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# HIGH SULFIDATION EPITHERMAL MINERALIZATION AND ORE MINERAL ASSEMBLAGES OF CIJULANG PROSPECT, WEST JAVA, INDONESIA

Myo Min Tun*[1,2], I Wayan Warmada[2], Arifudin Idrus[2], Agung Harijoko[2], Okki Verdiansyah[3], and Koichiro Watanabe[4]

[1]*University of Yangon, Myanmar*
[2]*Geological Engineering Department, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia*
[3]*PT. Aneka Tambang Tbk.- Unit Geomin, Jl. Pemuda No.1, Jakarta Timur*
[4]*Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan*

## Abstract

*Cijulang is a high-sulfidation epithermal system hosted in the calc-alkaline rocks of andesite lava and lapilli tuff. Mineralization in the prospect is characterized by pyrite-enargite-gold and associated acid sulfate alteration. Studies on ore and gangue mineral assemblages and their mutual textural relationships were carried out in order to explore the paragenetic sequence of mineralization. Hypogene mineralization primarily occurs in the silicic core and the advanced argillic zone in the form of massive replacement, fracture-filling veinlets, vug-filling, patches and dissemination. Mineralization is apparently controlled by both lithology and structures. Common ore minerals include pyrite, enargite, luzonite, tennantite, chalcopyrite, covellite, galena, emplectite and Te-bearing minerals. The paragenetic study indicates that the epithermal prospect evolved from an early stage of intense acid leaching resulting in the formation of vuggy silica and advantage argillic mineral assemblage which was followed by the sulfides deposition. Two metal stages were identified during ore deposition: an early Fe-As-S stage and the later Cu-Fe-As-S stage. The former stage is characterized high-sulfidation state sulfides such as enargite/ luzonite+covellite whereas a later stage of Cu-Fe-As–S is represented by intermediate sulfidation state sulfides assemblage of tennantite+chalcopyrite. Gold is probably introduced in the early stage within the ore system and more abundant in the late stage.*
**Keywords:** *Cijulang, high-sulfidation, acid sulfate, mineralization, enargite, paragenetic, metal stages*

## 1 Introduction

Cijulang prospect is located in Talegong Subdistrict, Garut Regency of West Java, Indonesia (Figure 1) and belongs to the Papandayan Mineral District. The prospect was found by Aneka Tambang (Persero) Tbk during systematic gold exploration in West Java area since two decades ago. Currently, selected diamond drilling has being conducting in the prospect area by GeoMin Unit (Papandayan) of PT Aneka Tambang (Persero) Tbk. High-sulfidation epithermal mineralization occurs in the calc-alkaline volcanic and volcaniclastic rocks of Tertiary age. The occurrence of enargite-gold mineralization and associated acid sulfate alteration features the mineralized hydrothermal system in the prospect as epithermal high-sulfidation system (Verdiansyah *et al.*, 2012; Tun *et al.*, 2013, 2014). The current study presents the characteristics of

*Corresponding author: M.M. TUN, Geological Engineering Department, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia. E-mail: mintunmyo@gmail.com

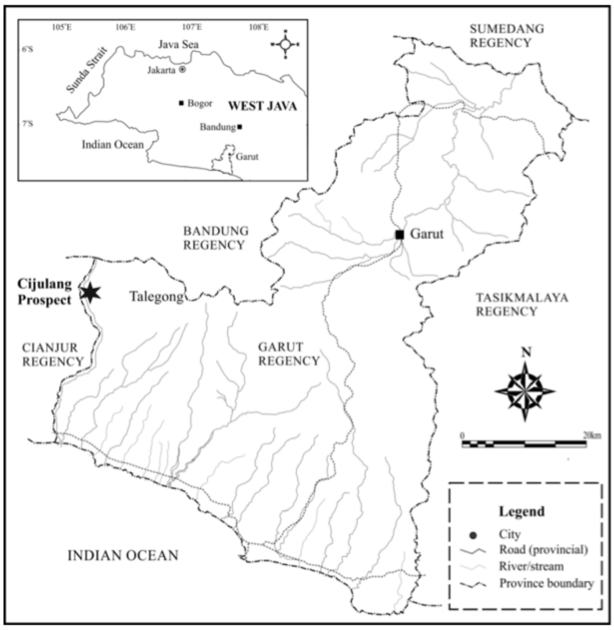


Figure 1: Location map of Cijulang Prospect, Garut Regency, West Java, Indonesia.

mineralization, ore mineralogy, mineral assemblages and paragenetic sequence of mineralization for the Cijulang prospect.

