IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 11, Issue 1 Ser. II (Jan. – Feb. 2023), 01-12
www.iosrjournals.org

Gold Mineralization Of The Grindulu River, Ngreco Region And Surroundings, Tegalombo District, Pacitan Regency, East Java Province, Indonesia

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Abstract
The mineralization of gold and other ore minerals in the quartz vein was found in the Grindulu River area and its surroundings. The research area is in Grindulu River and its surrounding, Pacitan Regency, East Java. Grindulu River and its vicinity was the location for the early stage of the research program on mineralization in Pacitan area. This area has good mineralization, and according to previous studies, is a low-sulfidation area with the presence of pyrite, chalcopyrite, and sphalerite. The presence of chalcopyrite, pyrite, and sphalerite minerals has suggested that instead of low sulfidation, based on the results of ICP-MS analysis there are Cu, Ag, Pb, Zn, and Au elements, the area zone state supported by other data such as quartz breccia, banded quartz, and shear as a control structure.Lithology in the area consists of Lava Watupatok and Tuff ofJampang formation inthe Early Miocene.The alteration and mineralization of the research area were classified as propylitic alteration zone with the presence of chlorite, epidote, and calcite mineral, argillic alteration zone with montmorillonite, kaolinite mineral, silicic alteration zone with the presence of quartz-sericite, a bit of calcite mineral. Observed ore minerals are pyrite, chalcopyrite, galena, and sphalerite.The geological structure was controlled by strike-slip or lateral fault in West-East (W-E) Fault, Left Slip Fault N 270^O E/56^O found in the main river body, North-East-Southwest direction Left Slip Fault (NE-SW) was found with position N235ºE/80º almost north-south direction of N 170^O -180^O E and North-South (N-S) faults are found with a position of N190ºE/85ºand northeast – southwest horizontal fault in N 40^O – 50^O E, while the mineralization zone was controlled or following fault pattern of N 170^O - 175^O E.
Keywords*: Mineralization, alteration, sulfidation, sheared*

Date of Submission: 10-02-2023 Date of Acceptance: 22-02-2023

I. Introduction

The presence of gold and its accompanying minerals depends on the amount of sulfide mineralization on rocks inthe area. In the study area, the ore mineral accumulation is mainly on the quartz veins, they are chalcopyrite, pyrite, sphalerite, and galena with Au, Cu, Ag, Pb, and Zn elements andmay occur in epithermal type. Research by geological mapping of the study area was conducted to confirm the presence of the ore mineral elements and their deposit type.

The relation between various deposit types in an area may be observed from the genetic process of continuous magmatic-hydrothermal activity and its fluid dispersion. Gold mineralization zone is usually characterized by small-large quartz veinsand disseminated minerals on rocks or brecciated zone.

Based on a comprehensive understanding of the relationship between various deposit types and various productivestage characteristics in the evolution of the magmatic-hydrothermal system, the exploration is pointing toward the mineralization alteration to focus on the high-potential deposit type. We must fully explore every event to determine whether it satisfies the criteria to be economically feasible.

Research Location

The area of interest is located inNgreco Village, Kemuning, Tegalombo and its surrounding, Tegalombo Districts, Pacitan Regency, East Java Province, Indonesia (Figure 1)

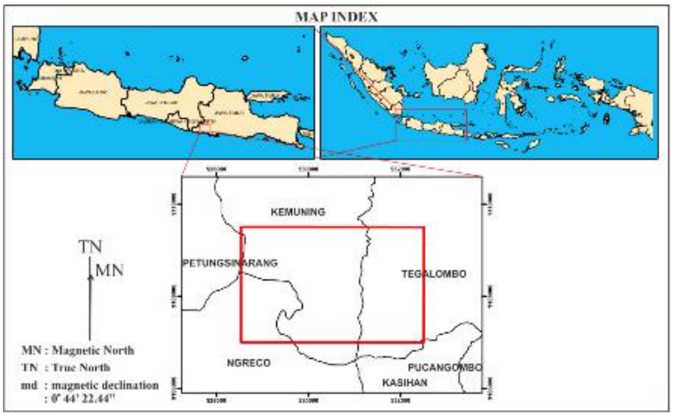

Figure 1. The research area is at Ngreco Village and its surroundings, Tegalombo Districts, Pacitan Regency, East Java Province, Indonesia

II. Methodology

The research was conducted by surface geological mapping combined with analysis of petrology, mineragraphy, structures, and geochemistry.The gold content was identified using FA (Fire Assay) process, whileAg, Cu, Pb, and Zn content was confirmed with ICP (Inductively Coupled Plasma) analysis and XRD (X-Ray Diffraction) analysis.

The stratigraphic observation includes data collection of detailed lithology, rockorientation, rock samples for petrography, samples of altered rock, and mineralization. The local stratigraphic column is based upon the regional stratigraphic column of the Regional Geology of Pacitanmap sheet.

The geological structure of the research area is generally controlled by joints predominantly in North-South and Northeast-Southwest directions (SRTM images). This research will investigate the relationship between the structures found and the presence of alteration and gold mineralization in the research area.

GEOLOGY OF THE RESEARCH AREA

According to the regional stratigraphy from the Geological Map of Pacitan sheet by Samodra, et.al. (1992), the research area is a part of the Watupatok Formation (Tomw) and Arjosari Formation (Toma). Based on the field observation and the result of physical observation analysis, such as lithology, structures, geology, and rock orientation as well as geological cross-sections, the stratigraphy of the study area is divided intoWatupatok Formation Lava Unit and Arjosari Formation Tuff Unit.

