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Fluid Inclusion and Mineralization of Base Metals in Cretaceous Metamorphic Rocks, in Jiwo Hills, Bayat, Klaten, Central Java

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Abstract - The lack of mineralization research on metamorphic rocks in Java, especially in the Jiwo area, is part of the research interest. The host rock of ore mineralization in the Jiwo area is Cretaceous metamorphic rock located in the hilly area of Jiwo, Klaten, Central Java. The presence of chlorite, actinolite, quartz, epidote, and garnet minerals indicates the metamorphic facies of greenschist. Meanwhile, the presence of glaucophane, quartz, and epidot minerals is a metamorphic facies of blueschist. The metamorphic rock research method was carried out in several stages: 1. Observation; 2. Field data collection, including mapping of metamorphic rock distribution, general geological conditions and rock sampling; and 3. Laboratory analysis. Laboratory analysis testing consists of petrography, ore microscopy, geochemistry (AAS), and fluid inclusion. Alterations that develop in the researched area are in the form of propylitic (chlorite, calcite, epidote), argillic, and silicification (quartz, graphite, calcite, carbonate minerals). Ore microscopy analysis has identified the presence of mineral sulfide such as pyrite, chalcopyrite, bornite, galena, and covellite. In addition, galena was found covered with chalcopyrite. Based on AAS analysis on mineralized metamorphic rocks, Au levels are 0.001 - 0.008 g/t, Ag 0.1 - 2.4 g/t, Cu 4 - 75 g/t, Zn 14 - 166 g/t, and Pb 11 - 60 g/t. The inclusion of fluid from the discordant vein was obtained with a homogenization temperature (Th) of 312 - 435 ^{0}C, with a salinity of 1.95 - 5.05 wt. % eq. with isothermal mixing and heating depressurization conditions. The isothermal mixing process is a mixture of meteoric fluids and metamorphic fluids. Meanwhile, heating depressurization occurs during subduction, so that the temperature is relatively high. The homogenization temperature (Th) of the concordant vein ranges from 168.5 - 296.55 °C, with a salinity of 1.95 -12.6 wt% NaCl eq. A salinity of 12 wt% NaCl is formed due to liquids that are aquos trapped at high pressure and temperature conditions and the devolatilization process that occurs during subduction. Based on the plotting of the homogenization temperature range and the salinity of fluid inclusion, which is 168.5 - 435^{0}C and 1.95 - 12.6 wt% NaCl eq, the type of deposits in the study area is in the range of Au lode or orogenic deposits. The existence of two homogenization clusters in the Jiwo Hill is estimated to be part of the process of forming the blueschist facies with greenschist which is shown in the retrograde actinolite in the glaucophane epidote schist rock which is part of the blueschist facies.

Keywords: Jiwo, blueschist, devolatilization, deposit type

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Introduction

Mineralization research on metamorphic rocks in Indonesia has been carried out in eastern Indonesia (Ernowo *et al.,* 2019). The lack of mineralization in Java Island related to metamorphic rocks is the interest of this research. Generally, the types of mineralization that exist in Indonesia, such as epithermal, porphyry, and skarn, are all related to magmatism (Idrus *et al*., 2017 and Samalehu *et al*., 2023). This time, only a few of them related to orogenic deposits. The mineralization that presents in orogenic deposits is generally related to green schist facies (Idrus *et al*., 2014; Hakim *et al*., 2018; Ernowo *et al.,* 2019 and 2022). The studied area is situated in the hills of Jiwo, characterized predominantly by metamorphic rocks, intrusive and extrusive igneous rocks, and sedimentary rocks (Prasetyadi, 2007). Radiometric dating using the K-Ar method that indicates absolute ages for the metamorphic rocks are around 98.049 ± 2.10 and 98.542 ± 1.45 million years, suggesting Late Cretaceous age (Setiawan *et al*., 2013). The high quartz content in every Jiwo metamorphic rocks indicates their continental pelitic origin (Prasetyadi, 2007). Metamorphic rocks in Jiwo are classified into three facies, those are greenschist, blueschist, and amphibolite facies (Setiawan *et al*., 2013). Orogenic mineralization in Indonesia is found predominantly in the eastern regions, such as Bombana and Buru Island associated with greenschist facies. Mineralization in Bombana is associated with minerals like pyrite, chalcopyrite, cinnabar (HgS), stibnite (Sb_2S_3), tripuhyite ($FeSbO_4$), and some arsenopyrite ($FeAsS_2$) with gold concentrations ranging from 0.005 g/t to 134 g/t. Mineralizing fluids formed at homogenization temperatures (Th) of 114 - 245°C with salinities of 0.35 - 4.03 wt.% NaCl eq (Idrus *et al*., 2017). In Buru Island, the mineralization is associated with pyrite, native gold, pyrrhotite, and arsenopyrite, with homogenization temperatures (Th) ranging from 234 - 400°C and salinities of 0.36 to 0.54 wt.% NaCl eq. (Idrus *et al*., 2017).

Mineralization associated with blueschist facies in the Big Hurrah Mine, Seward Peninsula, Alaska, shows silicification alteration associated with carbonate minerals. Glaucophane association within metabasite, mafic schist, and pelitic rocks, along with arsenopyrite and minor scheelite minerals, suggests mineral inclusion fluids formed at homogenization temperatures (Th) of 250 - 390° C with salinities of 2.1 to 6.6 wt. % (Read and Meinert, 1986). To date, there has been no research specifically investigating metamorphic rock mineralization during the Late Cretaceous period in Jiwo area, especially regarding blueschist and greenschist facies, despite the presence of some mineralization in metamorphic rocks. The research aims to analyze the processes of mineralization formation in Jiwo and its surrounding metamorphic rocks.

Regional Geology and Tectonic Settings

This research was conducted in the western Jiwo and eastern Jiwo areas, Klaten Regency, Central Java Province, Indonesia (Figure 1). The Jiwo Hills generally consist of Cretaceous metamorphic rock formations, Wungkal Formation, igneous rock

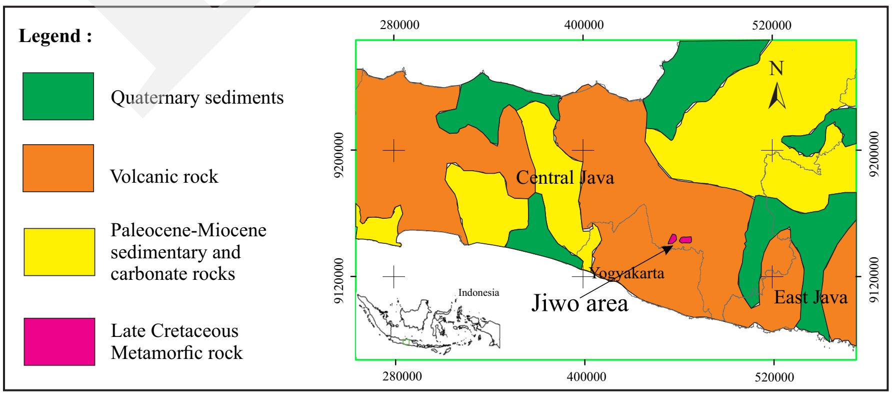

Figure 1. Map of the researched location.

intrusions, Wonosari Formation, and Quaternary deposits (Kurniasih *et al*., 2018). The formation of Late Cretaceous Bayat Complex rocks is associated with the subduction of an oceanic plate, characterized by the presence of blueschist, epidote-glaucophane schist, glaucophane marble, gabbro, and serpentinite (Setiawan *et al*., 2013). The blueschist facies with the glaucophane schist subfacies is commonly found, as well as the greenschist facies with chlorite zone, biotite zone, and garnet zone subfacies, and the amphibolite facies with almandine sillimanite - K-feldspar subfacies, and sillimanite - K-feldspar subfacies (Kurniasih *et al*., 2018). A previous research indicates that the greenschist facies is the most widely distributed facies in the western Jiwo Hill (Warmada *et al*., 2008). This facies is characterized by the presence of chlorite, epidote, actinolite, quartz, garnet, mica, and accessory minerals such as graphite and zeolite (Kurniasih *et al*., 2018). These rocks were formed as a result of retrograde metamorphism of igneous/metamorphic rocks formed at high temperatures of 420 - 580° C (Zhang *et al*., 1996). Retrograde metamorphism in rocks generally occurs due to hydration reactions, involving the transformation of high-temperature minerals into low-temperature minerals (Winter, 2014). The original metamorphic rocks in the Jiwo Hills are pelitic sedimentary rocks with amphibolite facies indicator minerals such as staurolite, garnet, diopside, and Mg-Fe amphibole, which are considered as part of the amphibolite facies (Warmada *et al*., 2008). Regionally, the metamorphic rock facies of the Jiwo Hills are divided into three facies: greenschist, blueschist, and amphibolite facies. The blueschist facies is believed to have formed under high-pressure conditions through regional metamorphism processes (Bucher and Grapes, 2002). The formation of high-pressure metamorphic rocks is associated with the complexity of subduction events during the Cretaceous Period (Hutchison, 2014).