## 2 Geologic setting

Convergence of the Indo-Australia and Sunda plates during the Cenozoic created the two active magmatic-volcanic arcs: Sunda arc, which extends from 105° to 122°E longitude, and Banda arc, stretching from 122° to 128°E longitude (Hamilton, 1979; Rangin *et al.*, 1990): The Sunda arc has developed entirely from relatively simple oceanic plate subduction, while the Banda arc has resulted from oceanic subduction to continental collision, characterized by a complex and regional deformed zone. These magmatic-volcanic arcs comprises mainly of calc-alkaline andesitic rocks and Quaternary volcanic cover. West Java constitutes part of the Sunda-Benda Magmatic arcs.

The research area is located in the Southern Mountains of the West Java which consists of Eocene-Miocene sediments and volcanic rocks such as Jampang Formation (Old Andesite Formation, Van Bemmelen, 1949). Southern Mountains represent a present day fore-arc located between Java trench and the Quaternary volcanic chains which was resulted from Late Eocene to Early Miocene magmatism along the magmatic arcs. Jampang Formation comprises andesite lava, andesite breccias and fine tuff and most of its rocks experienced regional propylitic alteration. The Jampangs hosts several mineralization in West Java area such as porphyry copper-gold mineralization in the Cihurip/Ciparay (Yuningsih *et al.*, 2012), polymetallic base metal mineralization in the Arinem (Suparka *et al.*, 2007), and low-sulfidation and associated porphyry-related mineralization in Jampang area (Lubis, 2009).

Lithologic units exposing in the Cijulang prospect are of mainly calc-alkaline volcanic and volcaniclastic rocks and comprise andesite lava, lapilli tuff, andesite and andesite breccia (Figure 2). All of the rock types exhibit calc-alkaline nature (Tun *et al.*, 2013). Andesite lava is the oldest rock in the prospect and regarded as member unit of Middle Miocene Jampang Formation. It is composed of phenocrysts and micro-phenocrysts of plagioclase, pyroxene which were embedded in a microcrystalline groundmass of the same composition as phenocrysts. Lapilli tuff is the most widespread covered rock and composed of fine- to medium-grained crystalline quartz with lithic fragments cemented by the fine-grained matrix. Lapilli tuff serves as the main host for the epithermal high-sulfidation alteration/ mineralization. It is regarded as the member rock of Late Miocene Koleberes Formation. Andesite and andesitic breccias blankets the older rocks of lapilli tuff and andesite lava, and suffers little or no hydrothermal alteration. It is composed of phenocrysts of plagioclase and pyroxene, hornblende embedded within the microcrystalline groundmass of feldspar and other mafic minerals. Andesite and andesitic breccia belong to member rocks of Mt. Kendeng Lava of Pleistocene age.

## 3 Alteration and mineralization

Cijulang prospect is a high-sulfidation epithermal system that was developed from an early stage of acid leaching resulting in the forma-

 

