

Hydrothermal Alteration and Mineralization of the Randu Kuning Porphyry Cu-Au and Intermediate Sulphidation Epithermal Au-Base Metals Deposits in Selogiri, Central Java, Indonesia

Sutarto^{*1,2}, Arifudin Idrus², Agung Harijoko², Lucas Donny Setijadji², Franz Michael Meyer³, Sven Sindern³, and Sapto Putranto⁴

¹*Universitas Pembangunan Nasional "Veteran", Yogyakarta, Indonesia*

²*Universitas Gadjah Mada, Yogyakarta, Indonesia*

³*RWTH Aachen University, Germany*

⁴*PT. Alexis Perdana Mineral*

ABSTRACT. The Randu Kuning Porphyry Cu-Au prospect area is situated in the Selogiri district, Wonogiri regency, Central Java, Indonesia, about 40 km to the South-East from Solo city, or approximately 70 km east of Yogyakarta city. The Randu Kuning area and its vicinity is a part of the East Java Southern Mountain Zone, mostly occupied by both plutonic and volcanic igneous rocks, volcanoclastic, siliciclastic and carbonate rocks. Magmatism-volcanism products were indicated by the abundant of igneous and volcanoclastic rocks of Mandalika and Semilir Formation. The Alteration zones distribution are generally controlled by the NE–SW and NW–SE trending structures. At least eight types of hydrothermal alteration at the Randu Kuning area and its vicinity had been identified, i.e. magnetite + biotite ± K-feldspar ± chlorite (potassic), chlorite + sericite + magnetite ± actinolite, chlorite + magnetite ± actinolite ± carbonate (inner propylitic), chlorite + epidote ± carbonate (outer propylitic), sericite + quartz + pyrite (phyllic), illite + kaolinite ± smectite (intermediate argillic), illite + kaolinite ± pyrophyllite ± alunite (advanced argillic) and quartz + chlorite (sillitic) zones. The Randu Kuning mineralization at Selogiri is co-existing with the porphyry Cu-Au and intermediate sulphidation epithermal Au-base metals. Mineralization in the porphyry environment is mostly associated with the present of quartz-sulphides veins including AB, C, carbonate-sulphides veins (D vein) as well as disseminated sulphides. While in the epithermal prospect, mineralization is particularly associated with pyrite + sphalerite + chalcopyrite + carbonate ± galena veins as well as hydrothermal breccias. The Randu Kuning porphyry prospect has copper gold grade in range at about 0.66–5.7 gr/t Au and 0.04–1.24 % Cu, whereas in the intermediate sulphidation epithermal contain around 0.1–20.8 gr/t Au, 1.2–28.1 gr/t Ag, 0.05–0.9 % Zn, 0.14–0.59 % Pb and 0.01–0.65 % Cu.

Keywords: Hydrothermal alteration · Mineralization · Porphyry · Epithermal.

1 INTRODUCTION

The Randu Kuning Porphyry Cu-Au prospect area is situated in Selogiri, Wonogiri, Central Java Province, Indonesia at the coordinate UTM 485800-48700 mE and 9137200-9138600 mS (49

South zone) within the mining exploration concession (IUP) of PT Alexis Perdana Mineral (Figure 1). . This location is reachable with four wheel or two wheel vehicle, about 40 km to the south-east from Solo city, or approximately 70 km east of Yogyakarta city.

The Randu Kuning project is one of several mineral prospects of the Wonogiri area. Explorations of copper and gold deposits in

*Corresponding author: SUTARTO, Department of Geological Engineering, UPN "Veteran" Yogyakarta, JL. SWK. 104 Condongcatur, Yogyakarta, E-mail: sutarto_geo@upnyk.ac.id

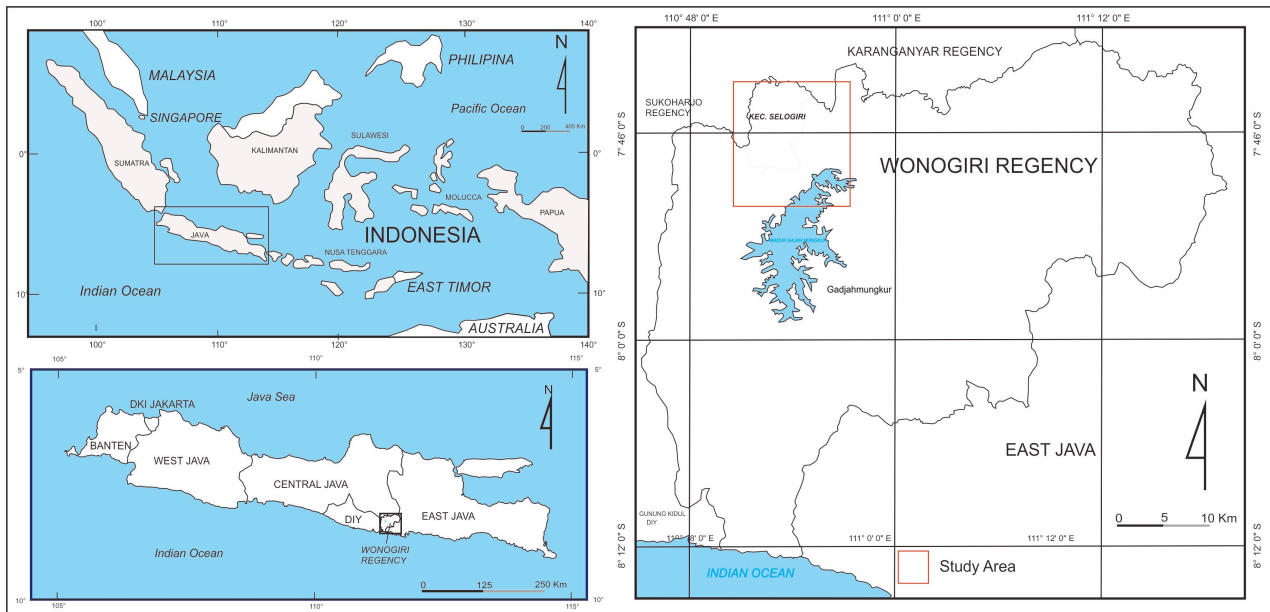


Figure 1: Location map of Selogiri area, Wonogiri.

Wonogiri area have been done since the Dutch era (1929–1935), and by reference of this exploration, then were followed by the Japanese during the occupation of Indonesia (1942–1954) (Isnawan *et al.*, 2002). The production recorded from this mine is in small amounts and could be exported to Japan (van Bemmelen, 1949). 13 years after independence, in 1958, the Indonesian government evaluated the existing hydrothermal ore deposits in Tirtomoyo, which stated that there were three abundant outcrops of quartz veins containing chalcopyrite (Isnawan *et al.*, 2002). Since 1995, the Randu Kuning prospect area attracted the attention of university students when illegal gold mining activity started in the area (Suasta and Sinugroho, 2011). May 2009, PT. Alexis Perdana Mineral the owner of the IUP in Selogiri, started exploration particularly on the Randu Kuning and others several prospects surrounding.

The Mineralisation type of Randu Kuning prospect was interpreted by many researchers as a porphyry Cu-Au ore deposit and a number gold-base metals epithermal deposits in its surroundings (Imai *et al.*, 2007; Suasta and Sinugroho, 2011; Corbett, 2011, 2012 and Muthi *et al.*, 2012). The intensive erosion process has uncovered the upper parts of the porphyry deposit, whereas several gold-base metal epithermals are preserved along adjacent ridge (Suasta and Sinugroho, 2011). Many epithermal veins were also found and crosscut into deeply

porphyry veins and related potassic alteration (Suasta and Sinugroho, 2011; Corbett, 2012).

2 RESEARCH METHODS

In this study, veins and rocks samples were collected systematically from both drilling and local mining tunnels as well as surface outcrops. Secondary minerals assemblages were identified from polarisation microscopic observation (120 samples), X-ray diffractometer (43 samples), Qemscan (Quantitative Evaluation of Minerals by Scanning Electron Microscopy) analysis (4 samples). The X-ray diffractometer was conducted at the Geological Engineering Department of Gadjah Mada University using Rigaku RINT-2100. Petrographic and ore microscopic analyses were carried out at the Geological Engineering Department of Gadjah Mada University and the Department of Mineralogy and Economic Geology, RWTH Aachen University, Germany. QemScan analyses were carried out at the Department of Mineralogy and Economic Geology, RWTH Aachen University, Germany.

3 GEOLOGIC SETTINGS

Regional geology

Indonesian archipelagos are controlled by magmatic arcs, vary in age from Late Mesozoic through the Cenozoic. Most mineralizations are derived from five major Tertiary arcs including the Sunda-Banda, Central Kalimantan,

Sulawesi-East Mindanau, Halmahera and Medial Irian Jaya (Carlile and Mitchell, 1994) (Figure 2).

Sunda-Banda arc is one of the most important six major Tertiary arcs in Indonesia extending from Sumatra through Java to the east of Damar island, where many ore deposits have been known (van Leeuwen, 1994; Carlile and Mitchell, 1994) (Figure 2). The arc is the longest arc in Indonesia, developed by northwards subduction of the Indian-Australian oceanic plate beneath the southeastern margin of the Eurasian continental plate, named the Sundaland (Hamilton, 1979; Katili, 1989). The western segment of the arc has an abundance of low sulphidation epithermal vein system such as mineralization in Miwah, Sondi, Martabe, Way Linggo, Ojo Lali, Cibaliung, Pongkor and Banyumas. A marked change in the mineralization style is seen in the eastern arc segment, in which many porphyry copper-gold mineralizations were found (Carlile and Mitchell, 1994), such as in Batu Hijau, Elang, Tumpang Pitu (Hellman, 2010; Maryono *et al.*, 2012) and Selogiri (Muthi *et al.*, 2012).