The Lava Unit of Watupatok Formation

The lava unit in the research area is found in the riverbed and the side of the road trench, occupying 65% of the total study area. The lithology unit isdominated by andesite lava, small brecciated andesite, and locally basalt lava (Figure 2).

The hydrothermal alteration ranged from strong to unaltered, while quartz veins were found at several observation locations. This unit is ofthe Late Oligocene – Early Miocene age (Samodra, et.al., 1992). The stratigraphic relation between this unit and the Tuff Unit of the Arjosari Formation is fingering.

The Tuff Unit ofArjosari Formation

This unit occupies about 35% of the research area. At the site, the characteristics of this unit are grey for the fresh one,cream color for the weathered,have layering and massive structures, ash--lapillus grain size, are poorly sorted, angular, have open fabric, sialic mineral: quartz and K-feldspar, ferromagnetic mineral: hornblende, accessory mineral: fine ash.The hydrothermal alteration is between strong to unaltered, and veins with mineralization were found at several observation locations (Figure 4). This unit is in the Late Oligocene – Early Miocene(Samodra, et.al., 1992). This unit and the Lava Unit ofthe WatupatokFormation havean interfingering relationship (Figure 3).

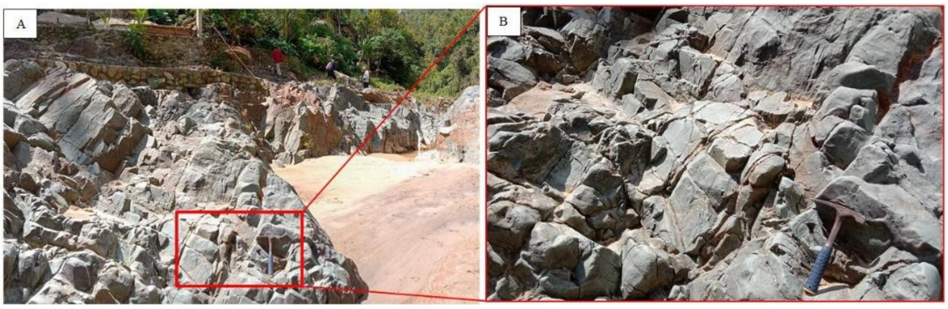

Figure 2. (A) The outcrops of andesite lava with sheeted joints from the Lava Unit of Watupatok Formation at LP 27, the direction of the picture is N 057^{O} E, and (B) the close-up of andesite lava from the Lava Unit of Watupatok Formation.

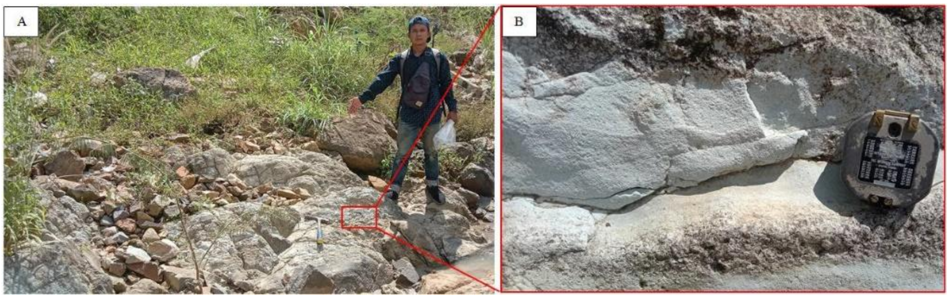

Figure 3. (A) The outcrop of tuff with massive bedding fromthe Tuff Unit of Arjosari Formation at LP 6, with the direction of the picture is N 350^{O} E, and (B) the close-up tuff with massive structure from Tuff Unit of Arjosari Formation

Geological Structure of Research Area

A geological structure is an essential factor in controlling mineralization and has an important role in the distribution pattern of copper and lead ore mineral in the study area. The geological structure was preserved in the rock, causing rock deformation in the area. The geological structure in the study area is distinguished by the alignments of the river valley. The structures present in the field are shear joint, tension joint, and strike-slip joint. Data measurement of the geological structure at the field includes shear joint, tension joint, plunge, rake, bearing, and the joints accompanying shear fractures and gash fractures.

Joints

A joint is a fracture on a rock that to some extent does not undergo significant shifting or translation. Rock that underwent pressure beyond its elasticity strength will break and create a certain pattern. Afracture pattern that is relatively parallel with the direction of stress will forman extension joint, and a jointcreated relatively perpendicular to the stress direction will form a release joint. Simultaneously, a cross-cutting pattern on the joint is created and forms an acute angle with the direction of stress known as a shear joint. The shear joints are easily found on lava units and are mostly filled with minerals. The shear joints in the study area arelargely filled with quartz veins in a relatively north-south direction to the quartz vein orientation.

Faults

The faults in the study area are well-recorded in the Lava Unit of the Watupatok Formation. Based on the stereographic analysis, there are 3 prominent directions of the main faults; West–East (W—E), Northeast–Southwest (N—S), and North-South(N—S). The fault structure might be a factor controlling the mineralization and alteration process in the research area as a channel way of hydrothermal fluid to interact with the country rock. The parameters of fault data measurement are fault plane, slickensides, and data of joints resulting from fault formation. The regional faults whose parameters might not be found wereexamined based on the contour, the distribution of lithology, alteration, and mineralization.