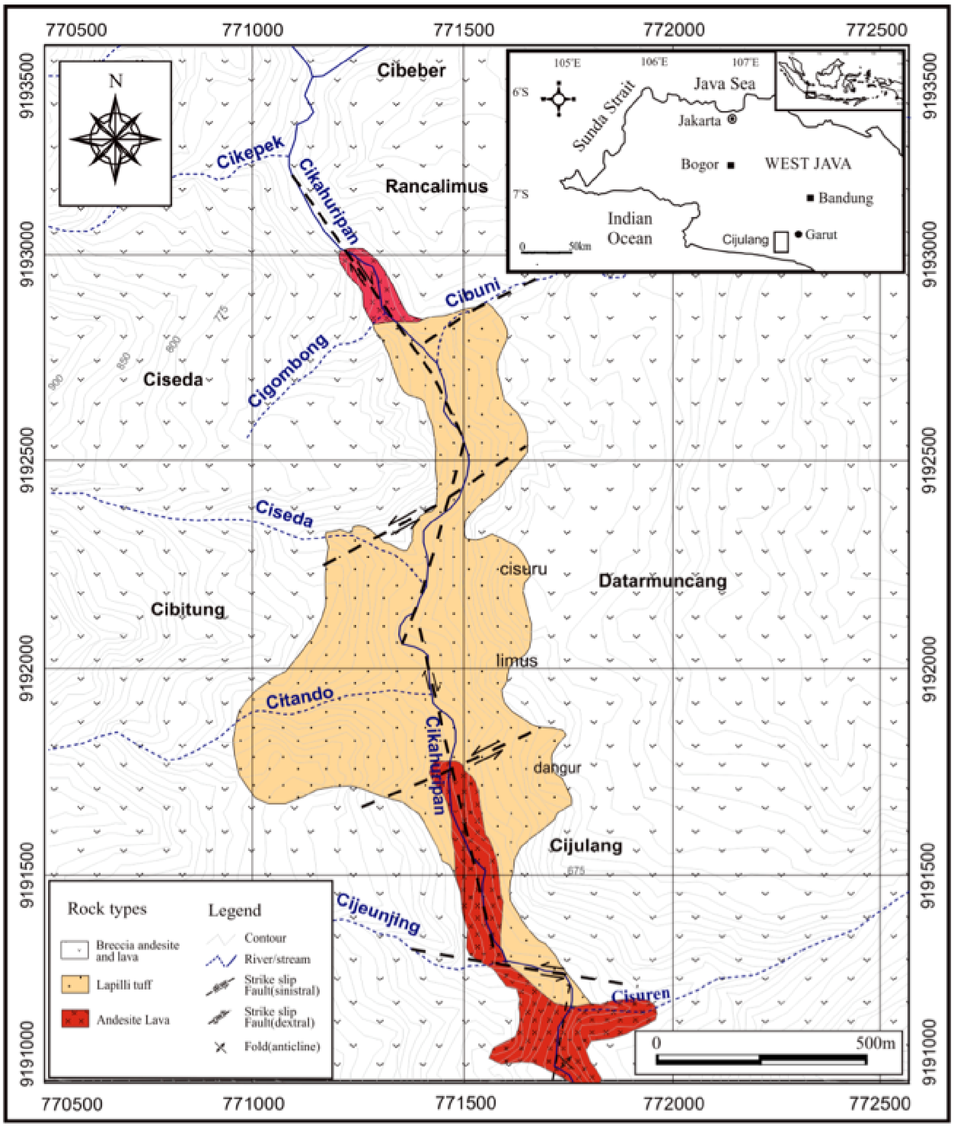


Figure 2: Geological Map of the Cijulang prospect, Garut agency, West Java, Indonesia.

 

tion of vuggy silica and advanced argillic alteration, with later deposition of sulfide ores such as enargite/luzonite-covellite assemblage and tennantite-chalcopyrite assemblage.

Hydrothermal alteration is hosted mainly by lapilli tuff and andesite lava, and comprises a siliceous core (vuggy and massive) with outward zonation of advanced argillic, argillic and propylitic alteration. Silicification was mainly developed in the lapilli tuff (Figure 3a) whereas advanced argillic, argillic and propylitic alteration occurred in lapilli tuff, andesite lava and hydrothermal breccia. Silica-altered rock is composed of microcrystalline quartz, pyrite, with minor amount of kaolinite, anatase and rutile. Advanced argillic alteration in the outcrop comprises quartz+pyrophyllite+dickite/kaolinite±diaspore assemblage and quartz-alunite-native sulfur in the sub-surface. Argillic zone is characterized by quartz+ kaolinite+illite+ illite/smectite, smectite assemblage. Propylitic assemblage consists of quartz+chlorite+ epidote+calcite±magnetite. Pyrite is the universal sulfide mineral occurring in all types of alteration.

Sulfides and sulfosalts mineralization occurs in vuggy silica and advanced argillic-altered rocks and found as massive replacement, fractures- and vug-filling veinlets/microveinlets, patches and dissemination (Figures 3b–f). Common ore minerals include enargite, luzonite, pyrite, tennantite, chalcopyrite, galena, emplectite, copper telluride, and covellite. Pyrite, enargite/luzonite,tennantite, and chalcopyrite are the principal sulfides. Pyrite, enargite/luzonite and covellite are the main constituent minerals in surface mineralization whereas tennantite, chalcopyrite, emplectite and tellurides are the principle minerals in sub-surface epithermal ore mineralization. Hematite, goethite, sulfur and scorodite are common late minerals filling in the vugs and fractures and coating on the surfaces of mineralized zones. Their occurrences reflect the oxidation of primary sulfides and sulfosalts. Gold is intimately associated with enargite and pyrite. High grade gold is generally confined to the silicic core and advanced argillic zone. Average assay value of gold from vuggy silica is about 1g Au/ton (Antam unpublished data). Permeable lithology such as lapilli tuff also served as favorable ground for alteration and mineralization. Mineralization is also controlled by strike-slip faults system as the hydrothermal alteration/mineralization cropped out along such features.