Geology and mineralization in Java

Soeria-atmadja *et al.*, (1994) divided the Tertiary magmatism on Java into two periods, i.e. the Late Eocene-Early Miocene and the Late Miocene-Pliocene magmatism. The volcanic rocks of Late Eocene-Early Miocene magmatism are widespread alongside the southern part of Java, which usually has tholeiitic affinity, while the Late Miocene-Pliocene magmatism has tholeiitic, calc alkaline to high K calc alkaline series, distributed mostly northward from the Late Eocene-Early Miocene magmatism. Many Eocene-Early Miocene volcanic rocks have been identified and observed in few areas especially in the Southern Mountain of Java island, including Cikotok Formation (Bayah dome) and Jatibarang Volcanic Formation in West Java, dioritic and diabasic intrusive rocks in Karangsambung Central Java and andesite intrusion (Besole Formation) Pacitan East Java. Whereas many Late Miocene volcanic rocks have also observed such as in Karangko-bar Banjarnegara, Cilacap-Pangandaran, Pacitan and Selogiri (Soeria-atmadja *et al.*, 1994).

Ore mineralizations on Java island which are found ranging from Cibaliung West Java to

Tumpang Pitu East Java, are mostly due to the magmatism-hydrothermal processes. Various types of mineralization mostly epithermal low sulphidation and porphyry Cu-Au are generally hosted on the "Old Andesite" volcanic rocks. Although other indications of mineralisation types such as skarn, volcanogenic massive sulphide, polymetallic, carbonate base metals and quartz sulphide veins are also found in some places (Setijadji *et al.*, 2006) (Figure 3). The different crustal type and source components for the magmatism processes may produce a different type of mineralisation in West Java and East Java. West Java is dominated by a low-sulphidation Au-Ag epithermal system associated with Neogen-Quaternary high K to shoshonitic volcanism at continental crust setting, on the other hand, Eastern Java to Sumbawa is dominated by a porphyry-related Cu-Au mineralisation system associated with low to moderate K, minimum crustal contamination Middle Tertiary--Neogen magmatism (Setijadji and Maryono, 2012).

The Pongkor epithermal Au-Ag deposit which has reserves of more than 98 tonnes Au and 1026 tonnes Ag (Milési *et al.*, 1999), up to now is the largest Au-Ag mining in Java. Most epithermal Au-Ag mineralizations are hosted within volcanic rocks, except those which were found in Cikotok West Java and Karangsambung, Central Java, indicating a sediment hosted and a metamorphic hosted respectively. Many porphyry Cu-Au mineralization are also reported in some places, such as Tumpang Pitu prospect in Banyuwangi (Hellman, 2010), Kali Sanen prospect in Jember (Tain *et al.*, 2005), Tempungsari prospect in Lumajang (Tain *et al.*, 2005), Randu Kuning prospect in Wonogiri (Prihatmoko *et al.*, 2002; Imai *et al.*, 2007; Suasta and Sinugroho, 2011; and Muthi *et al.*, 2012), Trenggalek, and Ciemas prospect (Tain *et al.*, 2005). The Randu Kuning Porphyry Cu-Au, Wonogiri and the Tumpang Pitu Porphyry Cu-Au±Mo, Banyuwangi are the most promising prospects of porphyry type deposits on Java island.

Geology of the Randu Kuning Area

The Randu Kuning area is situated in the area where porphyry Cu-Au and epithermal Au low sulphidation occurred, at the center of the Selogiri area. The area is occupied by dioritic

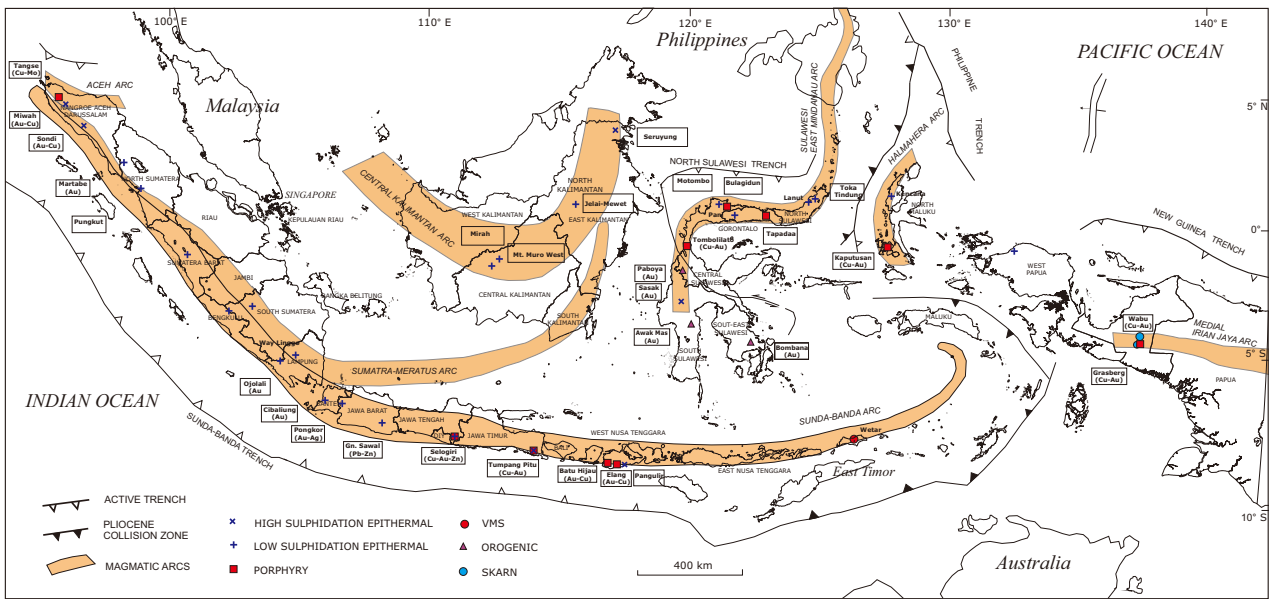


Figure 2: Magmatic arcs distributing in Indonesia (redraw after Carlile and Mitchell, 1994) and different styles of mineral deposits in Indonesia (Carlile and Mitchell, 1994, Setijadji and Maryono, 2012).

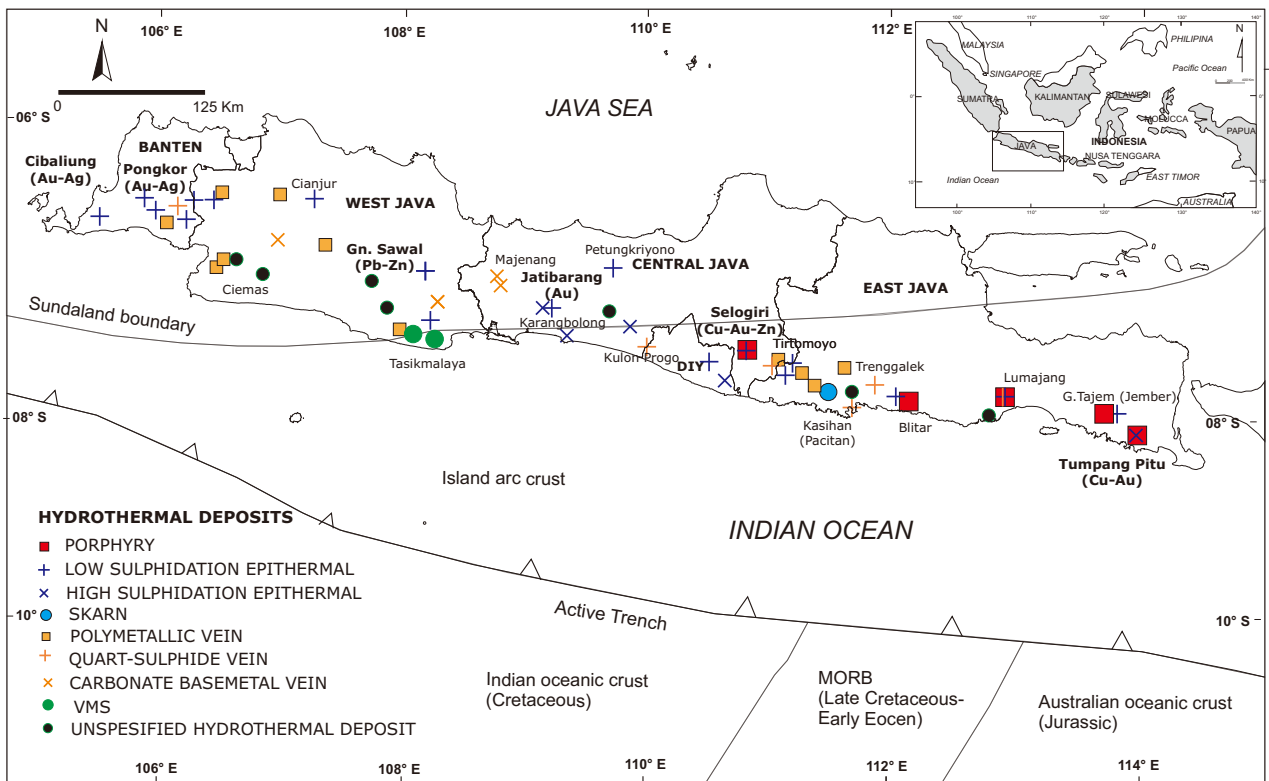


Figure 3: The different styles of mineral deposits distribution in Java island (Modified from Setiawan and Yudawinata, 200; Setijadji *et al.*, 2006; Setijadji and Maryono, 2012). Basement crusts is from Setijadji *et al.* (2006); Setijadji and Maryono (2012).

intrusive rocks and hydrothermal breccias as well as many types of veins/veinlets. Intrusive rocks consist of hornblende-pyroxene diorite, hornblende microdiorite and quartz diorite, while the hydrothermal breccia can be classified as magmatic hydrothermal breccia and phreatomagmatic breccia (Figure 4). Based on the observation both on the surface outcrops and drilling core samples, the intrusive rocks at the study area consist of hornblende-pyroxene diorite (previous researcher called as medium diorite), hornblende microdiorite and quartz diorite.