West – East (W—E) Fault

The West-East fault was found on the riverbed in the study area, at the Grindulu River. This fault is well-preserved on the lava rock of the Lava Unit of Watupatok Formation, at LP 12. This fault has a horizontal movement to the left side, named Left Slip Fault. A gradation was found where the silicic alteration at the center of this fault zonetransitionsinto argillic as it goes outwards thenturns into propylitic alteration at the outmost part of the zone. Faultsinthe west-east direction control alteration and mineralization in the research area.

Northeast – Southwest (NE-SW) Fault

The faults in the Northeast–Southwest (NE—SW) direction were found at the main riverbed in the study area, at Grindulu River. These faultsare well-preserved on the lava rock of the Lava Unit of Watupatok Formation, right at LP 24 and LP 28. The fault at LP 28 has a right movement called Right Slip Fault, while the one at LP24 is called Left Slip Fault. The fault in Northeast – Southwest direction is associated with mineralization veins at LP 24 inthe orientation of N235ºE/80º, N237ºE/79º, N233ºE/79º, N233ºE/78º, and N239ºE/82º. The fault zone in the Northeast–Southwest direction is an alteration zone havinga spectrum from the center part of the fault to the outer part, starting from silicic alteration at the center, transitioninginto argillic and propylic outwards. The faults in the northeast-southwest direction control the alteration and mineralization in the research area.

North – South (N-S) Fault

A fault in North-South (N-S) direction was found at the main riverbed in the study area, at Grindulu River. This fault is well-preserved on the lava rock of the Lava unit of Watupatok Formation, particularly at LP 4, LP 11, LP 26, and LP 30. The faults at LP 4, 26, and 30 have left movement, they are Left Slip Fault, Normal Left Slip Fault, and Reverse Left Slip Fault, respectively, while the fault at LP 11 has a right movement which is Reverse Right Slip Fault (Rickard, 1972). This fault is associated with mineralized veins at LP 26 in theorientation ofN190ºE/85º, N220ºE/86º, N223ºE/84º, N165ºE/79º, and N215ºE/83º and at LP 30 having orientation in N190ºE/80º, N193ºE/56º, N200ºE/54º, N190ºE/79º, and N192ºE/83º. The fault in the North-South direction is an alteration zone showing changes from the center of the fault zone to the outer part, starting from silicic alteration at the center, into argillic and propylitic alteration at the outmost part. The faults in this direction generally control alteration and mineralization in the research area.

THE ALTERATION OF THE STUDY AREA

Hydrothermal alteration is a complex process involving changes in mineralogy, texture, and the chemical composition of a rock. The process is the result of interaction between hydrothermal solution and the rocks it passed at certain physical and chemical conditions (Pirajno, 1992). Each type of alteration zoneshasa unique pattern and characteristics which is likely to be identified. The zoning pattern starts from the closest zone tothe ore deposit.

The resultsfrom megascopic, petrographic, and XRD analysis of several altered rock samples in the field show three alteration zones, they are:

1. Silicic type (identified by Quartz ± Illite ± Calcite ± Pyrite mineral)
2. Argillic type (identified by Smectite ± Kaolinite ± Quartz ± Pyrite ± Albite mineral)
3. Propylitic type (identified by Chlorite ± Albite ± Quartz ± Dolomite ± Pyrite ± Smectite ± Illite)

Sillicic Type (Quartz ± Illite ± Calcite ± Pyrite)

The silicic type alteration is manifested by an assemblage of Quartz ± Illite ± Calcite ± Pyrite minerals. This zone is altered in pervasive pattern and strong to very strong intensity (61 – 85% secondary mineral), characterized by the presence of secondary quartz. It is formed at the last phase when volatile-rich hydrothermal fluid emerges through the cracks during the post-magmatic process. After the liquid-rich phase, this alteration underwent leaching and became vuggy, even brecciated, opening a space for the deposition of metals brought by hydrothermal solution. The silicic alteration is formed when the hydrothermal solution is at pH < 2 and at a relatively low temperature, that is <100-150ºC (Corbett dan Leach, 1997). The XRD analysis result of samples of altered silicified rocks at LP 3 shows the presence of Quartz, Illite, Calcite, and Pyrite minerals (Figure 4)

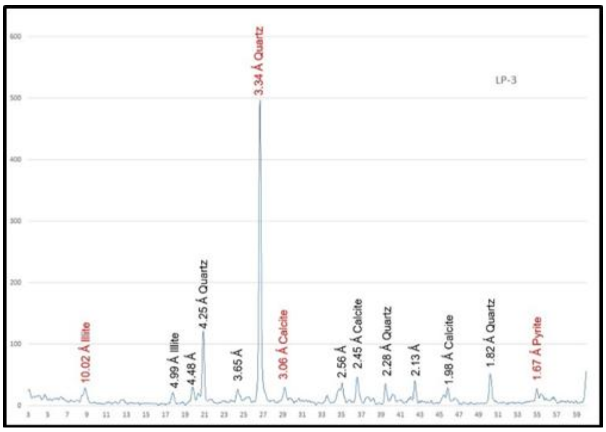

Figure4. The XRD analysis result at LP 3 shows the presence of Quartz, Illite, Calcite, and Pyrite