Materials and Methods

Field observations and data collection were carried out to determine the distribution of metamorphic rocks and general geological conditions in the researched area. This method plots rock data, geological structures, and sample data (Rahim *et al*., 2022). Metamorphic parent rocks are identified by mineral composition, using petrographic analysis (Akinola *et al.,* 2021). The physical character of metal minerals is carried out by the process of identification using ore microscopy. It was carried out by observing ore minerals on thin incision under a microscope, illuminated by reflected rays (reflected light) from a Carl Zeiss Axioplan microscope. The results obtained are in the form of physical properties, mineral composition of metal and mineral parameters. The ore microscopy examination was carried out at the Central Laboratory of Mineral, Coal and Geothermal Resources Bandung.

Geochemical analysis by the Atomic Absorption Spectroscopy (AAS) method was carried out to determine the content of metal elements such as Au, Cu, Ag, and Pb. The samples used for this analysis came from quartz veins that cut or parallel to the foliation plane of metamorphic rocks. The analysis of the AAS method was carried out at the Central Laboratory of Mineral, Coal and Geothermal Resources, Bandung. The temperature and salinity of mineralization formation are very important to know for the petrographic analysis of fluid inclusions, microthermometry, knowing when the mineralization was formed, identification of the type of primary inclusion, and the phase of inclusion (monophase or biphase). The way it works is to measure the homogenization temperature (Th) by slowly heating the fluid inclusions until all the gases disappear. The last temperature at which the gas disappeared was recorded to obtain the T*h* (temperature of homogenization) value and the salinity of the fluid could be calculated using the BULK software version 01/03. The melting temperature (Tm) value is obtained by freezing the fluid inclusion process until it reached -60° C, then the temperature was slowly increased until melting occured and the Tm (temperature of melting) value was obtained. The instrument for measurement used Linkam THMS600 freezing and heating stage. This analysis was carried out at the Central Laboratory of the Geological Survey (PSG) in Bandung.

Results and Discussion

Field Observation

Based on the results of field observations, the Jiwo Hills are divided into two parts: West Jiwo and East Jiwo. Based on the results of general observations of the geological conditions of the studied area, the rock distribution consists of Cretaceous metamorphic rocks (schist, slate, phyllite), Wungkal Formation intruded by igneous rocks, and Wonosari Formation (Figure 2). The West Jiwo Hill extends from the south to the north, and then turn westwards around Mount Tugu. Mount Sari is a hilly area that is generally composed of metamorphic rocks of schist. Locally, there is found marble by breaking through igneous rocks in the form of andesite and diorite rocks, deposited unconformably Wonosari Formation in the northern part. At Mount Sari observation location, silicified schist is found in a contact with carbonate schist rocks at the location. Quartz and carbonate veins are also found between the veins containing sulfide minerals. In other West Jiwo areas, there are Pagerjurang area, Mount Jabalkat, Mount Cakaran, and Mount Butak which are dominated by metamorphic rocks (schists and phyllites) which are the different type of metamorphics. The metamorphic rocks are intruded by igneous rocks (diorite, basalt, and andesite). The existence of horizontal fault structures in the NE−SW direction results in joints such as those found in the Mount Sari,

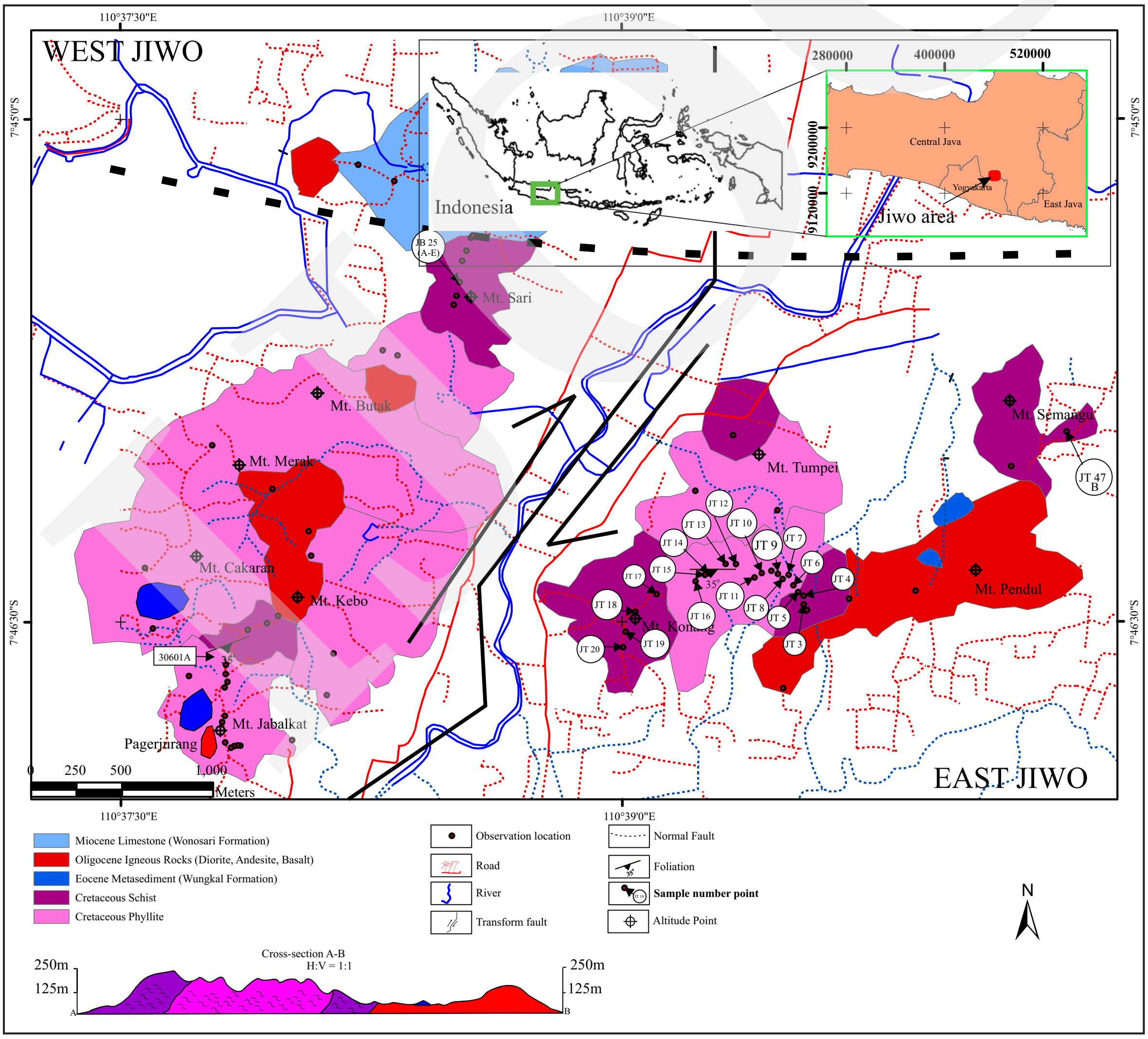

Figure 2. Simple geological map of Jiwo, Bayat, Klaten (modified after Setiawan *et al.*, 2013).

which is filled with quartz and calcite in igneous or metamorphic rocks. The foliation field of metamorphic rocks has a foliation direction generally NE-SE with a foliation slope of 35^0. The morphology of East Jiwo Hill generally has a W-E longitudinal direction. In the western part, around Mount Konang, metamorphic rocks crop out. Most of these metamorphic rocks consist of schist and phyllite. Locally, in this area slate is also found. The phyllites have a greenish-brown grey colour and foliated, some have undergone chlorite and epidote alteration. The schist is reddish brown with some greenish grey, mostly weathered and some fresh one. In the northern part of Mount Tumpai area, metamorphic rock lithologies comprising schist and phyllite are also found. The schists, megascopically have a reddish brown colour, some are greenish grey. The condition is mostly weathered and some are found in fresh conditions, with the presence of chlorite, muscovite, and epidote minerals. Mount Pendul plateau outcrop has been recognized as metasedimentary rocks composed of dark grey nummulites limestone and reddish-brown sandstone. These metasedimentary rocks are intruded by igneous rocks consisting of gabbro and microdiorite. The condition of the igneous rocks is mostly weathered, whilst in some places are fresh. In the northwestern part, where Mount Semanu is situated, the area is mostly occupied by phyllite, which has a greenish brown grey colour. In these rocks, foliation of quartz and calcite are found, some of which have undergone to chlorite and epidote alteration. Localized schists with quartz and grey graphite compositions are found. Pyrites are recognized within quartzite following the direction of foliation along with quartz calcite minerals.