The Hornblende-pyroxene diorite which is not associated with the ore mineralization (pre-mineralisation), occurred prior to the microdiorite formation which is responsible for Cu-Au porphyry mineralization in the Selogiri area (syn-mineralisation). Previous researchers described this intrusive rock as hornblende diorite (Suasta and Sinugroho, 2011) and medium diorite (Muthi *et al.*, 2012). On the surface outcrops, it mostly shows weathered conditions, but in some locations, especially in river walls, the pyroxene diorite is still relatively fresh. Generally it shows a gray colour in fresh condition (lighter than hornblende microdiorite), porphyritic texture (moderate-strong), having medium crystal size (0.3–2 mm) with pyroxene and hornblende phenocrysts size varies up to 2 cm. It contains a high proportion of plagioclase or at about 35–50 percent with a lesser amount of hornblende and pyroxene (3–8 %) (Sutarto *et al.*, 2015b).

The hornblende microdiorite is characterized by fine grained phenocrysts size (0.1–1 mm), many of samples which are microscopically classified as andesite (porphyritic texture), commonly consist of about 30–45 percent of plagioclase and 5–14 percent of hornblende. The hornblende microdiorite is believed to be responsible for the extensive alteration and Cu-Au porphyry ore deposit in the study area. Physically, it appears darker in colour and finer in crystals size than hornblende-pyroxene diorite. It is caused not only by the amount of mafic but also due to the abundance of the secondary magnetite. Most of the hornblende microdiorite intrusive body altered to potassic zone and lack of prophyllitic and phyllic alteration types. The contact between hornblende microdiorite and hornblende-pyroxene diorite is commonly

characterized by the formation of intrusive contact with breccia (magmatic hydrothermal breccia). The peak part of the Randu Kuning hill is a representative of this type of intrusion (Sutarto *et al.*, 2015b).

The quartz diorite has the brightest colors and the coarsest crystal sizes (0.8–3.2 mm), equigranular to weak porphyritic texture, characterized by the abundance of plagioclases (40–55 percent) and small quantities of quartz (4–7 percent) and alkali feldspars (2–5 percent) (Sutarto *et al.*, 2015b). Due to coarse grained crystal size, Muthi *et al.* (2012) recognized and described the intrusive as coarse diorite. It was generally altered to phyllic-argillic and prophyllitic alteration type, associated with Au-base metals epithermal type mineralization. The dimensions and the distribution of this intrusion is relatively narrower and smaller than those of hornblende-pyroxene diorite and hornblende microdiorite intrusions (Sutarto *et al.*, 2015b). There are at least two types of hydrothermal breccia recognized in the research, i.e., magmatic-hydrothermal breccias and phreatomagmatic breccias, which were found in the Randu Kuning hill area. Magmatic-hydrothermal breccias in the research area are characterized by various irregular bodies showing subvertical to vertical shapes in contact with the wall rocks, fragments mostly monomic, i.e. various altered diorite, angular-subrounded and larger in grain size (0.5–8.4 cm), matrix mostly consisting of hydrothermal minerals (magnetite, chalcopyrite and pyrite) as open space infilling, fragment/matrix ratio is high (60–90 vol.%) or predominantly fragment supported, texture/structures usually crackle, jig-saw and rotated fragments, no fluidization (Sutarto *et al.*, 2015b). Phreatomagmatic breccias exhibit, irregular dyke and pipe body, subvertical, fragments/clasts consist of polymictic components including juvenile (mostly rounded) and various wall rock such as altered diorites, veins/veinlets, sandstone, quartzite, conglomerate and schist (mostly subangular), 0.2–4.5 cm in size, low fragment/matrix ratio (10–65 vol.%). These breccia commonly show fluidization, associated with potassic, prophyllitic and argillic alteration type, mineralisation

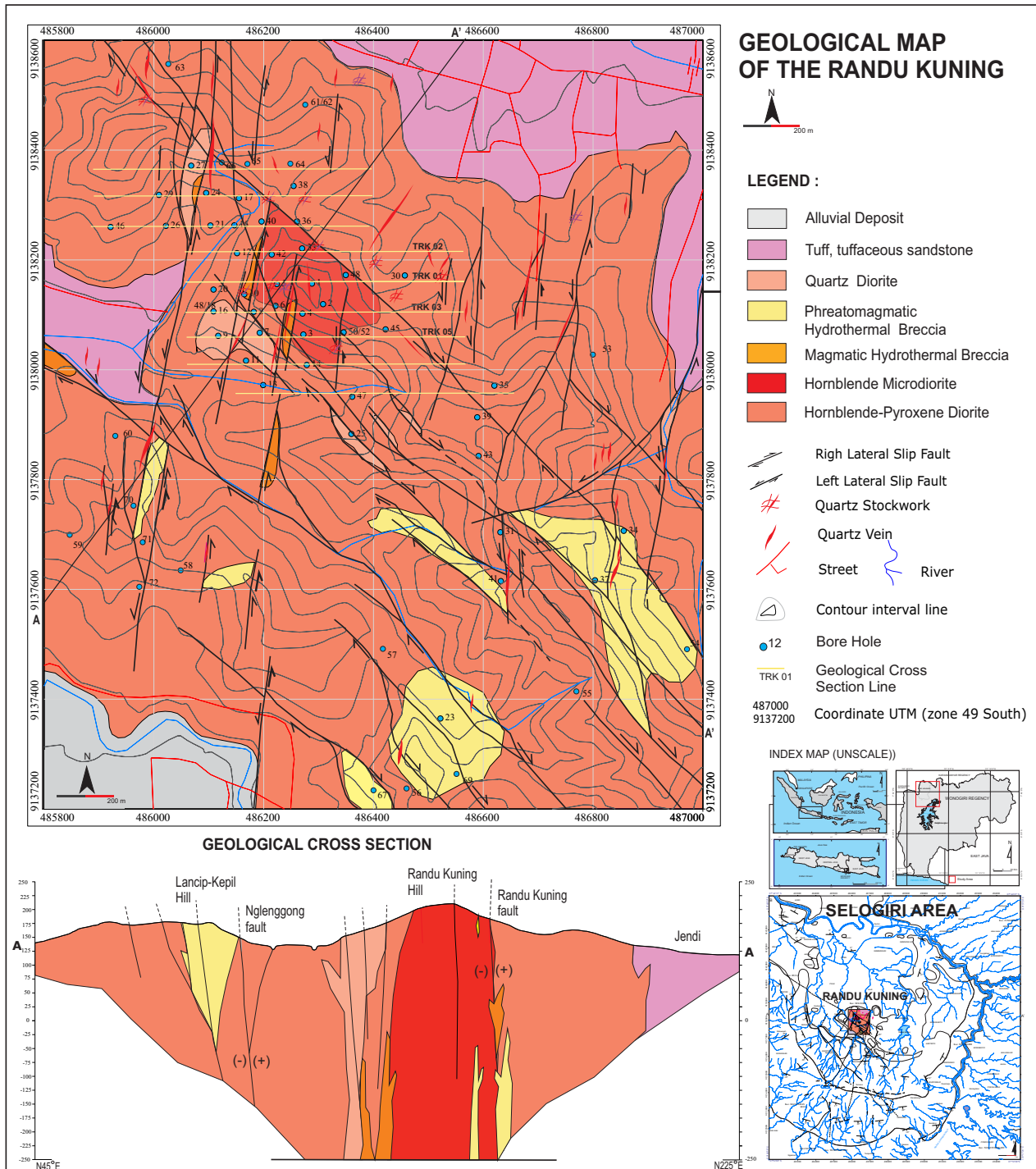


Figure 4: Geological map of the Randu Kuning area (Sutarto *et al.*, 2015b).

occurred in both desimination and open space infilling (Sutarto *et al.*, 2015b).

Major structures at the Randu Kuning area, dominated by relatively the NW–SE, NE–SW, and rare N–S trendings, cross cut all of the rocks in the area. The earliest and most dominant structures in the research area are the NW–SE dextral (right) lateral-slip faults, and commonly have a longer dimension than other trends. These structural trends then were cross-cut by NE–SW and N–S sinistral (left) lateral-slip faults. The NE–SW and N–S trend mostly concentrated in the central area. Drilling core and surface outcrop data suggest the earlier porphyry vein types were perhaps controlled by dextral (right) lateral-slip faults, whereas the later porphyry vein and epithermal vein types were controlled by sinistral (left) lateral-slip faults (Sutarto *et al.*, 2015b).

4 HYDROTHERMAL ALTERATION AND MINERALIZATION

Alteration types

Alteration zones distributions of the researched area are generally controlled by the NE–SW and NW–SE trending structure. At least eight types of hydrothermal alteration at the Randu Kuning area and its vicinity had been identified, i.e., 1) Magnetite + biotite ± K-feldspar ± chlorite (potassic); 2) Chlorite + sericite + magnetite ± actinolite; 3) Chlorite + magnetite ± actinolite ± carbonate (inner propylitic); 4) Chlorite + epidote ± carbonate (outer propylitic); 5) Sericite + quartz + pyrite (phyllic); 6) Illite + kaolinite ± smectite (intermediate argillic); 7) Illite + kaolinite ± pyrophyllite ± alunite (advanced argillic) and 8) Quartz + chlorite (sillitic) zones Figure 5.