The petrographic analysis of the silicified rock sample from LP 9 showedan appearance of grey, holocrystalline, fine phaneriticgranularity (<1 mm), anhedral crystal shape, a crystal size of 0.05 – 0.2 mm, inequigranular texture, composed of quartz mineral (60%), clay mineral (30%), and opaque mineral (10%) (Figure 5). Petrographic analysis was performed on the silicified rock sample from LP19 and showedthe presence of intermediate volcanic rock that is silicified, grey, holocrystalline, fine phaneritic (<1 mm), subhedral-anhedral crystal, 0.05 – 0.8 mm in size, inequigranular, composed of plagioclase mineral (labradorite) (5%), quartz (70%), carbonate (15%), oxide mineral (5%) and opaque mineral (5%) (Figure 6). The alteration covers a small areaonly about 4% of the research area, which is commonly found in epithermal mineralization systems. The silicic alteration found in the study area had undergone strong alteration and could be found on andesite lava. The distribution pattern of this alteration is influenced by the presence of structure developed in the study area.

Argillic Type (Smectite ± Illite ± Kaolinite ± Quartz ± Pyrite ± Feldspar)

This zone is characterized by an assemblage of main minerals, they are Smectite ± Illite ± Kaolinite ± Quartz ± Pyrite ± Feldspar. This zone underwent alteration with pervasive pattern and strong intensity (61% of secondary mineral) and is characterized by the presence of white and reddish white color, dominated by clay mineral of Smectite – Illite – Kaolinite. This zone influences the andesite lava unit of Watupatok and the tuff unit of Arjosari. The XRD analysis result taken from the argillic altered rock sample at LP 2 shows the presence of Smectite, Illite, Kaolinite, Quartz, Pyrite, and Feldspar minerals (Figure 7)

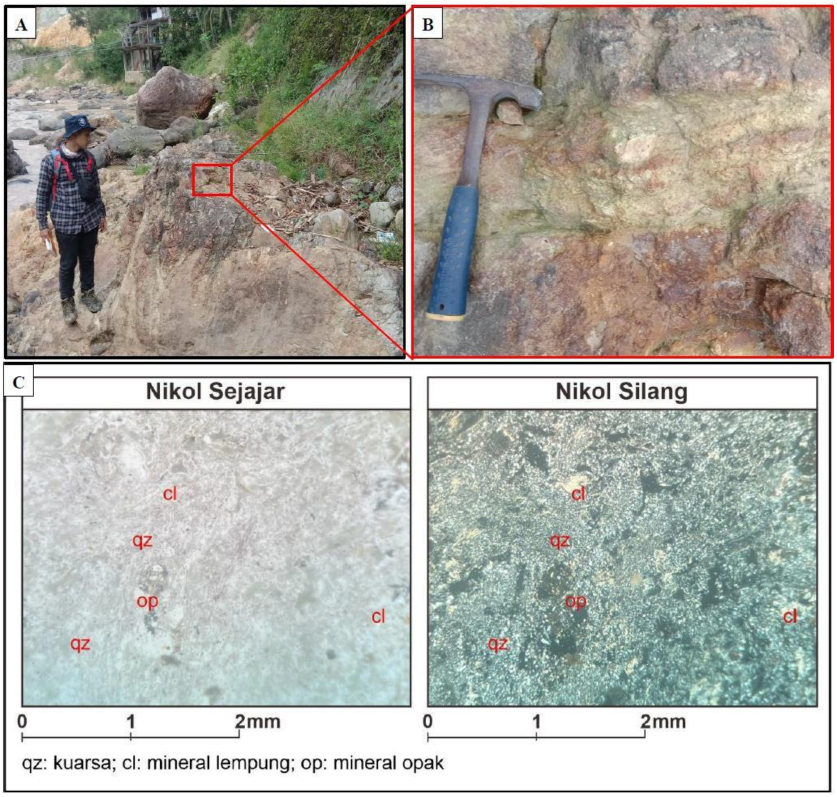

Figure5. (A) The brecciated rock outcrop of the Lava Unit of Watupatok Formation underwent silicic alteration at LP 9 of Grindulu River (picture direction is N 190 E). (B) Close-up outcrop of brecciated rock of the Watupatok Formation Lava Unit which had undergone silicification. (C) The petrographic features of the silicified altered sample at LP 9.