Petrography

Based on the field observations, the studied area are mostly metamorphic rocks that have a foliated structure, visible in field and during microscopic observations with very clear mineral juxtaposition (Figure 3a - c). The results of petrographic analysis showed eight types of metamorphic rocks, those are schist, mica slate, calcite slate, gneiss, hornfels, quartzite, chlorite schist, quartz muscovite phyllite, and graphite schist (Table 1) (Williams *et al.*, 1983). Chlorite minerals are found in various metamorphic rocks (Figure 3a) with a chlorite mineral composition of 30 - 13 % in rock mass with physical appearance of yellowish -green colour, n>nKb, parallel/one-way cleavage, fibrous, grain size of 0.05 - 0.08 mm, (Figure 3b - c). In quartzite, epidote minerals are found (Figure 3d) which have a physical colour of pale green, parallel/one-way cleavage, high relief, pleochroic, strong bf, mineral size of 0.05 - 0.2 mm (Figure 3e - f). Epidote minerals are abundantly present in the rock fractures as well as around the fractures. Garnet and actinolite minerals are present together in mylonitic marble (Figure 3g). Garnet are pale brown-pale red, euhedral dodecahedral, very high relief, variable bf, partly present in marble clasts (Figure 3h). Whereas actinolite minerals are present with physical appearance of colourless-pale green, fibrous-columnar, n>nKb, bidirectional cleavage, one direction in the longitudinal plane of the crystal, moderate-moderate strong bf, grain size of 0.15 - 1.2 mm (Figure 3i). Glaucophane was found on the western part of Jiwo Hill along with yellowish-brown glaucophane epidote schist (Setiawan *et al.*, 2013). The presence of chlorite, quartz, epidote, and garnet minerals indicates the characteristics of the green schist metamorphic facies. The presence of actinolite, glaucophane, quartz, and epidote minerals indicates the characteristics of the blue schist metamorphic facies (Table 1).

Ore Microscopy

Ore microscopic analysis carried out on the samples, shows the presence of quartz veins alongside sulphide minerals. Based on field observations at the two locations where ore microscopy was carried out, outcrops of silicified schist sample number JB25 (A - E) are in contact with marble on Mount Sari, and Semanu highlands on graphitic quartz schist sample number JT47B. In Mount Sari Highs, the sulphide minerals together with quartz and calcite minerals cut the foliation

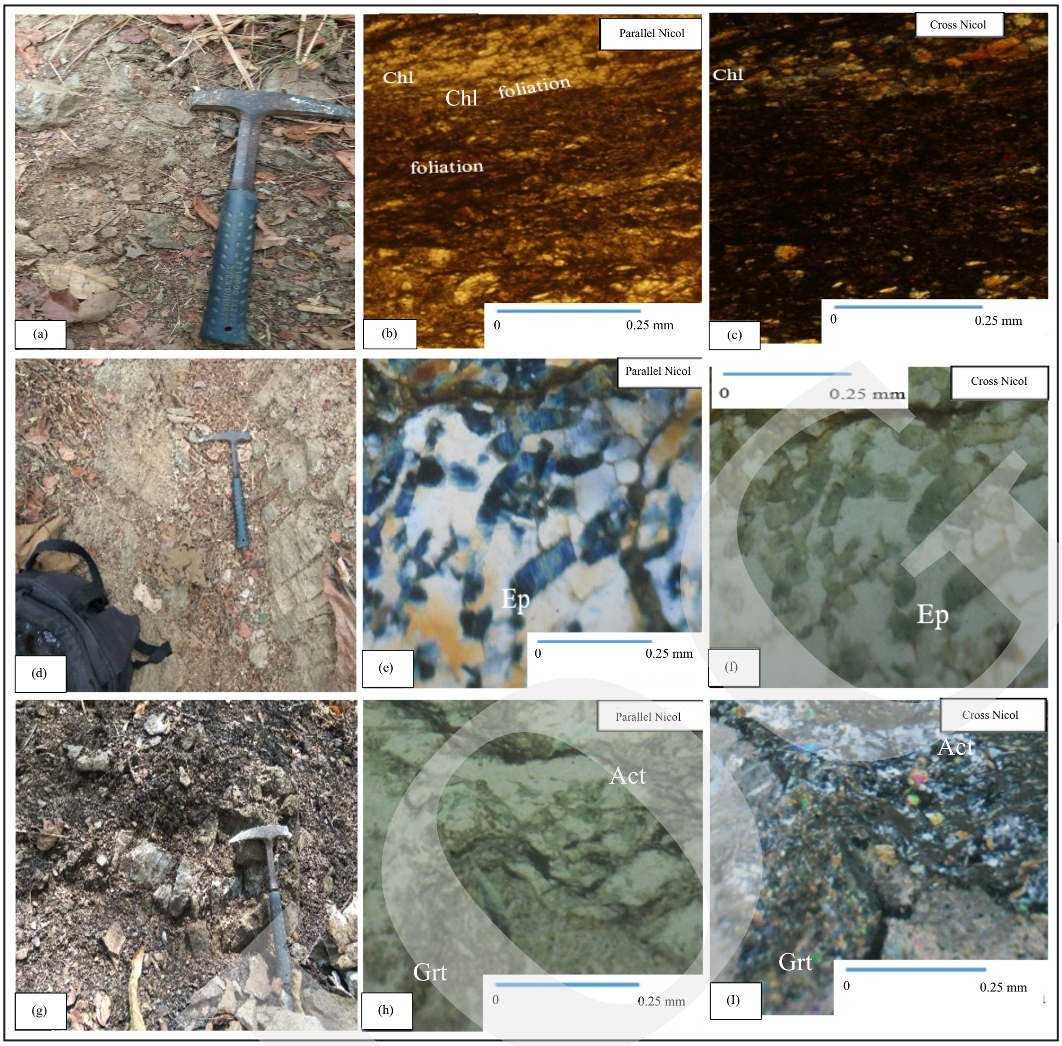

Figure 3. (a). Photographs of chlorite schist outcrop showing foliation planes N 087^0 E/35^0, located in Jiwo Timur highlands; (b). An appearance of chlorite minerals under a petrographic microscope in parallel nicols, in chlorite schist; (c). Photomicrographic view of chlorite minerals under cross nicols; (d). Outcrop of quartzite rock containing chlorite minerals; (e). Photomicrographic view of epidote minerals under a microscope in parallel nicols; (f). Epidote minerals following fractures under a microscope in cross nicols; (g). Outcrop of mylonitic marble with actinolite and garnet as some of its mineral components; (h). Photomicrographic view of actinolite and garnet minerals in parallel nicols; (h). Photomicrographic view of actinolite and garnet minerals in cross nicols.

and some are relatively parallel to the foliation on one direction (Figure 4 a). Based on ore microscopic observations on the Mount Sari samples, several sulphide minerals were found including pyrite, chalcopyrite, galena, and bornite (Figures 4a - h). The pyrite mineral (FeS2) is physically yellowish white, very fine (<0.05 mm) to fine (0.05 mm to <1 mm), euhedral-anhedral shape, weakly anisotropic/generally isotropic, looks replaced by hydrous iron oxide, and spread unevenly/very rarely in the rock mass (Figure 4a). Chalcopyrite mineral is physically seen together with bornite mineral with a physical appearance of yellow colour, very fine (<0.05 mm), subhedral to anhedral shape, weak anisotropic. This mineral replaces galena, grows with bornite, and is distributed unevenly/very rarely in the rock mass (Figure 4 (b). Galena mineral is physically grey in colour, very fine in size (<0.05 mm), subhedral in shape, isotropic. Galena overprint is replaced by chalcopyrite, and distributed unevenly/very rarely in the rock mass (Figure 4c). Bornite mineral, pinkish brown to orange in colour, very fine (<0.05 mm), subhedral to anhedral in shape,

Table 1. Major Mineral Composition of Metamorphic Rocks of the Jiwo Hills

Number of samples	Rock Type	Major Mineral											Metamorfic grade (Winkler, 1979)
		Grt	Qtz	Ep	Act	Cal	Mc	Fsp	Gr	Ms	Gln	Chl	
JT3	Schist		Δ	-	-	●	□	●	-	-	-	Δ	Greenschist
JT4	Mica slate		□	-	-	Δ	●	Δ	-	-	-	◙	
JT6	Calcite Slate		-	-		●	□	Δ	-	-	-	Δ	Greenschist
JT7	Gneiss		Δ	-	-	●	□	Δ	-	-	-	●	
7JT8	Hornfels		Δ			●	□	●	-	-	-	Δ	Hornfels
JT9	Quartzite		◙	-	-	-	-	-	-	-	-	-	
JT10	Chlorite Schist		Δ	-	-	●	□	●	-		-	●	Greenschist
JT11	Muscovite Quartz Phyllite		●	-	-	-	-	-	-	◙	-	-	
JT12	Quartzite		◙	-	-	-	-	-	-	-	-	-	
JT13	Hornfels			-	-	●	-	●	-	-	-	Δ	Hornfels
JT14	Quartzite		◙	-	-		-	-	-	-	-	-	
JT15	Schist		□	-	-	●	□	Δ	-	-	-	●	Greenschist
JT17	Quartzite		◙	●	-		-	-	-	-	-	-	
JT18	Quartzite		◙	-	-		-	-	-	●	-	-	
JT19	Quartz Schist		●	-	-	●	□	Δ	-	-	-	Δ	Greenschist
JT20	Mica Schist		Δ	-	-	●	●	-	-	-	-	Δ	Greenschist
JB25A	Quartz Calcite Muscovite Schist		◙	-	-	●	-	-	-	●	-	-	
JB25B	Marble		-	-	-	◙	-	-	-		-	-	
JB25C	Calcite Mylonite Calcite Quartz		●	-	-	◙	-	-	-	□	-	-	
JB25D	Quartz Marble		●	-	-	◙	-	-	-	-	-	-	
JB25E	Marble Mylonite	●	◙	-	□	●	-	-	-	Δ	-	-	
JT47	Muscovite Calc Graphite		◙	-	-	●	-	●	●	-	-	-	
30601A	Epidote Glaucophane Schist)*			●	□						Δ	Δ	Blueschist