The magnetite + biotite ± K-feldspar ± chlorite (potassic) zone is scattered on microdiorite intrusive rocks body and small part of pyroxene diorite intrusive rocks especially in contact to the microdiorite intrusion of Randu Kuning hill. This zone is characterized by the present of secondary minerals assemblage, i.e., one or both of secondary biotite and/or K-feldspar associated with magnetite, actinolite, quartz and lack of carbonate minerals (Suasta and Singroho, 2011; Corbett, 2011, 2012 and Muthi *et al.*, 2012). Microscopically, biotite usually has dark-brown colour, fine grained, fibrous Figure 6A and is present predominantly in

the central part of the hornblende microdiorite intrusion and gradually will decrease to the edge part of the hornblende microdiorite and the part of pyroxene-hornblende diorite. The Qemscan analysis of the potassic-altered hornblende-pyroxene diorite (sample WDD 03-47.20), shows many kinds of hydrothermal secondary minerals such as biotites, alkali-feldspars, chlorites, quartzes, calcites, kaolinites, illites, sericite and rare of ore minerals (pyrite-pyrrhotite-chalcopyrites) Figure 7.

The chlorite + sericite + magnetite ± actinolite is widespread on the upper part of the magnetite + biotite ± K-feldspar ± chlorite (potassic) characterized by the dominant of chlorite and sericite, although other secondary minerals such as magnetite, quartz, and sometimes actinolite are still found. The chlorite + sericite + magnetite ± actinolite zone is developed on the small upper part of hornblende microdiorite. The chlorite + magnetite ± actinolite ± carbonate alteration type Figure 6B is commonly recognised between magnetite + biotite ± K-feldspar ± chlorite (potassic) zone and chlorite + epidote ± carbonate (outer propylitic) zone. The zone mostly is widespread in pyroxene-hornblende diorite rocks, and within a small part of hornblende microdiorite. In some places these alteration zones cut to minerals assemblage of the magnetite + biotite ± K-feldspar ± chlorite (potassic) zone and gradually changed outward to the chlorite + epidote ± carbonate (outer propylitic) zone. The chlorite + epidote ± carbonate, (outer propylitic) alteration zone is widespread on pyroxene-hornblende diorite rocks and a small part of quartz diorite, gradually from the inner propylitic to least altered rock, comprising of chlorites, epidotes, carbonates and quartz.

The illite + kaolinite ± smectite, (intermediate argillic) zone appears mainly adjacent to breccia and fault zone, especially in the epithermal prospect area, which is characterized by the present of clay minerals. Illite, kaolinite and smectite are the main minerals identified in the vein samples suggesting structural controlled argillic alteration (Muthi *et al.*, 2012). The illite + kaolinite ± pyrophyllite ± alunite (advanced argillic) is situated at the centre of Kepil hill, southwest of the Randu Kuning hill, comprising mostly illite, pyrophyllite,

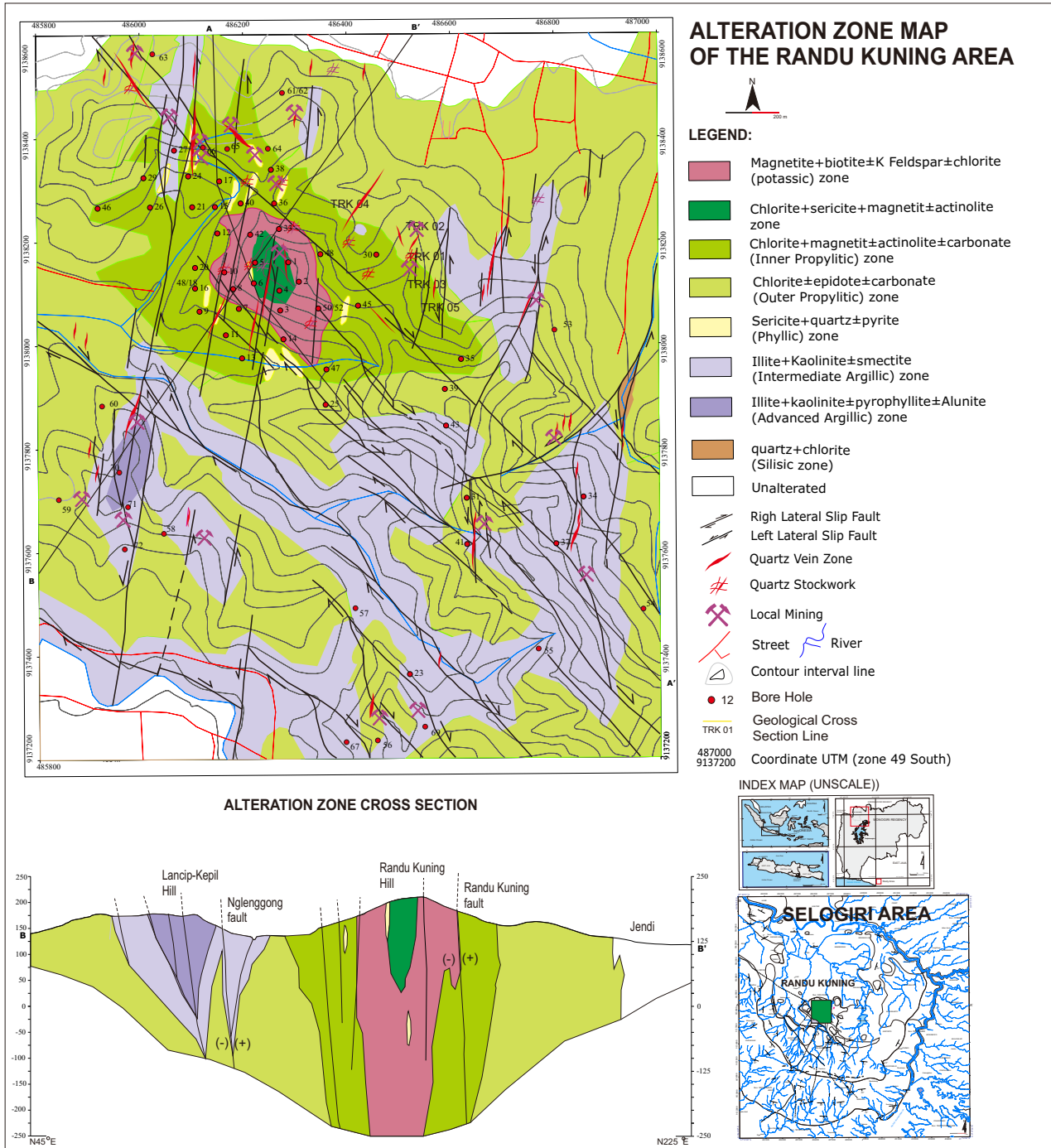


Figure 5: Alteration zone map of Randu Kuning area and its vicinity (Sutarto *et al.*, 2015b).