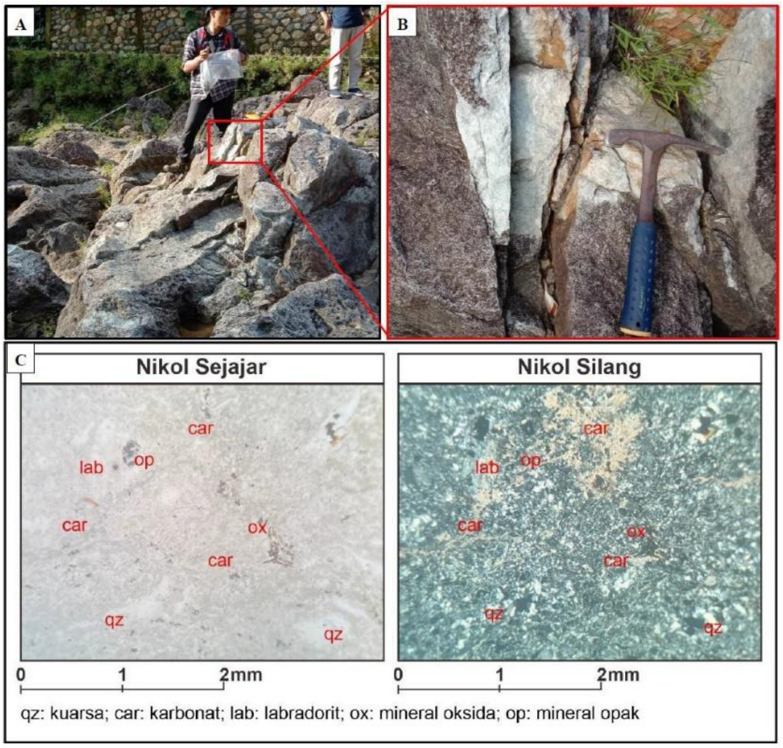

Figure6. (A) The lava rock outcrop of Watupatok Formation Lava Unit underwent silicic alteration at LP 19 ofGrindulu River (picture direction is N 040^{O} E). (B) Close-up outcrops of lava rock of Watupatok Formation Lava Unit which underwent silicic alteration. (C) The petrographic features of the silicic altered sample at LP 19.

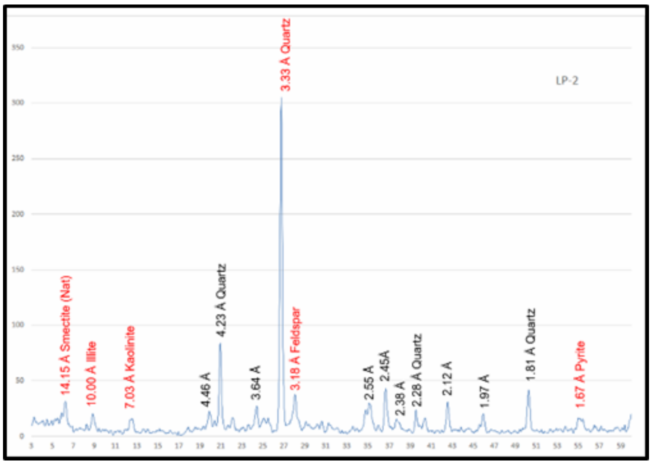

Figure7. The result of XRD analysis at LP 2 shows Smectite, Illite, Kaolinite, Quartz, Pyrite, and Feldspar.

This alteration zone occupies 10% of the research area spreading around the silicic zone inthe area. The distribution of the alteration zone is believed to be vertically controlled by the geological structure which is faults. The argillic alteration is formed at a phase after propylitic alteration takes place with pH 4-5 and a temperature of 200- 250˚C (Corbett dan Leach, 1997). This alteration zone is common to be near the heat source surrounding the silicic alteration zone due to decreasing temperature as it goesfurther fromthe fault line where the hydrothermal fluid emerges.

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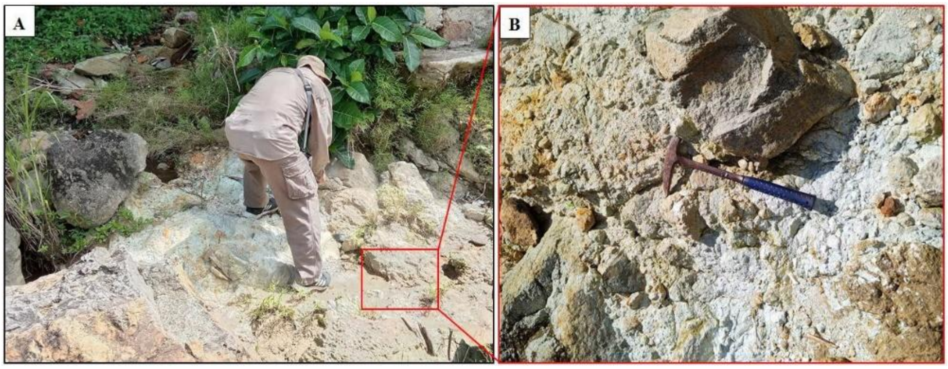

Figure8. (A) Argillic altered outcrops of Tuff Unit of Arjosari Formation at LP 2. (B) Close-up argillic altered outcrop of Arjosari Formation Tuff Unit at LP 2 (picture direction is N 290 E)

Propylitic Type (Chlorite ± Kaolin ± Calcite ± Quartz ± Pyrite)

The propylitic alteration is characterized by the presence of Chlorite ± Kaolin ± Calcite ± Quartz ± Pyrite. This propylitic zone underwent alteration ina nonpervasive-pervasive pattern with low to very strong intensity (24-78% of secondary mineral). In the field, this alterationgenerally still has the texture of the original rock butgreen chlorite mineral begins to appear locally. Some parts had been altered strongly, having a vivid green color. The propylitic alteration was formed in the early phase when hot and volatile-rich hydrothermal fluidemerges through the cracks at high temperatures > 250˚C and pH > 6 (Corbett dan Leach, 1997).

