Early Miocene, and re-realtered by the youngest andesitic volcanism in Middle Miocene (Nglanggeran period). By the repeating superimposed volcanism, there were intersecting with tectonism by subduction zone of Indian-Australian plate under the Eurasian plate, built the superimposed volcanic arc.

Acknowledgements

Many thanks are addressed to Geological Engineering IST AKPRIND Yogyakarta to giving the opportunities to get the funding research. A highest gratitude is also spoken to the crew of Resources Minerals Laboratories IST AKPRIND Yogyakarta with the friendly and warm acceptance, deeply supports and fully helps. The last, so many-many appreciations are talked to people and local government of Arjosari Village, Pacitan Regency, East Java Province for the warm full greetings.

References

Abdullah, C.I., Magetsari, N.A. and Purwanto, H.S., 2003. Analisis dinamik tegasan purba pada satuan batuan Paleogen–Neogen di daerah Pacitan dan sekitarnya, Provinsi Jawa Timur ditinjau dari studi sesar minor dan kekar tektonik. *Proceeding ITB Saind & Tek*, *35*, pp.111-127.

Bronto, S., Mulyaningsih, S., Hartono, G. and Astuti, B., 2009. Waduk Parangjoho dan Songputri: Alternatif Sumber Erupsi Formasi Semilir di daerah Eromoko, Kabupaten Wonogiri, Jawa Tengah. *Indonesian Journal on Geoscience*, *4*(2), pp.77-92.

Bronto, S., 2013. Geologi Gunung Api Purba, cetakan kedua. *Badan Geologi, Kementerian ESDM, Bandung, 184pp*.

Bronto, S., 2016. Pengembangan dan terapan geologi gunung api. *Badan Geologi, Kementerian ESDM, Bandung, 370pp*.

Corbett, G.J. and Leach, T.M., 1998. *Southwest Pacific Rim gold-copper systems: structure, alteration, and mineralization* (No. 6). Littleton, Colorado: Society of Economic Geologists.

Daliran, F., 2008. The carbonate rock-hosted epithermal gold deposit of Agdarreh, Takab geothermal field, NW Iran—hydrothermal alteration and mineralisation. *Mineralium Deposita*, *43*(4), pp.383-404.

Hartono, G., Sudrajat, A. and Syafri, I., 2008. Gumuk gunung api purba bawah laut di Tawangsari-Jomboran, Sukoharjo-Wonogiri, Jawa Tengah. *Indonesian Journal on Geoscience*, *3*(1), pp.37-48.

Hedenquist, J.W., Arribas, A. and Reynolds, T.J., 1998. Evolution of an intrusion-centered hydrothermal system; Far Southeast-Lepanto porphyry and epithermal Cu-Au deposits, Philippines. *Economic Geology*, *93*(4), pp.373-404.

Idrus, A., Warmada, I.W., Setyawan, I., Raditya, B.

and Kurnia, M., 2009. Endapan Urat Epitermal Logam Dasar Pb-Zn Daerah Tirtomoyo, Kabupaten Wonogiri, Provinsi Jawa Tengah: Studi Awal mengenai Alterasi Hidrotermal, Mineralisasi Bijih dan Inklusi Fluida. *Majalah Geologi Indonesia, Vol. 24 No. 1 April 2009:* pp. 13-20.

Ismadji, S., Soetaredjo, F.E. and Ayucitra, A., 2015. The Characterization of Clay Minerals and Adsorption Mechanism onto Clays. In *Clay Materials for Environmental Remediation, Springer, Cham.* pp. 93-112.

Liu, Z., Mao, X., Deng, H., Li, B., Zhang, S., Lai, J., Bayless, R.C., Pan, M., Li, L. and Shang, Q., 2018. Hydrothermal processes at the Axi epithermal Au deposit, western Tianshan: insights from geochemical effects of alteration, mineralization and trace elements in pyrite. *Ore Geology Reviews*, *102*, pp.368-385.

Mulyaningsih, S., 2016. Volcanostratigraphic Sequences of Kebo-Butak Formation at Bayat Geological Field Complex, Central Java Province and Yogyakarta Special Province, Indonesia. *Indonesian Journal on Geoscience*, *3*(2), pp.77-94.

Mulyaningsih, S., 2015. Vulkanologi. *Yogyakarta: Penerbit Ombak, 284pp.*

Mulyaningsih, S., Muchlis, M., Heriyadi, N.W. and Kiswiranti, D., 2019. Volcanism in The Pre-Semilir Formation at Giriloyo Region; Allegedly as Source of Kebo-Butak Formation in the Western Southern Mountains. *Journal of Geoscience, Engineering, Environment, and Technology*, *4*(3), pp.217-226.

Prihatmoko, S. and Idrus, A., 2020. Low-sulfidation epithermal gold deposits in Java, Indonesia: Characteristics and linkage to the volcano-tectonic setting. *Ore Geology Reviews*, *121*, p.103490.

Samodra, H., Gafoer, S., & Tjokrosapoetro, S., 1992. *Peta geologi lembar Pacitan. Jawa. Sekala 1 : 100.000. Puslitbang Geologi.* Bandung.

Soeriaatmadja, R., Sunarya, Y., Sutanto And Hendaryono, 2014. Epithermal gold-copper mineralization, late Neogene calc-alkaline to potassic calc-alkaline magmatism and crustal extension in the Sunda-Banda arc.

Soeriaatmadja, R., Maury, R., Bellon, H., Pringgoprawiro, H., Polvé, M., & Priadi, B., 1994. Tertiary magmatic belts in Java. *Journal of Southeast Asian Earth Sciences, 9*, 13-27.

Sribudiyani, N.M., Ryacudu, R., Kunto, T., Astono, P., Prasetya, I., Sapiie, B., Asikin, S., Harsolumakso, A.H. and Yulianto, I., 2003. The collision of the East Java Microplate and its implication for hydrocarbon occurrences in the East Java Basin. *The Twenty-Ninth Annual Convention & Exhibition, October 2003, Proceedings, Indonesian Petroleum Association, IPA03-G-085.*

Sukisman, Y.R.S., 2021. *Geologi dan Alterasi Hidrotermal di Daerah Temon dan Sekitarnya, Kecamatan Arjosari, Kabupaten Pacitan, Jawa Timur, Laporan Skripsi S1, Institut Sains & Teknologi AKPRIND Yogyakarta, 236pp.*

Suyanto, I. and Rugayya, S., 2019. Identification of hydrothermal deposit mineralized zones using the induced polarization method in Kasihan Area, Pacitan, East Java. In *Journal of Physics: Conference Series* (Vol. 1242, No. 1, p. 012046). IOP Publishing.

Warren, I., Simmons, S.F. and Mauk, J.L., 2007. Whole-rock geochemical techniques for evaluating hydrothermal alteration, mass changes, and compositional gradients associated with epithermal Au-Ag mineralization. *Economic Geology*, *102*(5), pp.923-948.

White, N.C. and Hedenquist, J.W., 1990. Epithermal environments and styles of mineralization: variations and their causes, and guidelines for exploration. *Journal of Geochemical Exploration*, *36*(1-3), pp.445-474.

Widodo, W. and Simanjuntak, S., 2002. Hasil Kegiatan Eksplorasi Mineral Logam Kerjasaman Teknik Asing Daerah Pegunungan Selatan Jawa Timur (JICA/MMAJ-Jepang) dan Cianjur (KIGAM-Korea). *Kolokium Direktorat Inventarisasi Sumber Daya Mineral (DIM) TA*.pp: 8.14.