◙ Abundant, ● rich, Δ moderate, □ poor, -absent. *(Setiawan *et al.*, 2013). Grt = garnet, Qtz = quartz, Ep = epidote, Act = actinolite, Cal = calcite, Mc = mica, Fsp = feldsfar, Gr graphite,Ms = muscovite, Glv = glaucophane, Chi = chalcopyrite.

weakly anisotropic or isotropic when very fine, growing with chalcopyrite, and unevenly/very sparsely distributed in the rock mass (Figure 4d). Covellite, blue in colour, very fine (<0.05 mm) to fine (0.05 to <1 mm), anhedral in shape, highly bireflective, strongly anistrope reddish brown in colour, and unevenly/very sparsely distributed in the rock mass. On Mount Semanu Highland, outcrops of graphite schist (JT47B) are found along with pyrite sulfide minerals that follow the foliation plane and there are also quartz and calcite minerals (Figure 4e). Some pyrite sulfide minerals have been weathered with a yellow brown–black appearance in the field (Figure 4f). Ore microscopy observations of pyrite minerals have a yellowish white colour, very fine (< 0.05 mm) to fine (0.05 mm to < 1 mm), anhedral to tabular shape, weakly anisotropic or generally isotropic. The pattern fills rock fractures, appears hollow and cracked, and is unevenly or very sparsely distributed in the rock mass. It appears on ore microscopy observation to be tabular and flow-like. The tabular and flow-like physical form of pyrite minerals indicates the pressure and temperature changes (Mériaud *et al.*, 2022) (Figure 4h).

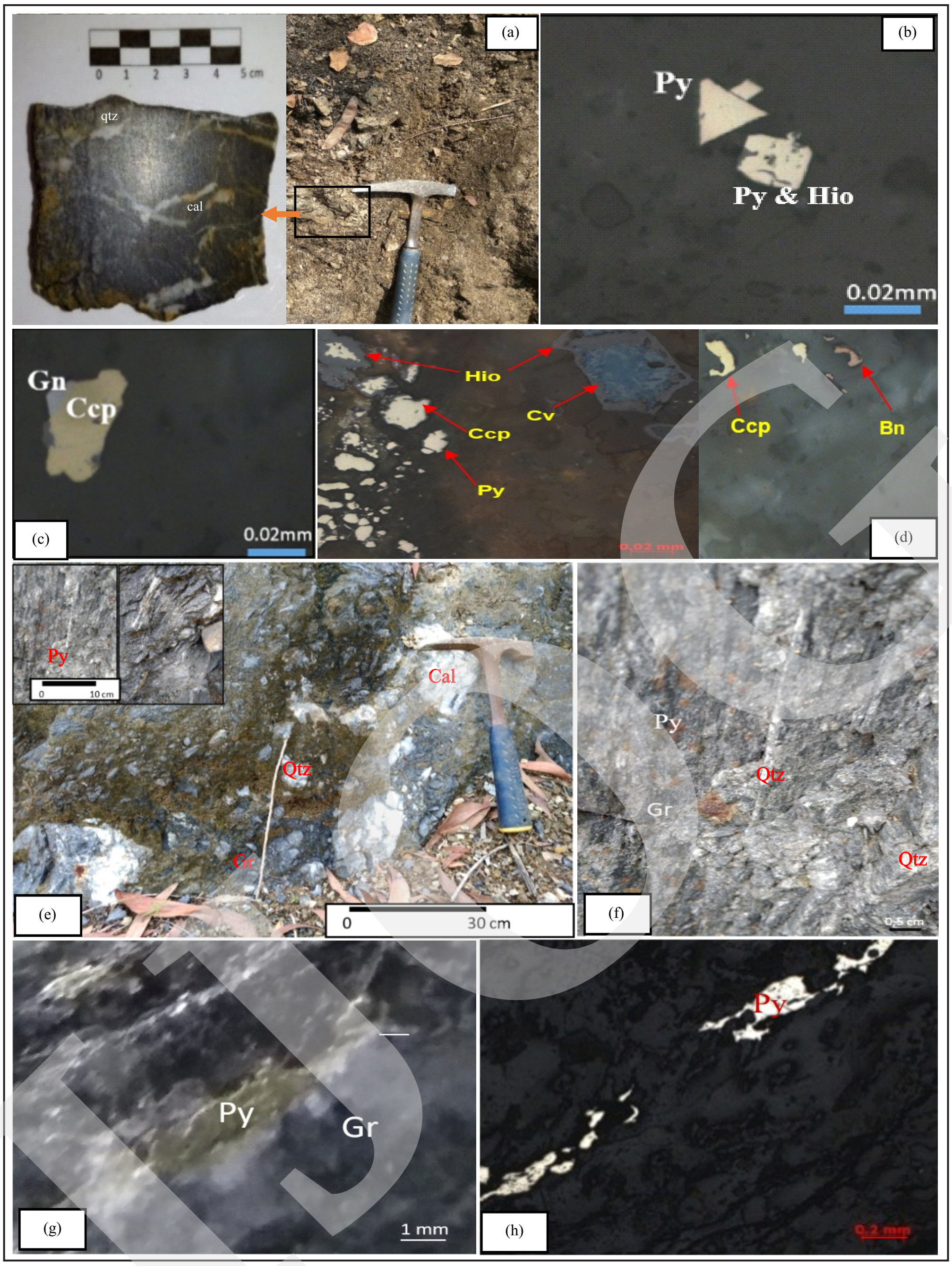

Figure 4. (a). Photograph of outcrop of Mount Sari Hill silicified schist, sample number JB25 (a - e) containing pyrite along with quartz (Qtz) and calcite (Cal) minerals that cuts and relatively in the direction of foliation; (b). Pyrite (Py) mineral observed by ore microscopy, euhedral crystal shape, growing together with iron oxide mineral; (c). Galena (Gn) overlaps with chalcopyrite (Ccp); (d). Chalcopyrite grows together with bornite and covellite; (e). Outcrops of Mount Semanu blackish grey schist, main composition of graphite (Gr) and quartz (Qtz); (f). Pyrite sulfide (Py) mineral along with quartz mineral, parallel foliation; (g). Pyrite (Py) along with quartz (Qtz) of Mount Semanu Highland outcrop, Sample JT47A, 20x magnification; (h). Pyrite mineral pattern that follows the direction of flow or tabular foliation, this pyrite sulfide mineral along with graphite mineral.

Geochemistry

The analysis of metal elements in metamorphic rocks was conducted on rock outcrops with quartz or calcite veins, whether they intersect or are parallel to the foliation. Measurements were also made on metamorphic rocks where sulfide minerals were found. Sampling were carried out at the West Jiwo and East Jiwo Mountains. The results of ore element analysis using the Atomic Absorption Spectrophotometric (AAS) analysis method. Elemental results of Au 0.001 - 0.008 g/t, Ag 0.1 - 2.4 g/t, Cu 4 - 75 g/t, Zn 14 - 166 g/t, and Pb 11 - 60 g/t were obtained (Table 2).

Fluid Inclusion

Field data collection for fluid inclusions was carried out on quartz veins encountered in metamorphic rocks, either parallel to the foliation (concordant) or intersecting the foliation (discordant). Discordant veins are associated with chlorite schist and veins filled with quartz and calcite. Concordant veins are found in graphite schist and chlorite schist. There were five samples taken in the field of both parallel and foliation-cutting quartz veins in the metamorphic rocks. Nineteen measurements were taken on the quartz veins. Physically, the quartz veins are parallel to the foliation, transparent white to milky white in colour, and have a hairly geometry with sizes varying from + 1 cm - > 1 cm. These quartz veins are found together with graphite and some pyrite and chalcopyrite minerals (Figure 5a). Quartz veins, that cut the foliation, have a dominant milky white colour, and some have turned into quartzite. These quartz veins dominantly occur in phyllite schist associated with chlorite and mica minerals that have undergone advanced weathering (Figure 5b). The geometry of the quartz veins averages ± 1cm in size with sigmoidal and twisted shapes and in some places pyrite minerals are found.

Primary and secondary fluids are formed in quartz both cutting and parallel to the foliation. The physical shape of the primary inclusion fluid in quartz that is parallel to the foliation is more rounded, while the inclusion fluid in quartz that cuts the foliation is more sigmoidal (Figure 6).