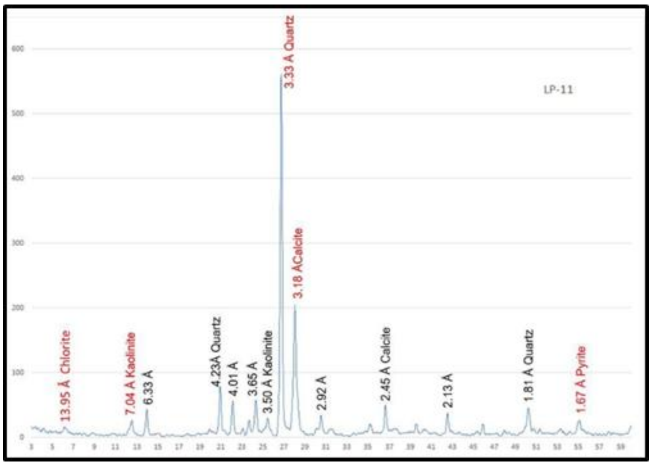

Figure9. The result of XRD analysis at LP 11 shows Chlorite, Kaolin, Calcite, Quartz, and Pyrite

The sample of propylitic altered rock from LP 27 analyzed by petrography shows the presence of alkaline volcanic rock, having greenish grey color, color index of 60%, holocrystalline, the granularity of fine phaneritic (<1 mm), euhedral-anhedral crystal shape, the crystal size of 0.05 – 0.5 mm, inequigranular connection, composed by plagioclase mineral (bytownite) (46%), quartz (4%), k-feldspar (sanidine) (10%), carbonate (10%), chlorite (20%) and opaque mineral (10%). The distribution pattern of propylitic alteration in the study area was controlled by the geological structure developed in the area. The propylitic alteration occupies about 64% of the total research area. Its presence encompasses other alterations and was found at several places in the research area.

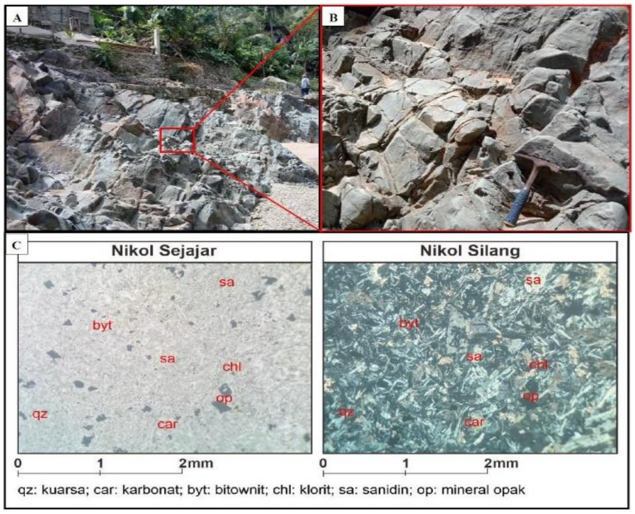

Figure10. (A) The outcrop of basalt from the Lava Unit of Watupatok Formation underwent propylitic alteration at LP 27 in Grindulu River (picture direction is N 057^{O} E). (B) Close-up outcrops of basalt of the Lava Unit of Watupatok Formation underwent propylitic alteration at LP 27. (C) The petrographic appearance of propylitic altered sample at LP 27.

MINERALIZATION OF THE STUDY AREA

The presence of mineralization in the study area was found at the silicic alteration zone. The mineralization is associated with quartz veins (vein, veinlets, and stockwork system) with a width of <1cm—1m, hydrothermal breccia, as well as on the rock body. The pattern of ore mineral deposition found in the study area tends to advance into dissemination and cavity infilling of voids on the rocks. The ore deposit in the study area had been determined by a mineragraphy analysis of six samples taken from the site location in the study area. The ore mineralization found in the study area is Pyrite (FeS_2), Chalcopyrite ($CuFeS_2$), Galena (PbS), Sphalerite (ZnS), Covellite (CuS), dan Bornite (Cu_5FeS_4) (Figure 11, 12, 13, 14, 15, and 16).

The pyrite ore mineral is an ore mineral abundantly found in the research area havinga sizeof<1 – 15 mm. The megascopic and microscopic featuresexhibitdisseminated and spotted textureof mineralization, generally in euhedral – subhedral shape. From the physical appearance in the field and microscopic analysis, the pyrite ore mineral is generally bright golden yellow, cube (regular), black streak, and metallic luster. This pyrite sulfide mineral was found at every site location having quartz vein and silicic alteration zone,from small to abundant amounts.

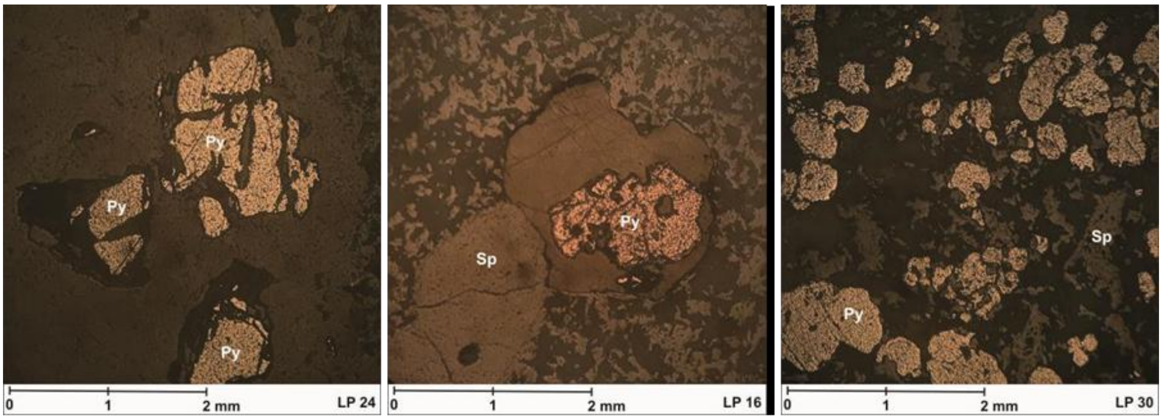

Figure 11. Mineragraphy analysis of the samples at LP 24 (left), LP 16 (middle), and LP 30 (right) shows the presence of pyrite (Py) and sphalerite (Sp) mineral