## 4 Research methods

Research was carried out by field investigation and follow-up laboratory analyses such as ore microscopy and SEM-EDX analysis. Samples are taken from the mineralized wall rocks and veins from the Cijulang prospect during field study. Five thin-sections and twenty polished sections of ore samples were prepared and examined under refracted-light optical microscope for mineralogical and textural studies. Ore microscopy was carried out in the laboratory of Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University, Japan. Microprobe examination of ore minerals was carried out by SHIMADZU SS-550 Scanning Electron Microscope equipped with a genesis-2000 EDX Spectrometer at the Centre for Advanced Instrumental Analysis, Kyushu University, Japan. Ten polished section were use for qualitative and semi-quantitative SEM-EDX analyses and the experimental condition for the analysis was performed at an accelerating potential of 15 kV, beam current about 10mA, and 3μm beam diameter.

## 5 Results and discussion

### 5.1 Ore mineral assemblages

***Pyrite [$FeS_2$].*** Pyrite is the most abundant sulfides mineral affected by hydrothermal alteration and mineralization in the Cijulang prospect. Pyrite generally occurs as replacement and/or fractures or open-space filling. It replaces the mafic minerals in the altered host rocks and directly deposited from solution filling the fractures, forming vein and veinlets. Pyrite can be seen as anhedral to euhedral grains. Pyrite from the quartz-alunite zone occurs as euhedral to subhedral discrete grains

 