Based on the observations, the Th values range from 168.5 to 435°C, the Tm values from 1.15 to 8.8°C, and the salinity from 1.95 to 12.66 wt.% NaCl eq. (Table 3). The Th values of discordant veins have a higher temperature

Table 2. Ore Element Content Based on AAS Analysis

Sample Number	Rock Type	Sample of analysis	AAS				
			Au	Ag	Cu	Zn	Pb
			g/t				
JT3	Muscovite Schist	Quartz Wall rock	0.001	0.8	19	81	30
JT4	Calcite Phyllite	Quartz Wall rock	0	0	31	14	13
JT5	Quartz Phyllite	Walls rock	0.005	1.3	5	127	34
JT6	Chlorite Calcite Schist	Quartz Wall rock	0.008	1.1	45	112	48
JT7	Quartzite Chlorite Phyllite	discordant Vein quartz	0.003	0.7	65	54	33
JT8	Quartz mica Phyllite	Quartz Wall rock	0.007	0.4	17	38	34
JT9	Quartz Phyllite	Wall rock	0.001	1.7	16	106	52
JT10	Quartz Phyllite	Wall rock	0.001	0.6	75	78	33
JT11	Mica Chlorite Phyllite	Wall rock	0	0.6	32	40	28
JT12	Chlorite Phyllite	Wall rock	0.001	1.2	8	14	11
JT13	Mica Schist	Wall rock	0	1.1	4	53	31
JT14	Mica Phyllite	Wall rock	0.001	1.4	23	78	54
JT15	Chlorite Schist	Wall rock	0.001	0.1	31	23	16
JT17	Chlorite Phyllite	Wall rock	0.002	0.3	20	20	18
JT18	Schist Chlorite	Wall rock	0	0.7	7	79	28
JT20	Quartz Calcite Schist	Foliated parallel quartz minerals and sulfide minerals	0.001	0.5	27	14	16
JB25A	Calcite Marble	Wall rock	0.001	2.1	22	46	32
JB25C	Mylonite Chlorite	Wall rock	0.001	2.2	23	64	48
JT25D	Graphite Chlorite Schist	Wall rock	0.001	1.9	47	83	28
JT25E	Chlorite Calcite Schist	Quartz Vein	0	2.4	12	45	32
JT47B	Quartz Graphite Schist	Wall rock	0.006	1.7	9	79	58

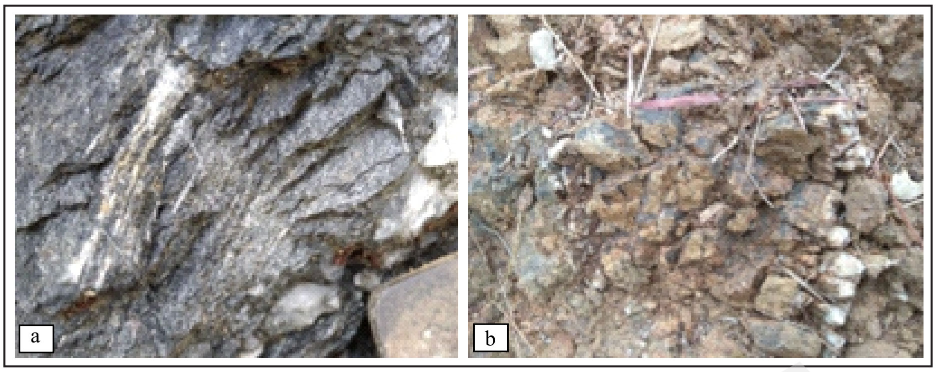

Figure 5. Photographs of (a). Quartz veins parallel to the foliation plane; (b). Quartz veins cutting the foliation plane of massive structures.

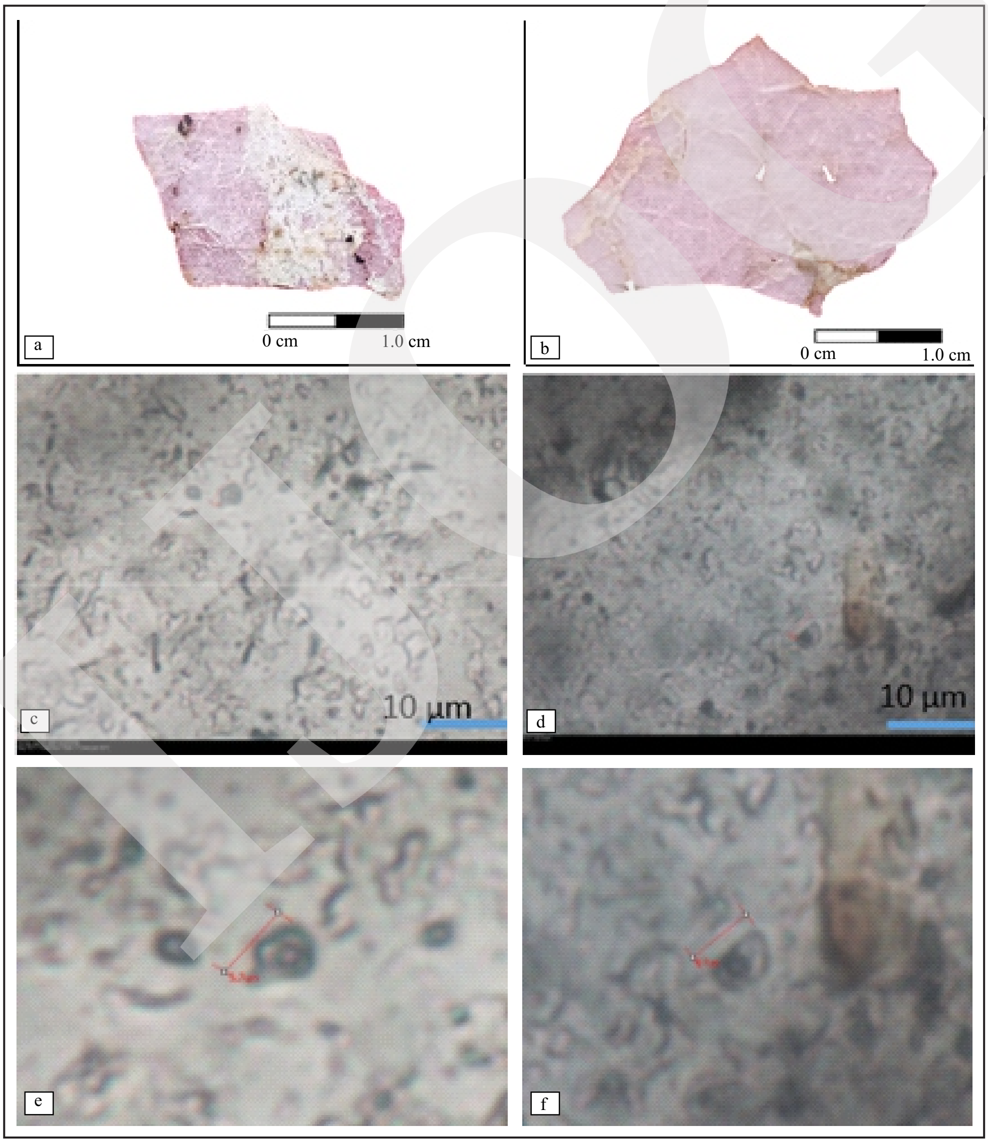

Figure 6. (a). Thin section of fluid inclusion vein aligned foliation; (b). Thin section of fluid inclusion vein cut foliation; (c). Bubble fluid inclusion vein aligned foliation; (d). Bubble fluid inclusion primary microscopic observation microscopic observation; (e). Fluid inclusion found liquid and vapor with rounded shape; (f). Fluid inclusion found liquid and vapour with sigmoidal shape.

Tabel 3. Result of Fluid Inclusion Analysis

Sample Number	Rock	Inclusion size	Generation Vein	Genesis	Type	Th ^{0}C (average)	Tm ^{0}C (average)	Tf ^{0}C (average)	Salinity
									% NaCl equiv.
JT5	Quartz Phyllite	4.9 µm	Concordant	primary	Bifase (L-V)	185.7	1.7	-59.4	2.85
		4.9 µm	Concordant	primary	Bifase (L-V)	206.35	1.2	-58	4.9
		5.7 µm	Concordant	primary	Bifase (L-V)	274.9	1.7	-59.05	2.85
		5.3 µm	Concordant	primary	Bifase (L-V)	285.2	3.05	-62.15	4.9
JT6	Chlorite Calcite Schist	10.3µm	Concordant	primary	Bifase (L-V)	278.5	1.15	-58	1.95
		5.2 µm	Concordant	primary	Bifase (L-V)	260.3	1.65	-58.7	2.75
		8.5 µm	Concordant	primary	Bifase (L-V)	266.5	1.15	-61.55	1.95
		5.0 µm	Concordant	primary	Bifase (L-V)	221	4.95	-66.5	7.8
JT8	Quartz Calcite Schist	2.5 µm	Discordant	primary	Bifase (L-V)	435	3.15	-41.9	5.05
		2.9 µm	Discordant	primary	Bifase (L-V)	399	2.25	-50.35	3.75
		3.8 µm	Discordant	primary	Bifase (L-V)	376.2	1.2	-52.7	2.05
		µm	Discordant	Primary	Bifase (L-V)	312	1.15	-54.5	1.95
JT12	Quartz Chlorite Schist	3.8 µm	Concordant	primary	Bifase (L-V)	168.5	1.65	-43.55	2.75
		2.6 µm	Concordant	primary	Bifase (L-V)	208	3.65	-52.3	5.7
		3.1 µm	Concordant	primary	Bifase (L-V)	296.55	1.15	-54.8	1.95
		4.0 µm	Concordant	primary	Bifase (L-V)	207.5	2.55	-53.9	4.2
JT47(B)	Quartz Graphite Schist	3.4 µm	Concordant	primary	Bifase (L-V)	171.1	1.25	-57.75	2.1
		2.8 µm	Concordant	primary	Bifase (L-V)	172.5	1.35	-53.25	2.3
		3.3 µm	Concordant	primary	Bifase (L-V)	186.35	8.8	-52.2	12.6

range of 312 to 435°C, while concordant veins have *T*h temperatures varying from 168.5 to 296.55°C. The type of fluid inclusions is liquid-vapour (Table 3).