Chalcopyrite ore mineral has copper yellow color in an anhedral shape. This mineral is relatively dispersed in moderate amounts and concentrated on quartz veins/veinlets and hydrothermal breccia. In the thin section metal mineragraphy analysis, this mineral is often found associated with other ore minerals, they are pyrite and sphalerite. The mineragraphy analysis result ofthe sample from LP 23 shows chalcopyrite mineral is substituted by sphalerite mineral (Figure 13). Chalcopyrite mineral was also found in samples from LP 1, LP 23, and LP 26 (Figure 12, Figure 13, Figure 14).

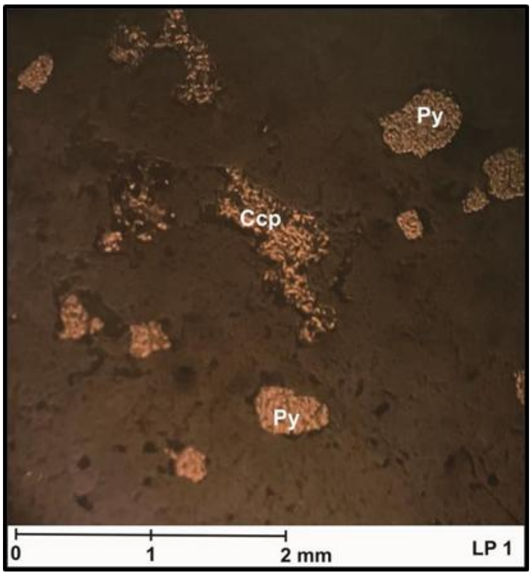

Figure12. The mineragraphy analysis of the sample from LP 1 shows Chalcopyrite (Cp) and Pyrite (Py) mineral

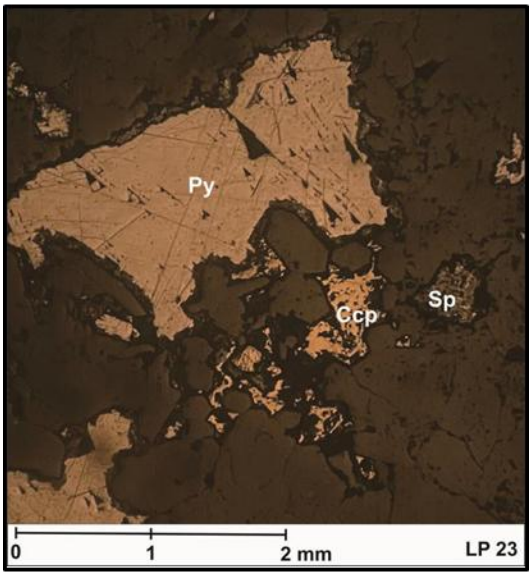

Figure13. Mineragraphy analysis of the sample at LP 23 shows chalcopyrite (Ccp) and pyrite (Py) mineral is substituted by sphalerite (Sp) mineral

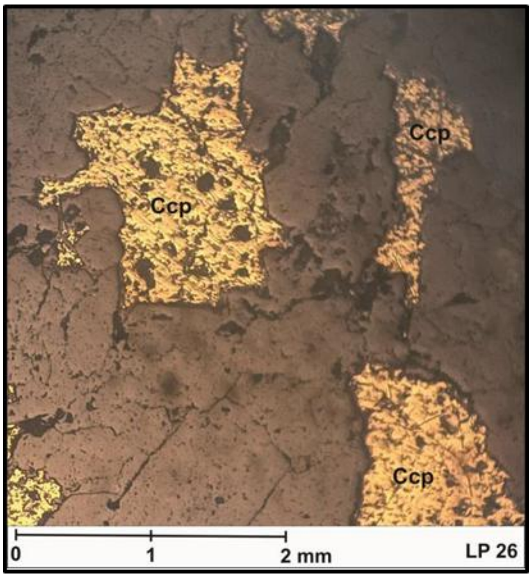

Figure 14. Mineragraphy analysis of the sample from LP 26 shows the presence of chalcopyrite (Ccp) mineral in size up to 2 mm

Sphalerite mineral appears in several cases of analysis on rocks from the research area and was found abundantly after pyrite mineral. Its presence is usually found in veinlets or veins and also in hydrothermal breccia, associated with pyrite or chalcopyrite mineral, characterized by black colorand glass luster. This mineral is seen in dark grey coloron mineragraphy samples of LP 16, LP 30, LP 23, and LP 25 (Figure 13, 14, 15). This mineral is also found substituting chalcopyrite and pyrite minerals observed in the mineragraphy of LP 23 (Figure 13)