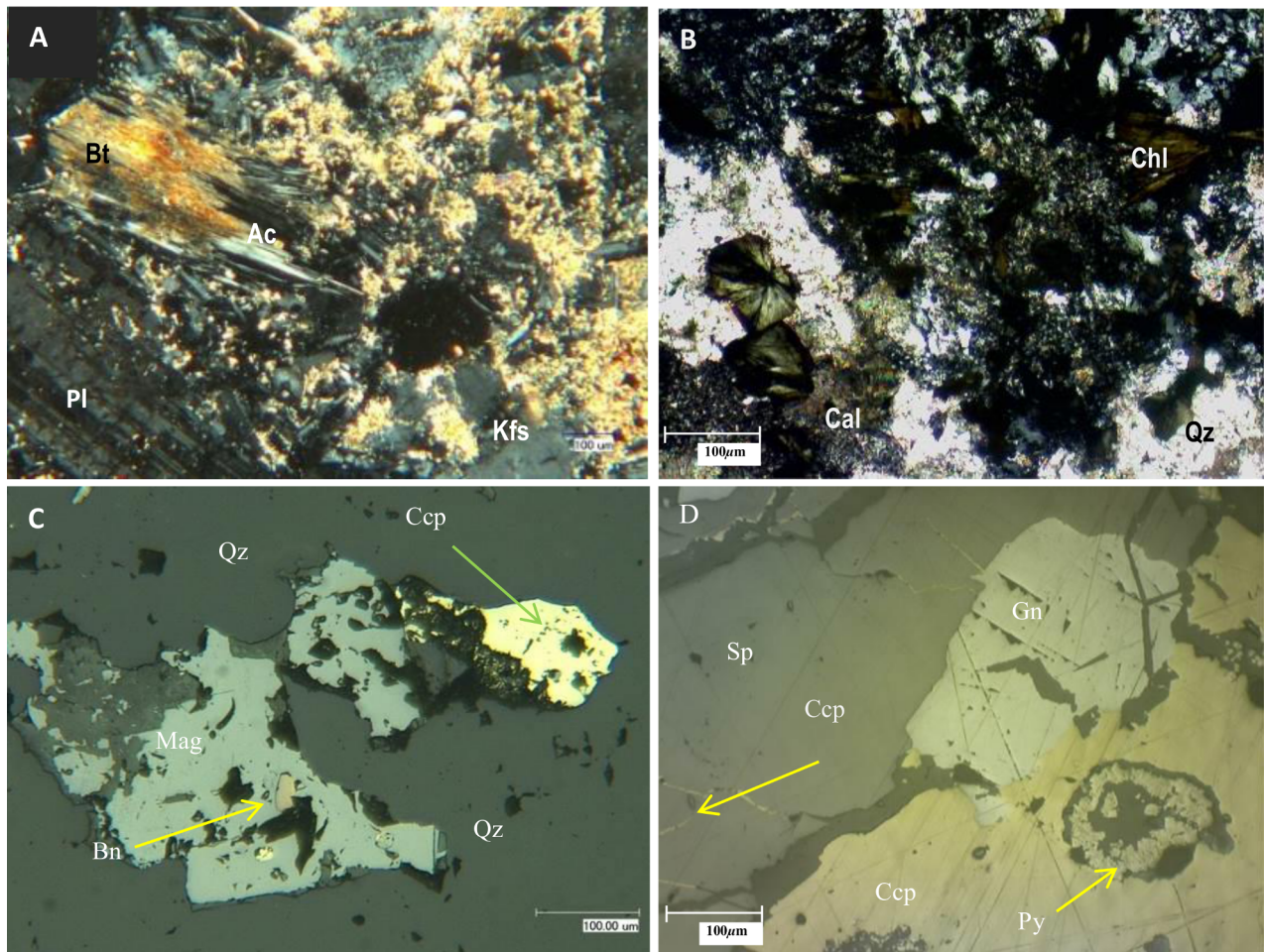


Figure 6: A) Crossed polars light photomicrograph of magnetite+biotite±K-feldspar±chlorite (potassic) altered hornblende-pyroxene diorite. Most potassic type minerals (biotite, K-feldspar) were overprinted by inner prophyllitic type minerals (actinolite-chlorite-silica) (Sample: WDD-09-157.65); B) Crossed polars light photomicrograph of the chlorite+magnetite±actinolite±carbonate (inne prophyllitic)-altered hornblende-pyroxene diorite (sample: WDD 30-59.05); C) Crossed polars light polished section photomicrograph under the reflected light of the magnetite-chalcopyrite-bornite assemblages within magnetite+biotite±K-feldspar±chlorite (potassic) zone (Sample: WDD 19-82.40); D) Crossed polars light photomicrograph polished section under the reflected light of sphalerite-chalcopyrite-galena-pyrite of carbonate-sulphides vein within inne prophyllitic-altered hornblende-pyroxene diorite (Sample: WDD 19-64.75). Mineral abbreviations: Bt = biotite, Pl = plagioclase, Ac = actinolite, Kfs = K-feldspar, Qz = quartz, Mag = magnetite, Ccp = chalcopyrite, Bn = bornite. Cal = calcite, Chl = chlorite, Ccp = chalcopyrite, Py = pyrite, Sph = sphalerite, Gn = galena.

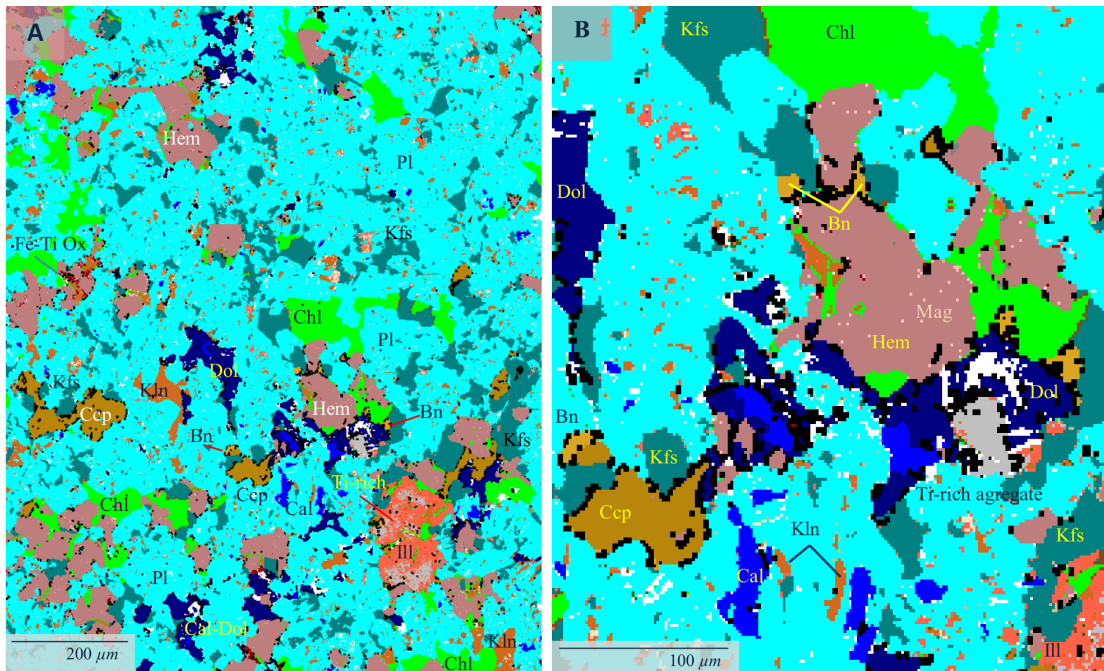


Figure 7: Qemscan image of A). The magnetite+biotite±K-feldspar±chlorite (potassic)-altered hornblende-pyroxene diorite, consist of many secondary minerals such as K-feldspar-biotite-magnetite-hematite were replaced by chalcopyrite-bornite-chlorite, quartz-calcite-dolomite and kaolinite-illite assemblages. B). Closed up the image of figure A. Sample WDD 03-47.20). Mineral abbreviations: Bn = Bornite, Bt = biotite, Qz = quartz, Chl = chlorite, Ccp = chalcopyrite, Dol = dolomite, Hem = hematite, Kfs = K-feldspar, Kln = kaolinite, Mag = magnetite, Pl = plagioclase Ill = illite.

kaolinite, quartz and lack of alunite, carbonate and chlorite. The quartz + chlorite (silicic) zone is restrictedly found at the fault zones, both within drilling core data and surface outcrop, consisting of quartz, sericite, carbonate, clay minerals and opaque minerals. It is mostly related to the preatmagmatic hydrothermal breccia occurrence of the epithermal system. The sericite + quartz + pyrite (phyllitic) alteration commonly appears in the fault structure zones, locally overprint to the potassic alteration and inner prophyllitic zone, on hornblende-pyroxene diorite rocks, microdiorite hornblende as well as quartz diorite (Suasta and Sinugroho, 2011; Corbett, 2011, 2012 and Muthi *et al.*, 2012). This zone is characterized by retrograde silica-sericite-chlorite-pyrite assemblages, which is mostly limited to fault zones or selvages to late stage quartz-pyrite veins or D veins (Corbett, 2012).

Mineralization

Based on the characteristics of many parameters such as pattern and type of hydrothermal alteration, veins type, gangue and ore min-

erals assemblages, fluid inclusions, the Randu Kuning mineralization at Selogiri is likely porphyry Cu-Au to intermediate sulphidation epithermal Au-base metals (Table 1. There are at least eight mineralisation prospects areas at the Randu Kuning and its vicinity, they are Randu Kuning porphyry Cu-Au prospect and many intermediate sulphidation epithermal Au-base metals prospects including Bukit Piti-Tumbu, Gawe, Geblak, Jangglengan, Lancip-Kepil and Randu Kuning South prospects (Table 2). Most mineralizations in the researched area are associated with the present of some sulphides such as chalcopyrite, pyrite, pyrrhotite, bornite, sphalerite, galena, and chalcocite. The copper gold resource of the Randu Kuning porphyry prospect comprises 90.9 Mt at 0.35 g/t Au and 0.10 % Cu, using a cut-off grade of 0.2 g/t AuEq (Nightingale, 2014).

Porphyry Cu-Au mineralization

Not all porphyry vein types contribute in copper and gold mineralization. The early quartz-magnetite veins (particularly A and M veins) generally do not contain Cu-Au or barren,

Table 1: Characteristic of the porphyry Cu-Au and epithermal Au deposits in the Randu Kuning area.

	PORPHYRY	IS EPITHERMAL
TECTONIC	Island arc	Island arc
INTRUSIVE ROCKS	Hornblende-pyroxene diorite, hornblende microdiorite	Hornblende-pyroxene diorite, hornblende microdiorite, quartz diorite
HOST ROCKS	Hornblende microdiorite, hornblende-pyroxene diorite	Hornblende microdiorite, hornblende-pyroxene diorite, hydrothermal breccia
STRUCTURES	NW Sinistral LF NE Dextral LF	NS Fault zone Hydrothermal breccia
ALTERATION	Potassic, inner propylitic, phyllic, outer propylitic	Outer propylitic, intermediate argillic, advanced argillic
GANGUE MINERALS	Magnetite, biotite, K-feldspar, anhydrite, chlorite, actinolite, sericite, quartz	Chlorite, epidote, sericite, quartz carbonate, illite, kaolinite, smectite, gypsum, pyrophyllite, alunite
METALS CONTENTS	Cu, Au	Au, Ag, Cu, Zn, Pb
ORE MINERALS	Chalcopyrite, pyrite, bornite, pyrrhotite	Sphalerite, chalcopyrite, pyrite, galena
MINERALISATION STYLES	Disseminated chalcopyrite, quartz-sulphide veins	Sphalerite-chalcopyrite-pyrite-carbonate vein, quartz-carbonate-sphalerite vein
TEMPERATURE	300°C to >600°C	200-300°C
SALINITY	16-72 wt.% NaCl equiv.	<8-24 wt.% NaCl equiv.

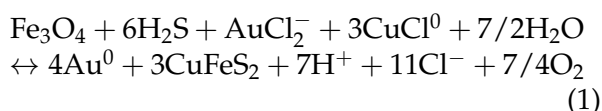
Table 2: Mineralisation prospect area and their characteristic. All of the metal contents data are summarized from PT. Alexis Perdana Mineral.