The temperature frequency of Th vein is a concordant that often appears at Th 180^0 C and 280^0 C, Tm temperature 20 and 40^o C, with salinity of 3 - 5 wt. % NaCl eq. Vein temperature discordant Th 320 - 435^0 C salinity 1.95 - 5.05 6 wt. % NaCl eq. (Figure 7).

Discussion

The mineralized host rocks of the Jiwo area are metamorphic rocks comprising of schist, mica slate, calcite slate, gneiss, hornfels, quartzite, chlorite schist, quartz muscovite phyllite, and graphite schist. The major mineral composition of metamorphic rocks in the Jiwo area is composed of chlorite minerals, quartz, epidote, actinolite garnet, and glaucophane. This major mineral composition is part of the metamorphic facies of greenschist and blueschist. The metamorphic host rock is found in discordant veins and concordant veins, both of which have undergone alteration in the vein or wall rock. The alteration character is the replacement of calcite minerals and feldspar minerals (plagioclase) with chlorite, epidote, clay minerals, and biotite. The argillite alteration pattern which is a mineral alteration in the form of montmorillonite, illite, and pyrite develops in West Jiwo area. In this area, also develops silicified alteration in the highland area of Mount Sari, found together with calcite as carbonate minerals. Propylitic alteration does not developed in the West Jiwo area. In contrast to East Jiwo, propylitic and argillic alterations both developed. Propylitic alteration is characterized by the presence of chlorite, muscovite, clinochlore, and mica minerals, while argillic alteration is characterized

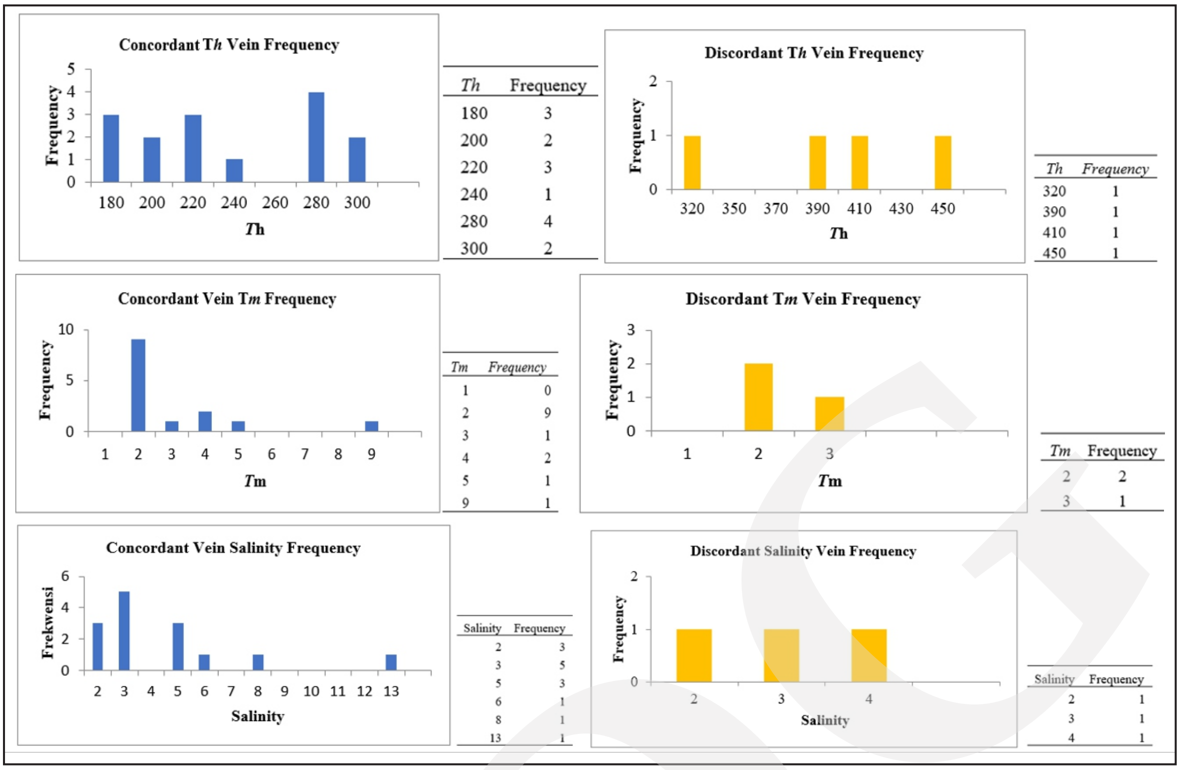

Figure 7. Diagrams showing the frequency of Th, Tm, and salinity.

by the presence of clay minerals. Silicification developed in conjunction with graphite schists located near the Semanu High. The type of alteration in the discordant, concordant veins and wall rocks of the Jiwo area is propylitic, argillite, and silicification alteration with a carbonate composition (graphite and calcite).

In the West Jiwo area, sulfide minerals such as bornite, covellite, chalcopyrite, galena, and pyrite (Brown *et al.*, 2014) are present together in quartz schist that have undergone silicification alteration. The physical form of sulfide minerals has a subhedral to anhedral shape. It is thought that the high pressure and temperature affected the mineral formation process, where at the time, this process is close to melting (Wang and Foley, 2020), forming subhedral sulfide minerals (Briggs *et al.*, 1977). Different forms of anhedral sulfide minerals in this phase of sulfide mineralization are approached at relatively low pressures and temperatures, possibly processed in the greenschist facies phase (Groves *et al.*, 2003). The effect of high pressure and temperature metamorphism tends to occur overprint on galena and chalcopyrite, where galena is overprinted by chalcopyrite (Brown *et al.*, 2014). The metallic element content of the Jiwo area includes relatively low levels of ore elements seen from the analytical results. However, the Cu element more developed than the Au element seen from the geochemical results of the Cu content of 4 - 75 g/t, while Au is 0.001 - 0.008 g/t. The development of Cu and the occurrence of covellite minerals is thought to be part of the subduction mineralization known as Fe-Cu-Ni-S (Fleet, 2006). Fluid inclusions in discordant and concordant veins indicate the homogenization temperature and salinity of the fluid content. Discordant veins and concordant fluid inclusions are of primary genesis. Discordant veins have chloride complexing fluid composition, while concordant veins are dominated by sulphide complexing (Pirajno *et al.*, 2016). The chlorite discordant vein composition is a blueschist facies that is thought to have formed at a depth of approximately 30 km (Stern *et al.*, 2012) near the melting process, allowing chemical mixing of chlorite (Wang and Foley, 2020). The composition of sulfidation complex fluid concordant inclusions in quartz or calcite compositions whose association is close to metamorphic processes (Kouhestani *et al*., 2014) (Figure 8a). The Kesler curve of fluid ore formation between homogenazion temperature (Th) and the salinity of the mineralized ore-bearing solution of origin is divided into two kinds. Discordant veins show meteoric water with little influence of metamorphic water. While concordant veins show metamorphic water and predominantly meteoric water (Kesler, 2005) (Figure 8b).

Concordant veins proceed through the process of surface fluid dilution, boiling salinity and cooling pressurisation with a density of 0.7 - 1.0 g/cm^3, while discordant veins fluid process occurs isothermal mixing and heating depressurisation with a density of 0.5 - 0.7 g/cm^3 (Figure 9).