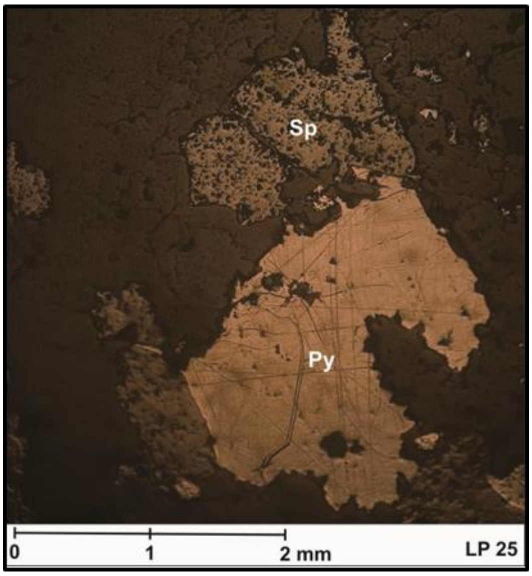

Figure 15. Mineragraphy analysis of sample LP 25 shows pyrite (Py) and sphalerite (Sp) mineral

ICPAnalysis (Inductively Coupled Plasma) and FA (Fire Assay)

The analysis result shows Au (0.01 – 0.22 ppm), Ag (<0,5 – 20,7 ppm), Cu (7- 1104 ppm), Pb (15-92969 ppm), and Zn (7-15770 ppm). The resultexhibits a very small amount of Au and is considered not economically feasible. The presence of Pb and Zn is very high and can be considered to be Intermediate Sulfidation.

NO	ELEMENT	Au	Ag	Cu	Pb	Zn
	UNITS	ppm	ppm	ppm	ppm	ppm
	DETECTION LIMIT	0,01	0,5	2	2	2
	METHOD CODE	FA	ICP	ICP	ICP	ICP
1	LP-1	0,01	1,6	158	15	19

2	LP-13	0,03	2,3	656	72	52
3	LP-15	0,03	<0.5	22	60	33
4	LP-20	0,01	<0.5	55	18	162
5	LP-20 R	0,01	<0.5	53	18	157
6	LP-23	0,13	20,7	1104	92969	15770
7	LP-24	0,01	<0.5	7	54	22
8	LP-26	0,22	2,6	8918	50	27
9	LP-30	0,06	<0.5	15	33	7
10	LP-30 R	0,06	<0.5	15	34	7

Figure16. An example of a quartz vein outcrop containing ore mineral at LP 30

III. Discussion

The analysis result of altered rock shows altered rocksof Argillic, Propylitic, and Silicic. The minerals found were pyrite, chalcopyrite, sphalerite, and galena, while the ICP analysis result exhibits Au, Cu,Ag,Pb, and Zn.

The quartz vein is dominantly in a vuggy texture, bended and massive, thus we consider the study area as a Low Sulfidation epithermal deposit type whereas some places with galena and sphalerite are Intermediate Sulfidation Epithermal deposits. The characteristics of the deposit type in the study area can be compared to the epithermal deposit type by White and Hedenquist (1995), Corbett and Leach (1997),and Sillitoe and Hedenquist (2003) which brings to the conclusion that the study area belongs to the low sulfidation and intermediate sulfidation epithermal deposits type, particularly in brecciated quartz zone, sheared zone or fault zone where galena and sphalerite exist.

Table1. The characteristic comparison of epithermal deposit type and the deposit type of the study area (conclusion of White dan Hedenquist, 1995; Corbett dan Leach, 1997; Sillitoe dan Hedenquist, 2003)

Approach Component	High Sulfidation	Low Sulfidation	Research Area
Tectonic Setting	Magmatic arc	Magmatic arc, back-arc basin, and continental rifting	Magmatic arc
Structure	Main regional fault and multigeneration fractures	Local/regional faults and fractures	Local fault and fractures
Texture	Vuggy, locally vein, breccias	Crustiform, colloform, comb, stockwork, vein breccia, drusy cavities	Crustiform, colloform, druzy, massive, comb, stockwork, vein, veinlets
Host rock	Intermediate acid volcanic rock, mainly rhyodacite (also rhyolite, trachyte, andesite)	Intermediate acid volcanic rock, rhyolite up to andesite and is associated with intrusion and sediment rock	Andesite lava

Ore mineral	Enargite-luzonite, tennantite, high % pyrite, chalcopyrite, tennantite-tetrahedrite, covellite, electrum, native Au, and tellurid	Galena, sphalerite, chalcopyrite, low % pyrite, arsenopyrite, tennantite-tetrahedrite, native Au, Ag, electrum, telluride	Chalcopyrite, pyrite, sphalerite, bornite, covellite
Precious metal/accessories	Au±Cu, abundant As Te	Au±Ag, Pb, Zn, Cu As, Te, Hg, Sb	Au, Ag, Pb, Zn, Cu
Associated, altered mineral	Pyrophyllite, alunite, diaspore, and kaolinite, the Illite and propylitic zone was formed further away	Sericite illite and clay mineral, the propylitic zone is formed further away	Quartz, Kaolinite, Chlorite, Albite, Quartz, Dolomite, Pyrite, Smectite, and Illite.
Alteration type	Silica (vuggy), advanced argillic, argillic, propylitic	Silicic, Phyllic-argillic, propyllitic	Silicic, argillic, propylitic
Conclusion			Low and intermediate sulfidation

Acknowledgment

This research could be accomplished with the aidof various parties. Our thanks to the University of Pembangunan Nasional Veteran Yogyakarta for the opportunities and facilities in the laboratory andthe Director for Research and Community Services University of Pembangunan Nasional Veteran Yogyakarta.

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Heru Sigit Purwanto, et. al. "Gold Mineralization Of The Grindulu River, Ngreco Region And Surroundings, Tegalombo District, Pacitan Regency, East Java Province, Indonesia." *IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*, 11(1), 2023, pp. 01-12.