	Randu Kuning Prospect	Randu Kuning South Prospect	Gawe Prospect	Bukit Piti-Tumbu Prospect	Geblog Prospect	Jangglengan Prospect	Lancip-Kepil Prospect
INTRUSIVE ROCKS	MD	MD/CD?	MD	MD	MD	MD, CD?	MD
WALL ROCKS	MD, MED	MD, MED	MD, MED	MED Hydrothermal breccia	MED MID	MED Hydrothermal breccia	Hydrothermal breccia
STRUCTURES	NW sinistral fault NE dextral LF	Dextral fault EW vein	Dextral fault EW vein	Fault zone	Fault zone	Fault zone Hydrothermal breccia	Fault zone Contact diatreme breccia
ALTERATION	Potassic, inner propylitic, phyllic	Phyllic, intermediate argillic	Propylitic, intermediate argillic	Propylitic, intermediate argillic	Propylitic, intermediate argillic	Propylitic, intermediate argillic, siltsic	Propylitic, intermediate argillic
GANGUE MINERALS	Bt, Mag, Kfs, Ac, Anh, Qz, Chl, Ep	Ser, Qz, Cal, Dol, Chl, Anh, Gyp, Ill, Kln, Sme,	Ser, Qz, Cal, Chl, Ill, Kln, Ill-Sme, Gyp, Alu	Chl, Mag, Ep, Qz, Py, Ser, Ill, Kln, Cal	Chl, Mag, Ep, Qz, Ser, Ill, Kln, Py	Chl, Cal, Mgs, Kfs, Ep, Ser, Ill, Kln, Gyp,	Chl, Ep, Qz, Cal, Mgs, Ill, Ill-Sme
METAL CONTENTS	Cu+Au 0.66-5.7 g/t Au 0.04-1.24 % Cu	Au±Cu±Ag±Zn±Pb 0.4-1.53 g/t Au 0.8-8.5 g/t Ag 0.17-0.39% Cu 0.003-0.37% Zn 0.0089-0.14% Pb	Au+Cu 0.2-0.92 g/t Au 0.01-0.21% Cu	Au±Zn±Pb±Ag 0.2-0.5 g/t Au 0.05-0.12% Pb 0.23-0.9% Zn 1.2-8.0 g/t Ag	Au+Zn 0.1-6.97 g/t Au 0.05-0.25% Zn	Au±Zn±Cu±Ag 0.26-2.29 g/t Au 0.02-0.65 % Cu 3.5-28.1 g/t Ag 0.05-0.57 % Zn	Au+Ag±Zn±Pb 0.82-20.8 g/t Au 3.5-20.7 g/t Ag 0.38-0.62 % Zn 0.02-0.14 % Pb
ORE MINERALS	Ccp, Bn, Pyrr, Py, Cv	Sph, Py, Ccp Minor	Sp, Py, Ccp Minor	Sph, Py, Ccp Abundant	Py, Ccp, Sph Minor	Py, Ccp Abundant	Red Sph, Ga, Py, Abundant
MINERALISATION STYLES	Stockwork Qz Disseminated Ccp Sul+Qz vein (porphyry vein types)	Py+Cal+Qz±Ccp veins	Py+Cal+Qz±Ccp ± Sph veins	Qz-Car vein Py+Car+Qz cut C and B types Dess Py-Ccp	Disseminated Py+Ccp+Sph Qz+Car+Py± Sph±Ccp vein Ep±Chl vein	Qz+Car+py±Sph ±Ccp±Gn vein	Disseminated Sph Qz+Py+Car Ep±red Sph vein
ORE DEPOSIT STYLE	Porphyry Cu-Au	IS epithermal Au cut main porphyry	IS Epithermal Au cut extension porphyry	IS Epithermal Au cut peripheral porphyry	IS epithermal Au cut extension porphyry	IS epithermal Au cut peripheral porphyry	IS epithermal Qz-sulphide Au Car-base metal Au

Abbreviations: MD = hornblende microdiorite, MED = hornblende-pyroxene diorite, CD = quartz diorite, An = anhydrite Bt = biotite, Bn = bornite, Ccp = chalcopyrite, Py = pyrite, Gn = galena, Sph = sphalerite, Pyrr = pyrrothite, Cc = chalcocite, Ac = actinolite, Kfs = K-feldspar, Qz = quartz, Mag = magnetite, Chl = chlorite, Ser = sericite, Cal = calcite.

while the later sulphide bearing veins (AB, C, D veins as well as chalcopyrite disseminated) mostly are rich of copper and gold. Based on the fluid inclusion analysis the hydrothermal fluid of the porphyry level were developed at temperatures from 300 to >600°C with salinity ranging between 16–72 wt.% NaCl equiv. Corbett (2011; 2012) reported that stockwork AB vein cut by C style chalcopyrite vein in WDD8-1384m comprising 1 g/t Au; 2570 ppm Cu, D veins contain locally elevated Au to 5 g/t Au, 1.1 g/t Ag and 292 g/t Cu (in DDH WDD18-358.4m) with typically low Ag:Cu ratios of 0.2 and disseminated magnetite-chalcopyrite mineralization in WDD18-336.9m comprising 102 g/t Au; 1080 ppm Cu and in WDD8-148.3m contains 1.74 g/t Au; 2550 ppm Cu.

Copper and gold are likely to be transported together as chloride complexes (CuCl^0 and AuCl_2^-) in magnetite stability field. The chlorite complexes then react with existing magnetite to produce free gold and chalcopyrite (Equation 1). Many of replacement ore texture, show many chalcopyrite replacing magnetite and minor bornite associated with gold mineralization.

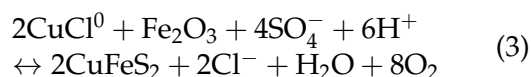
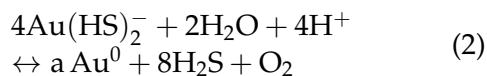


Hence, the Randu Kuning porphyry Cu-Au deposit is chalcopyrite- rich ore rather than bornite- rich ore. Arif and Baker (2004) suggested that porphyry Cu-Au deposits with chalcopyrite-rich ores are more likely to have a higher proportion of free gold and different with those of bornite-rich ores, where gold mostly occurred within copper sulphide grains as an invisible gold within the sulphide structure. The gold and copper grade in the Randu Kuning are mostly associated with the presence of chalcopyrite both in quartz-sulphides veins and or as a replacement in magnetite grains (Figure 8D).

Epithermal environment

On the other hand, the epithermal environment, gold and copper usually are transported in different ion complexes. Au is transported as the thio complex $[\text{Au}(\text{HS})_2^-; \text{Au}_2(\text{HS})_2\text{S}^{2-}$ and $\text{HAu}(\text{HS})_2^-]$ in pyrite stability field, while Cu

is preferably transported as chloride complex in the hematite stability field (Equation 3–4).



In the Randu Kuning epithermal projects, gold and base metals mineralization are mostly associated with sulphides + quartz + carbonate veins and hydrothermal breccias (Figure 8B,C). Many sulphides such as pyrite, chalcopyrite, sphalerite and lack of galena within open space hydrothermal breccia also have an important role in gold-silver-zinc-lead mineralization, particularly in the epithermal environment. Brecciated pyrite-carbonate vein in Geblag (WDD 54 depth 167-169 m) contains 0.63–2.229 ppm Au, 28.1–31.4 ppm Ag, 784–1150 ppm As, 0.45–0.65 % Cu, 301–640 ppm Pb and 0.054–0.57 % Zn. Hydrothermal breccia at the Janggalengan prospect has an important role in Au-Zn-Ag mineralization. Drilling core samples of WDD 69 depth 70–76 m comprising 0.3–1.08 ppm Au, 1–1.4 ppm Ag, 33–195 ppm Pb, 182–2010 ppm Zn and 13–56 ppm As. In the Figure 8E, free gold grain is found in an inclusion within galena, in sphalerite-galena-pyrite-chalcopyrite-carbonate vein.

Paragenetic sequences

Based on the veins/veinlets observation data both field outcrops and drilling cores indicate that there are two ore mineralizing systems in the Randu Kuning hills those are porphyry Cu-Au system and intermediate sulphidation epithermal Au-base metals system (Figure 9).

Hydrothermal fluids which responsible for the porphyry Cu-Au mineralization is associated with the occurrence of the hornblende microdiorite intrusion. The first ore mineralization is a Cu-Au porphyry type deposit characterized by the domination of potassic (biotite + K-feldspar + magnetite + quartz minerals assemblage) and propylitic alteration and small volume of phyllic and advanced argillic alteration within fault zone associated with the formation of several porphyry veins style, i.e.:

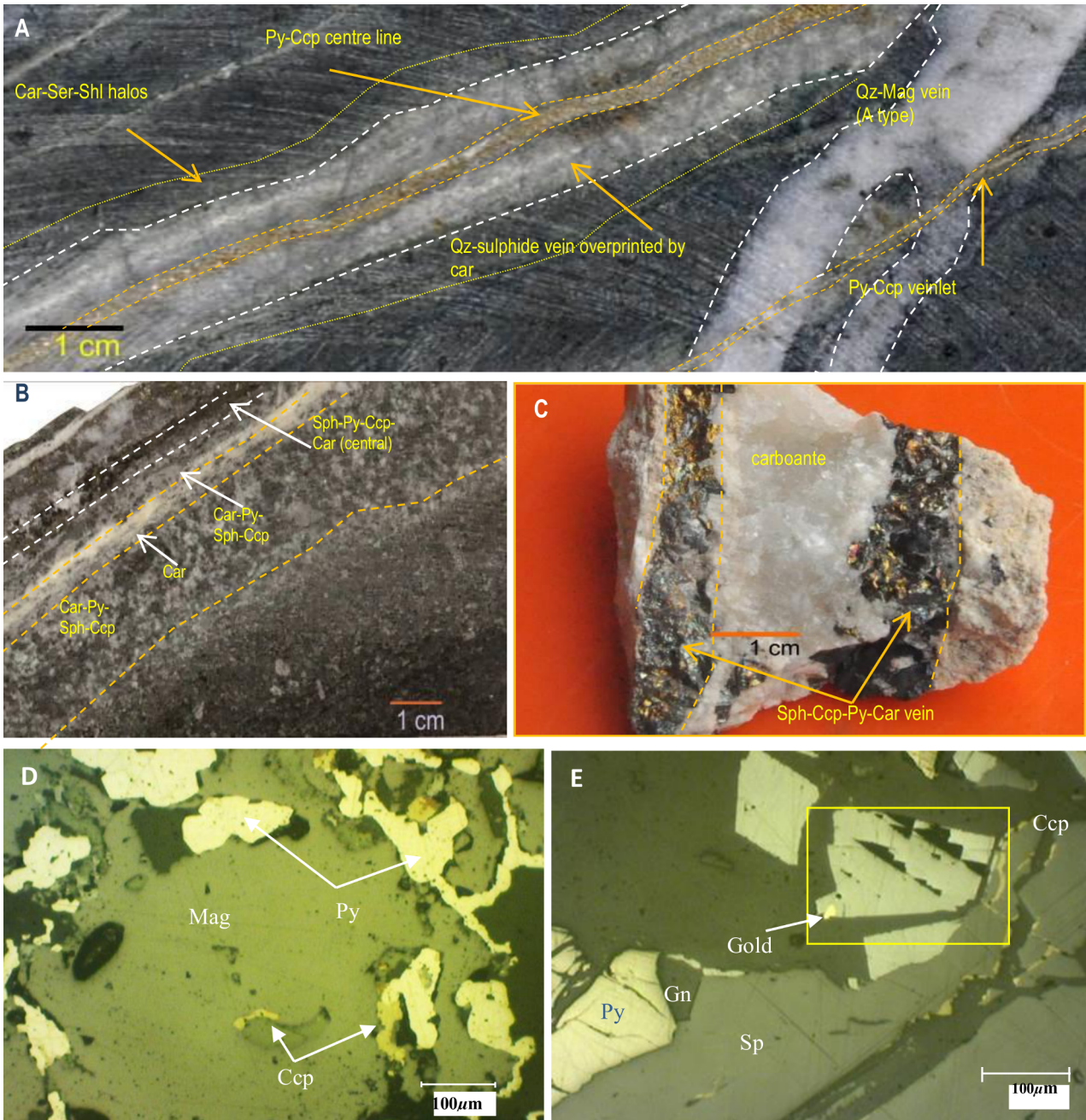
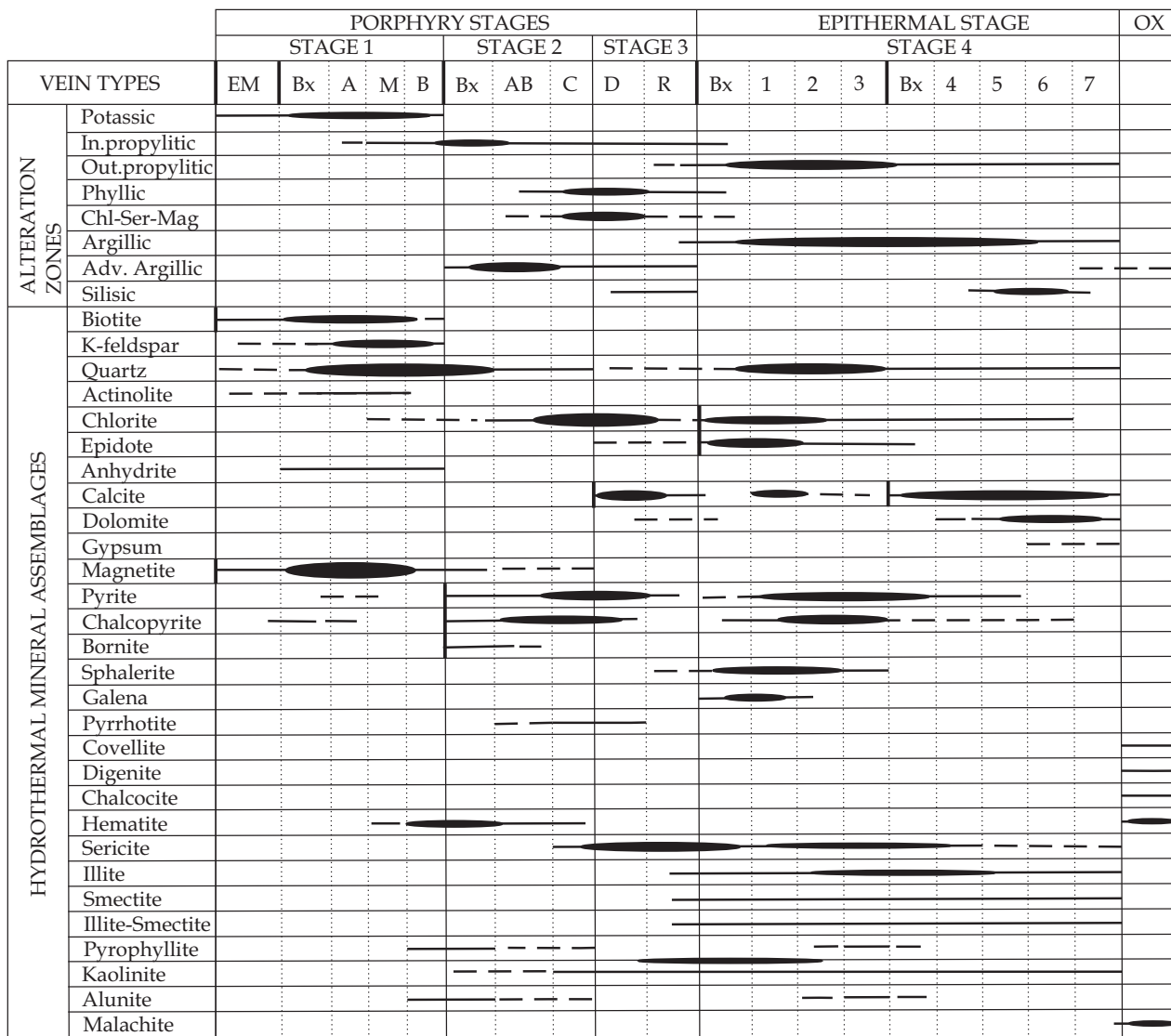


Figure 8: Some veins and breccia types related porphyry (top) and epithermal (bottom) mineralization in the Randu Kuning prospect area. A) The AB vein with pyrite-chalcopyrite centre line (left) and quartz-magnetite (A vein) cut by pyrite-chalcopyrite veinlet (C vein) (WDD30-427.30); B) Sphalerite-pyrite vein with carbonate centre line (WDD 53-76.00) at Gawe prospect; C) Gold-base metals mineralization associated with chalcopyrite-sphalerite-quartz-pyrite vein and carbonate centre line at Kepil-Lancip prospect. D). Photomicrograph polished section under the reflected light of magnetite grains are replaced by pyrite and chalcopyrite. Sample: WDD 49-369.60. and E) Sphalerite-galena-pyrite-chalcopyrite assemblage and free gold grain replaced galena. Sphalerite was replaced by chalcopyrite and galena. Mineral abbreviations: Pl = plagioclase, Ac = actinolite, Kfs = K-feldspar, Qz = quartz, Mag = magnetite, Car = carbonate, Ser = sericite, Ccp=chalcopyrite, Py=pyrite, Sph = sphalerite, Gn = galena.



Explanation:

- A : A vein type AB : AB vein type R : Replacement OX : Oxidation
- M : M vein type EM : Early magnetite-mica Bx : Brecciation 1,2,3,4,5,6,7: Epithermal vein stages
- B : B vein type C : C vein type D : D vein type

Figure 9: Paragenetic sequence of the hydrothermal veins/veinlets and minerals in the Randu Kuning prospect.

Stage 1: Early porphyry veining and brecciation 5 CONCLUSIONS

- a. Magnetite ± chalcopyrite ± quartz ± biotite veinlets.
- b. Magmatic Hydrothermal breccia.
- c. Quartz ± magnetite (A type) vein.
- d. Banded magnetite-quartz (M type) vein.
- e. Quartz ± K-feldspar ± magnetite ± pyrite (B type) vein

Stage 2: Middle porphyry veining and brecciation

- a. Phreatomagmatic breccia.
- b. Quartz ± pyrite ± chalcopyrite ± bornite (AB type) vein.
- c. Pyrite ± chalcopyrite (C type) veinlet.

Stage 3: Late porphyry veining

- a. Pyrite + quartz ± chalcopyrite ± carbonate (D type) vein.
- b. Sericite-chlorite-silica selvages.

While the second ore mineralization is an intermediate sulphidation epithermal Au-base metals mineralization which overprint earlier porphyry mineralization stage characterising by the formation of the outer propylitic and argillic alteration type as well as the formation of later epithermal vein types. Magmatism that produced both hornblende microdiorite and quartz diorite intrusions may be related and responsible to the intermediate sulphidation epithermal mineralization.

Stage 4: Epithermal veining and brecciation

- a. Phreatomagmatic breccia.
- b. Epidote + chlorite ± quartz ± carbonate ± pyrite vein.
- c. Sphalerite + chalcopyrite ± pyrite ± quartz vein.
- d. Chalcopyrite + pyrite + quartz ± sphalerite ± chlorite vein.
- e. Pyrite + quartz + carbonate ± chalcopyrite vein (carbonate as centre line or infill in the centre part of vein).
- f. Brecciation.
- g. Quartz + carbonate ± pyrite vein.
- h. Quartz + carbonate ± pyrite ± chalcopyrite vein.
- i. Carbonate ± gypsum vein.