Vein discordant homogenization temperature (Th) formed at 312 - 435^0 C with salinity 1.95 - 5.05 wt. % eq. temperature, and salinity can occur in blueschist facies (Brooks *et al*., 2019) with isothermal mixing and heating depressurization conditions. Isothermal mixing can take place mixing fluid meteoric water with metamorphic water. Heating depressurization of concordant veins in blueschist facies occurs during subduction, so that temperatures are relatively high (Shinji *et al*., 2019). Concordant veins have temperatures ranging from 168.5 - 296.5^0 C, where salinities are 1.95 - 12.6 wt. % NaCl eq. Salinity of 12 wt% NaCl eq can form in blueschists facies, resulting from aquatic fluids trapped at peak pressure and temperature conditions during devolatilization reactions in metamorphic processes due to subduction (Sachan *et al*., 2017). The type of deposit in the studied area was determined by plotting the range of homogenization temperature and fluid inclusion salinity, namely 168.5 - 435^{0}C and 1.95 - 12.6 wt% NaCl eq based on these data the type in the study area is in the range of Au lode or orogenic mineralization deposits. These data show that they relatively form two different clusters. The first cluster is in the temperature range of 300 - 400 ^{0}C and the second cluster is in the temperature range of 190-230 ^{0}C (Figure 10). The first cluster is relatively similar to the conditions at the Big Hurra Mine (Read *et al*., 1986) which is part of the formation of the blueschist facies. The existence of the second cluster, the conditions are relatively similar to those in Bombana, East

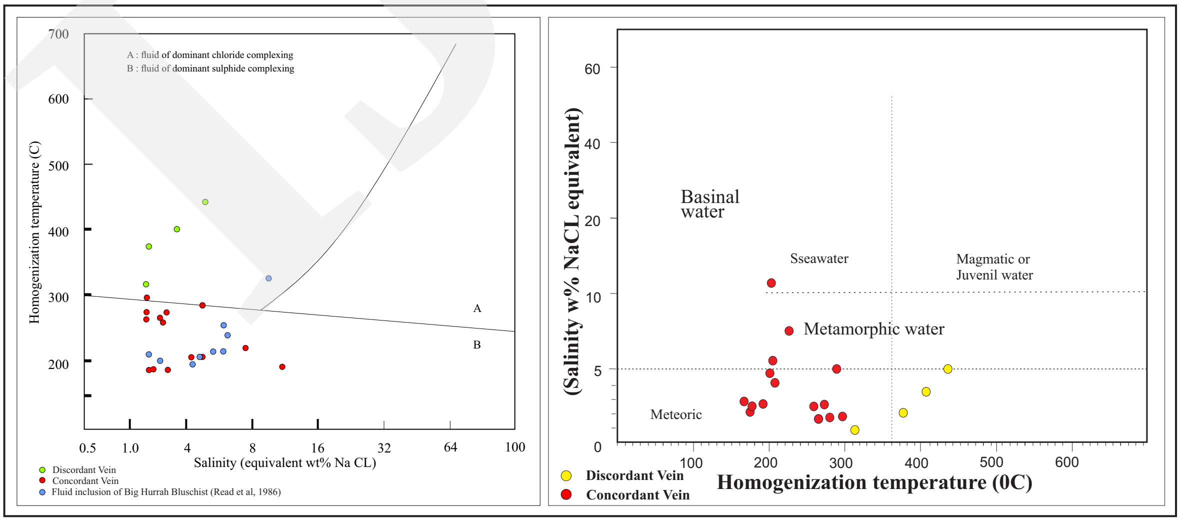

Figure 8. a) Homogeneity temperature curve (Th° C) against salinity (wt. % NaCl eq.) in the determination of sulphide and chloride solution boundaries as ore-bearing fluids, (Pirajno, 2009), b) Homogeneity temperature curve (Th° C) against salinity (wt. % NaCl eq.) in the determination of ore/mineralisation-bearing fluids (Kesler, 2005).

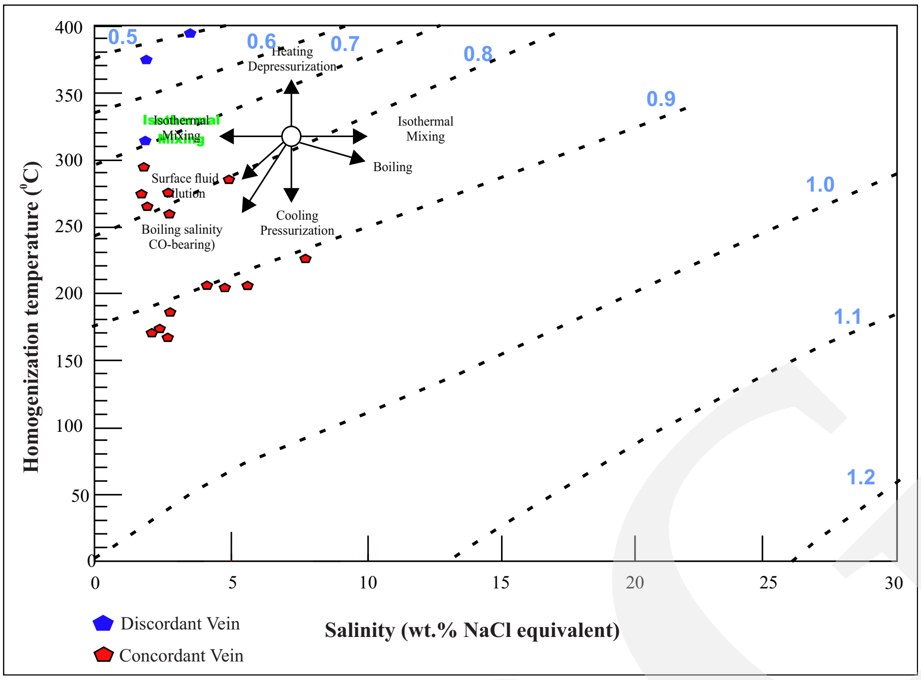

Figure 9. Density determination curve and ore bearing process based on the curve (Bodnar, 1983).

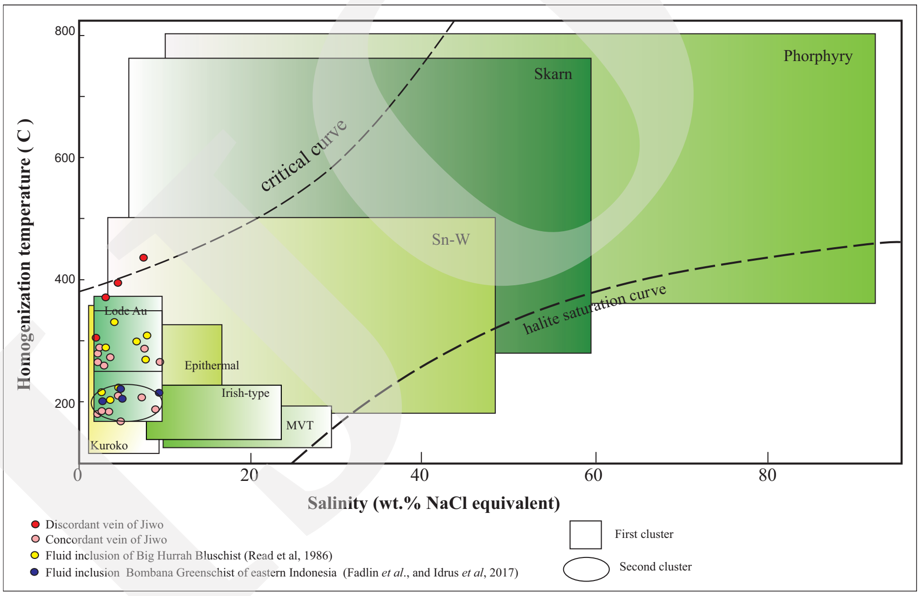

Figure 10. Classification of ore deposits based on temperature homogenization range (Th) and salinity of liquid inclusions based on Wilkinson (2001) (Samalehu, 2023). Two clusters of mineralization formation in the research area.

Indonesia (Fadlin, 2016 and Idrus, 2017). The existence of deposit type clusters in the Jiwo area is thought to be part of the process of forming the blueschist and greenschist facies as shown in the retrograde actinolite in the glaucophane epidote schist rock which is part of the blueschist facies (Setiawan et al, 2013).

Conclusion

Mineralization found in the Jiwo Hill is formed in the host rocks of Late Cretaceous metamorphic rocks that have undergone propylitic, argillic, and silicification alterations (calcite and graphite carbonate). Concordant and discordant veins are found the contain sulfide minerals such as bornite, covellite, chalcopyrite, galena, and pyrite, with galena being covered by chalcopyrite in the concordant veins. Discordant veins mainly contain pyrite (sulfide) minerals. The metal content is very low, with Au content ranging from 0.001 to 0.008 g/t and Cu from 4 to 75 g/t. Fluid inclusions in discordant veins are formed at homogenization temperatures (Th) of 168.5 to 435°C with salinity from 1.95 to 12.6 wt% eq., under conditions of isothermal mixing and heating depressurization. Isothermal mixing can occur due to the mixing of meteoric water with metamorphic water, while heating depressurization occurs during deep subduction in the blueschist facies phase, causing high temperatures and salinity. The deposit type based on homogenization temperature (Th) with salinity shows the type of Au lode deposit or orogenic deposit which has two character clusters associated with blueschist facies and greenschist facies. The first cluster is in the temperature range of 300-400 ^{0}C and the second cluster is in the temperature range of 190-230 ^{0}C.

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References

Akinola, O.O., Ghani, A.A., and James, E., 2021. Petrography and geochemical characterization of a granite batholith in Idanre, southwestern Nigeria. *Sains Malaysiana*, 50 (2), p.315-326. DOI: 10.17576/jsm-2021-5002-04.

Boyabe, M., Dawai, D., Tchameni, R., and Tchunte, P.M, F 2020. Petrography and Mineralogy of the Quartz and Quartz-Feldspar Sulfide Veins in the Pan-African Syenitic Massif of Guider (North Cameroon). *Open Journal of Geology*, 10 (03), p.235-259. DOI: 10.4236/ojg.2020.103013.