Based on the characteristics of many parameters such as pattern and type of hydrothermal alterations, vein types, gangue and ore minerals assemblages as well as fluid inclusions data, the Randu Kuning mineralization at Selogiri is co-existing between porphyry Cu-Au and intermediate sulphidation epithermal Au-base metals deposits. Porphyry environment was developed at 300 to >600°C with salinity ranges from 16–72 wt.% NaCl equiv., while intermediate sulphidation epithermal occurred at 200–300°C with salinity about <8–24 wt.% NaCl equiv.

A dioritic composition range of the intrusive rocks type and the domination of the potassic and propylitic zones also lack the phyllic alteration type, suggested that the alteration model of the Cu-Au porphyry ore deposit in the Randu Kuning area is more typically a diorite model rather than a common quartz monzonite model.

Not all porphyry vein types contribute in copper and gold mineralization. In the porphyry environment, the early quartz-magnetite veins (particularly A and M veins) generally do not contain Cu-Au or barren, while the later sulphide are bearing veins (AB, C, D veins as well as chalcopyrite disseminated) mostly are rich of copper and gold, with copper and gold grade ranges about 0.66–5.7 gr/t Au and 0.04–1.24 % Cu. In the intermediate epithermal, gold and base metals mineralization mostly associated with sulphides + quartz + carbonate veins and have metals content grade ranges 0.1–20.8 gr/t Au, 1.2–28.1 gr/t Ag, 0.05–0.9 % Zn and 0.14–0.59 % Pb. Many sulphides such as pyrite, chalcopyrite, sphalerite and lack galena within open space hydrothermal breccia also have important role in gold-silver-zinc-lead mineralization.

The tonnage and grade copper and gold in the Randu Kuning area become much smaller and lower than those of other porphyry Cu-Au deposits in Eastern Sunda Arc, i.e., Tumpang Pitu porphyry Cu-Au at Banyuwangi East Java and Batu Hijau porphyry Cu-Au, Sumbawa. This may be due to the small-size of intrusive rock (hornblende microdiorite) which is responsible for the mineralization or because of a

major eruption which is responsible for the formation of crater.

ACKNOWLEDGEMENTS

This paper is a part of PhD thesis research of the first author at Geological Engineering Department Gadjah Mada University, Indonesia. My sincere thanks go to Directorate General of Higher Education (DIKTI), the Ministry of Education and Culture, Republic of Indonesia for BPP-DN scholarship and PPPI (Sandwich-like) programs. My regards is extended to the management of PT. Alexis Perdana Mineral, which has given us permission to do this research in the Selogiri prospect area and its vicinity. I also would like to thank the Head of the Institute of Mineralogy and Economic Geology (IML) of Aachen (RWTH) University, Germany who gave me permission to access to the laboratories.

REFERENCES

- Arif, J. and Baker, T. (2004) Gold Paragenesis and Chemistry at Batu Hijau, Indonesia: Implications for Gold-Rich Porphyry Copper Deposits, *Mineralium Deposita* 39: 523-335.
- Carlile, J.C. dan Mitchell, A.H.G. (1994) Magmatic Arcs and Associated Gold and Copper Mineralisation in Indonesia, *Journal of Geochemical Exploration* 50: 92-142.
- Corbett, G. (2011) Comments on The Exploration Potential of The Wonogiri Porphyry Cu-Au Project, Central Java, Indonesia, Corbett Geological Services Pty. Ltd., Unpublished, 27 p.
- Corbett, G. (2012) Further Comments on The Wonogiri Porphyry Cu-Au Project Central Java, Indonesia, Corbett Geological Services Pty. Ltd., Unpublished, 37 p.
- Hamilton, W.B. (1979) Tectonics of the Indonesian Region. Professional Paper 1078, U.S. Geology Survey, Washington, DC., 345 p.
- Hellman, P.L. (2010) Tujuh Bukit Project Report on Mineral Resources, Located in East Java, Indonesia. Technical Report for Interprid Mines Limited. URL: <http://media.wotnews.com.au/esxann/01120-850.pdf>.
- Imai, A., Shinomiya, J., Soe, M.T., Setijadji, L.D., Watanabe, K., and Warmada, I.W. (2007) Porphyry-Type Mineralization at Selogiri Area, Wonogiri Regency, Central Java, Indonesia, *Resources Geology* 57: 230-240.
- Isnawan, D., Sukandarrumidi and Sudarno, I. (2002) Kontrol Struktur Geologi Terhadap Jebakan Tembaga Sebagai Arahan Eksploitasi di Daerah Ngerjo dan Sekitarnya Kecamatan Tirtomoyo, Kabupaten Wonogiri Propinsi Jawa Tengah, *Gama Sains* IV (2) Juli 2002, p. 149-157.
- Katili, J. A. (1989) Evolution of the Southeast Asian arc complex, *Geologi Indonesia* 12: 113-143.
- Maryono, A. (2008) Porphyry Veining Types and Characteristics, *Porphyry Deposit Workshop, Batu Hijau* December 1-5-2008.
- Maryono, A., Setijadji, L.D., Arif, J., Harrison, R., Soeria-Atmadja, E. (2012) Gold, Silver and Copper Metallogeny of the Eastern Sunda Magmatic Arc Indonesia, *Proceeding of Banda and Eastern Sunda Arcs 2012 MGEI Annual Convention*, 26-27 November 2012, Malang, East Java, Indonesia, p. 23-38.
- Milési, J.P., Marcoux, E., Sitorus, T., Simanjuntak, M., Leroy, J., and Bailly, L. (1999) Pongkor (West Java, Indonesia): A Pliocene Supergene-Enriched Epithermal Au-Ag-(Mn) Deposit, *Mineralium Deposita* (1999) 34: 131-149.
- Muthi, A., Basten, I.G., Suasta, I.G.M., and Litaay, N.E.W. (2012) Characteristic of Alteration and Mineralization at Randu Kuning-Wonogiri Project, *Proceeding of Banda and Eastern Sunda Arcs 2012 MGEI Annual Convention*, 26-27 November 2012, Malang, East Java, Indonesia, p. 117-132.
- Nightingale, P.L. (2014) Report on Activities for the Quarter Ended 30 September 2014, Augur Resources Ltd. 11 p.
- Prihatmoko, S., Digsowilogo, S., and Kusumanto, D. (2002) Potensi Cebakan Mineral di Propinsi Jawa Tengah dan Daerah Istimewa Yogyakarta, in: *Sumberdaya Geologi Daerah Istimewa Yogyakarta dan Jawa Tengah*, Ikatan Ahli Geologi Indonesia Pengurus Daerah DIY-Jateng, p. 87-103.
- Setijadji, L.D., Kajino, S., Imai, A., and Watanabe, K. (2006) Cenozoic Island Arc Magmatism in Java Island (Sunda Arc, Indonesia): Clues on Relationships between Geodynamics of Volcanic Centers and Ore Mineralization, *Resource Geology* 56: 267-292.
- Setijadji, L.D. and Maryono, A. (2012) Geology and Arc Magmatism of the Eastern Sunda Arc, Indonesia, *Proceeding of Banda and Eastern Sunda Arcs 2012 MGEI Annual Convention*, 26-27 November 2012, Malang, East Java, Indonesia, p.1-22.
- Setiawan, B. dan Yudawinata, K. (2000) Review of Mineral Exploration Along the Sunda-Banda Magmatic Arc, *Freeport-ITB Geological Symposium*, 13 p.
- Suasta, I.G.M. and Sinugroho, I.A. (2011) Occurrence of Zoned Epithermal to Porphyry Type Cu-Au Mineralization at Wonogiri, Central Java, *Proceeding of The 36th HAGI and 40th IAGI Annual Convention*.

- Soeria-Atmadja, R., Maury, R.C., Bellon, H., Pringgoprawiro, H., Polvé, M., and Priadi, B. (1991) The Tertiary Magmatic Belt in Java. The Proceeding of the Silver Jubilee Symposium On the Dynamics of Subduction and Its Products, Yogyakarta: p. 98-121.
- Soeria-Atmadja, R., Maury, R.C., Bellon, H., Pringgoprawiro, H., Polvé, M., and Priadi, B. (1994) Tertiary Magmatic Belt in Java. *Journal of Southeast Asian Earth Science* 9: 13-27.
- Sutarto, Idrus, A., Harijoko, A., Setijadji, L.D., Meyer, F.M, and Danny, R. (2015) Characteristic of The Fluid Inclusions in Quartz Veins at The The Randu Kuning Porphyry Cu-Au Deposit, Selogiri, Central Java. *Prosiding Seminar Nasional Kebumihan X-2015 Fakultas Teknologi Mineral UPN "Veteran" Yogyakarta 18-19 November 2015*, ISBN No. 978-602-8206-67-9. pp. 208-220.
- Sutarto, Idrus, A., Harijoko, A., Setijadji, L.D. and Meyer, F.M. (2015) Veins and Hydrothermal Breccias of The Randu Kuning Porphyry Cu-Au and Epithermal Au Deposits at Selogiri Area, Central Java, Indonesia. *Journal of SE Asian Applied Geology* 7: 80-99.
- Tain, Z., Sutrisno, Pohan, M.P., and Herudiyanto (2005) *Penilaian Sumberdaya Tembaga-Emas Porfiri Daerah Pulau Sumatra dan Pulau Jawa, Hasil Kegiatan Subdit Konservasi TA. 2005*. URL: <http://psdg.bgl.esdm.go.id/kolokium%202005/konservasi/6-Penilaian.pdf>.
- Van Bemmellen, R.W. (1949) *The Geology of Indonesia, and Adjacent Archipelagoes, Vol. IA*, Gov. Print. Office, Martinus Nijhoff, the Hague.
- Van Leeuwen, T.M. (1994) *25 Years of Mineral Exploration and Discovery in Indonesia*, *Jornal of Geochemical Exploration*, Elsevier Science, Amsterdam, 50: 13-89.