Briggs, R. M., Kobe, H. W., and Black, P. M. 1977. High-pressure metamorphism of stratiform sulphide deposits from the Idaho region, New Caledonia. *Mineralium Deposita*, 12 (3), p.265-278. DOI: 10.1007/BF00206166.

Brooks, H., Dragovic, B., Lamadrid, H., Caddick, M., and Bodnar, R. 2019. Fluid capture during exhumation of subducted lithologies: A fluid inclusion study from Sifnos, Greece. *Lithos*, p.332-333. DOI: 10.1016/j.lithos.2019.01.014.

Brown, J. L., Christy, A., G., Ellis., D. J., Arculus, R. J., 2014. Prograde sulfide metamorphism in blueschist and eclogite, New Caledonia. *Journal of Petrology*, 55 (3), p.643-670. DOI: 10.1093/petrology/egu002.

Bucher, K. and Grapes, R., 2022. *Petrogenesis of metamorphic rocks*. Springer Heidelberg Dordrecht London New York, 428pp.

Ernowo, E., Idrus, A., and Meyer, F. M., 2022. Elemental Gains and Losses during Hydrothermal Alteration in Awak Mas Gold Deposit, Sulawesi Island, Indonesia: Constraints from Balanced Mineral Reactions. *Minerals*, 12 (12), 1630. DOI: 10.3390/min12121630.

Ernowo, E., Meyer, F.M., and Idrus, A., 2019. Hydrothermal alteration and gold mineralization of the Awak Mas metasedimentary rock-hosted gold deposit, Sulawesi, Indonesia. *Ore Geology Reviews*, 113, p.1-16. DOI: 10.1016/j.oregeorev.2019.103083.

Fadlin., Idrus. A., and Warmada. I. W., 2016. Studi Kimia Fisika Fluida Hidrotermal Endapan Emas Organik Daerah Wumbubangka, Kabupaten Bombana, Sulawesi Tenggara. *Dinamika Rekayasa*, 12 (1), p.30-36 DOI:10.20884/1.dr.2016.12.1.141.

Fleet, M. E., 2006. Phase equilibria at high temperatures. *Reviews in Mineralogy and Geochemistry*, 61, p. 365-419. Mineralogical Society of America. DOI: 10.2138/rmg.2006.61.7.

Groves, D. I., Goldfarb, R.J., Robert., F., and Hart., C.J.R., 2003. Gold deposits in metamorphic belts: Overview of current understanding, outstanding problems, future research, and exploration significance. *Economic Geology*, 98(1), p.1-29. DOI: 10.2113/gsecongeo.98.1.1.

Hakim, A. Y. Al., Melcher, F., Prochaska, W., Bakker, R., and Rantitsch, G., 2018. Formation of epizonal gold mineralization within the Latimojong Metamorphic Complex, Sulawesi, Indonesia: Evidence from mineralogy, fluid inclusions and Raman spectroscopy. *Ore Geology Reviews*, 97, p. 88-108. DOI: 10.1016/j.oregeorev.2018.05.001.

Hutchison, C. S., 2014. Tectonic evolution of Southeast Asia. *Bulletin of the Geological Society of Malaysia*, 60, p.1-18. DOI: 10.7186/bgsm60201401

Idrus, A., Prihatmoko, S., Hartono, H. G., Fadlin, and Setiawan, I., 2014. Some key features and possible origin of the metamorphic rock-hosted gold mineralization in Buru Island, Indonesia. *Indonesian Journal on Geoscience*, 1 (1), p. 9-19. DOI: 10.17014/ijog.v1i1.172

Idrus, A., Prihatmoko, S., Harjanto, E., Meyer, F. M., Nur, I.,Widodo, W., and Agung, L. N. 2017. Metamorphic rock-hosted orogenic gold deposit style at Bombana (Southeast Sulawesi) and Buru Island (Maluku): Their key features and significances for gold exploration in Eastern Indonesia. *Journal of Geoscience, Engineering, Environment, and Technology*, 2 (2), p. 124-132. DOI: 10.24273/jgeet.2017.2.2.291.

Kesler, S. E., 2005. Ore-forming fluids. *Elements*, 1 (1), p.13-18.

Kouhestani H., Rashidnejad-Omran N., Rastad E., Mohajjel, M., Goldfarb, R.J., and Ghaderi M., 2014. Orogenic gold mineralization at the Chah Bagh deposit, Muteh gold district, Iran, *Journal of Asian Earth Sciences*, 91, p.89-106. DOI: 10.1016/j.jseaes.2014.04.027.

Kurniasih, A., Adha, I., Nugroho, H., and Rachwibowo, P., 2018. Petrogenesis Batuan Metamorf di Perbukitan Jiwo Barat, Bayat, Klaten. *Jurnal Geosains dan Teknologi*, 1 (1), p.1-7. DOI: 10.14710/jgt.1.1.2018.1-7.

Mériaud, N., Masurel, Q., Thébaud, N., and Tourigny, G., 2022. Fluid pressure–dominated orogenic gold mineralization under low differential stress: case of the Yaouré gold camp, Côte d'Ivoire, West Africa. *Mineralium Deposita*, 57 (4), p.539-556. DOI: 10.1007/s00126-019-00927-y.

Pirajno, F., Chen, Y., Li, N., Li, C.,, and Zhou, L., 2016. Besshi-type mineral systems in the Palaeoproterozoic Bryah Rift-Basin, Capricorn Orogen, Western Australia: Implications for tectonic setting and geodynamic evolution. *Geoscience Frontiers*, 7 (3), p.345-357. DOI: 10.1016/j.gsf.2015.09.003.

Prasetyadi, C., 2007. *Evolusi Tektonik Paleogen Jawa Bagian Timur*, *Dissertation*. Institut Teknologi Bandung. unpublish.

Read, J. J. and Meinert, L. D., 1986. Gold-bearing quartz vein mineralization at the Big Hurrah mine, Seward Peninsula, Alaska. *Economic Geology*, 81 (7), p.1760-1774. DOI: 10.2113/gsecongeo.81.7.1760.

Sachan, H. K., Kharya, A., Singh, P. C., Rolfo, F., Groppo, C., and Tiwari, S. K., 2017. A fluid inclusion study of blueschist-facies lithologies from the Indus suture zone, Ladakh (India): Implications for the exhumation of the subduction related Sapi-Shergol ophiolitic mélange. *Journal of Asian Earth Sciences*, 146, p.1-35. DOI:10.1016/j.jseaes.2017.05.025.

Samalehu, H., Idrus, A., and Setiawan, N.I., 2023. Ore-Forming Fluids of Orogenic Gold Deposit In Tamilouw- Haya, Seram Island, Indonesia. *Indonesian Journal on Geoscience,* 10 (3), p.363-377. DOI: 10.17014/ ijog.10.3.363-377

Setiawan, N. I., Osanai, Y., and Prasetyadi, C., 2013. A preliminary view and importance of metamorphic geology from Jiwo Hills in Central Java. *Prosiding Seminar Nasional Kebumian Ke-6, Teknik Geologi Universitas Gadjah Mada,* p.11-23.

Shinji, Y., Tsujimori, T., and Kawamoto, T.. 2019. Two groups of fluid inclusions in the Yunotani eclogite from the Hida-Gaien Belt: Implications for changes of fluid salinity during exhumation. *Journal of Mineralogical and*

Petrological Sciences, 114 (6), p.302-307. DOI: 10.2465/jmps.190729.

Stern, R. J., Reagan, M., Ishizuka, O., Ohara, Y., and Whattam, S., 2012. To understand subduction initiation, study forearc crust: To understand forearc crust, study ophiolites. *Lithosphere*, 4 (6), p469-483. DOI: 10.1130/L183.1.

Wang, Y. and Foley, S., 2020. The Role of Blueschist Stored in Shallow Lithosphere in the Generation of Postcollisional Orogenic Magmas. *Journal of Geophysical Research: Solid Earth*, 125 (10), p.1-31. DOI:10.1029/2020JB019910.

Warmada, I. W., Sudarno, I., and Wijanarko, D., 2008. Geologi dan facies batuan metamorf daerah Jiwo Barat, Bayat, Klaten, Jawa Tengah. *Media Teknik*, 2, p.113-118.

Wilkinson, J. J., (2001) Fluid Inclusion in Hydrothermal Ore Deposits. *Lithos,* 55. p.229-272. DOI:10.1016/S0024-4937(00)00047-5

Williams, H., Turner F. J., and Gilbert, C.M., 1983. *Petrography: an Introduction to the Study of Rocks in Thin Sections (Second Edition).*, W H Freeman & Co, New York, 626pp.

Winkler, H. G. F. 1979 *Petrogenesis of Metamorphic Rocks*. 6th ed. New York, 350pp.

Winter, J., 2014. *Principles Igneous and Metamorphic Petrology*. 2nd ed. United States of America: Pearson Education. 745pp.

Zhang, R. Y., Liou, J. G., and Tsai, C. H., 1996. Petrogenesis of a high-temperature metamorphic terrane: A new tectonic interpretation for the north Dabieshan, central China. *Journal of Metamorphic Geology*, 14 (3), p.319-333. DOI: 10.1111/j.1525-1314.1996.00319.x.