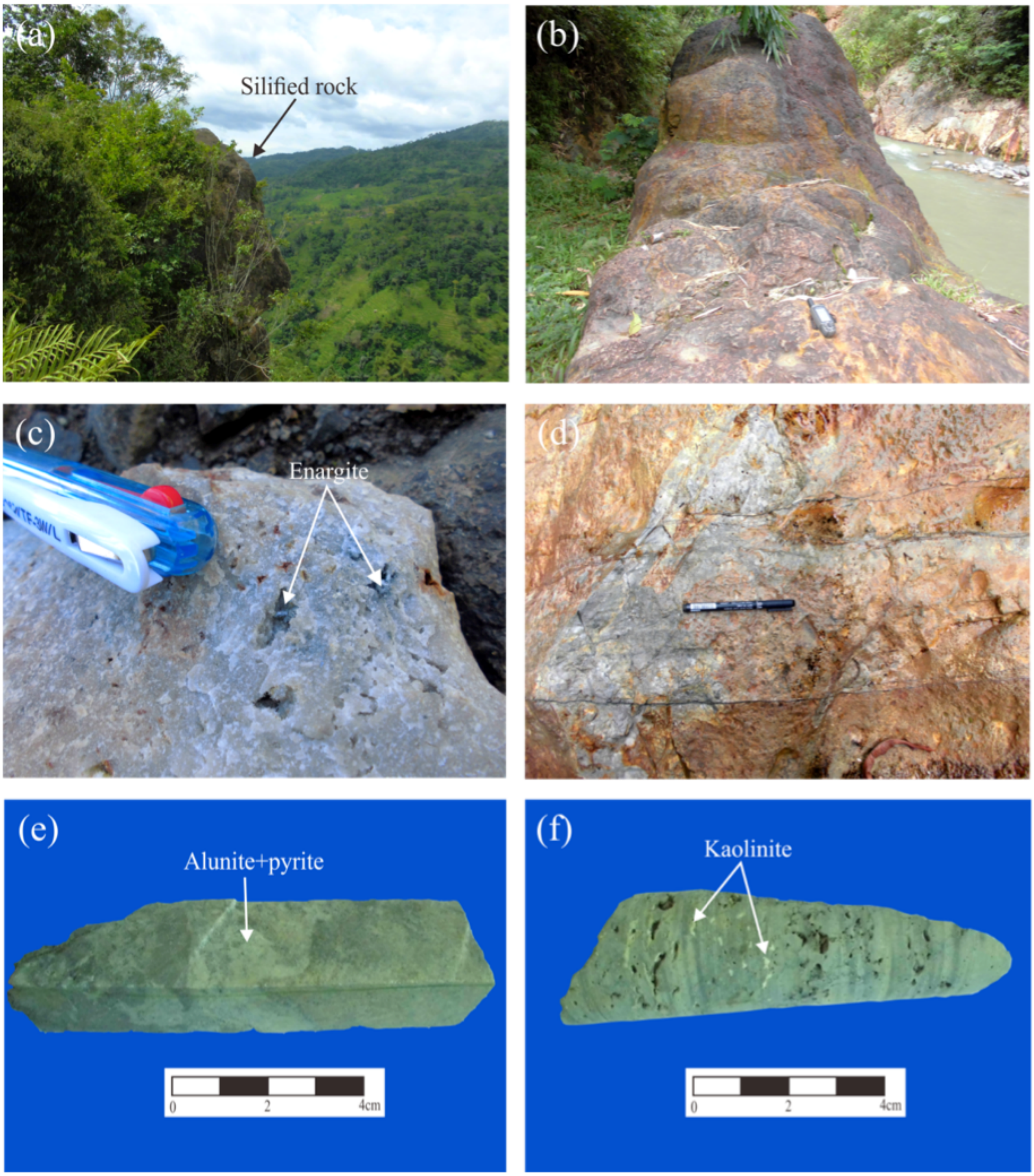


Figure 3: (a) View of massive silicified outcrop at Cisuru Hill (b) an exposure of silicified massive ore body outcropping along the Cikahuripan River in the prospect (c) enargite-pyrite mineralization filling in the vugs of silica alteration (d) sulfides (pyrite+enargite/luzonite) veinlets in the advanced argillically-altered hydrothermal breccia (e) drill core sample of alunite-pyrite-alteration (Dcjl04-261) (f) drill core sample showing massive replacement of pyrite+tennantite+chalcopyrite+emplectite+tellurides mineralization in the vuggy silica (Dcjl01-340).

 

(Figure 4a) or aggregates embedded within the laths of the alunite and native sulfur. Pyrite in the silica zone typically fills the vugs and is generally replaced by the enargite which is in turn rimmed or replaced by the covellite and scorodite (Figures 4b–d). In general, pyrite is intimately associated with enargite and its dimorph luzonite during the early stage of ore mineralization at the crustal level and spatially associated with tennantite in the late history of mineralization at the subsurface.

Early phase pyrite which fills the vugs during earlier hydrothermal alteration are severely fractured/crackled and ruptured due to post-alteration brecciation. Later ore mineralization generally filled and replaced within fractured or explosive pyrite. Another obvious feature in pyrite is the presence concentric zonation in pyrite within the ore zones and from this feature it can be deduced that, at least, three stages of pyrite generations have been documented. In the latest stage of ore deposition, pyrite is being replaced by tennantite-chalcopyrite vein or veinlets.

***Covellite [CuS].*** Covellite is generally found in association with enargite and covellite in the shallow-level setting or at outcrop. It generally replaces and rims the enargite within the vug of silica alteration (Figure 4c-d). They can be seen as fine-grained aggregate or disseminated grains around enargite and/or luzonite.

***Enargite/Luzonite [$CuAsS_4$].*** Enargite and its polymorph luzonite are very common and formed as an early mineral of the paragenetic sequence of Cijulang mineralization. Enargite generally occurs either as subhedral prismatic or anhedral mineral (Figures 4b–f) filling the vugs of silica alteration. It is commonly associated with pyrite and covellite at shallow level setting. Enargite generally replaces and/or rims pyrite and being rimed by covellite. Within the silica zone, enargite together with luzonite and chalcopyrite occurs as late veinlets (Figure 4f) cross cutting the vugs filled by former mineralized assemblage of enargite-pyrite. This evidence suggests that late vein phase mineralization post-dated primary vug filling after the major phase of silica alteration, and subsequent crackled brecciation.

***Chalcopyrite [$CuFeS_2$].*** Chalcopyrite is also one of the common sulfide minerals from the prospect and associated with enargite, luzonite, tennantite, galena and pyrite. It generally occurs as patches within enargite, and luzonite. Chalcopyrite occurs as late mineral forming veinlets together with enargite/luzonite cross cutting the vugs with earlier pyrite-enargite mineralization of silica alteration at outcrop. In the deeper level setting, it is associated with tennantite. Sometimes it occurs as minute bleb or as inclusions within the large tennantite (Figure 4g).

***Tennantite [$(Cu, Fe)_{12}As_4S_{13}$].*** Tennantite which belongs to the tetrahedrite isotypic series (Moëlo *et al.*, 2008) is very common ore minerals in the Cijulang area. Tennantite is restricted to the mineralization occurring at depth. Tennantite generally occurs as fracture-filling veins replacing the pyrite and accompanied by chalcopyrite, emplectite and tellurides (Figures 4g–h).

Occurrence of tennantite in association tellurides and Te-bearing minerals strongly suggest that the tennantite stage is regarded as the precious metal-bearing stage.

***Te-bearing minerals.*** Tellurium-bearing minerals is usually seen as tiny grain and commonly found in association with chalcopyrite and tennantite (Figure 4h). Pb, Cu, As and Sb- bearing phases are common and belong to altaite [PbTe], vulcanite [CuTe] and arsenic-bearing tellurium sulfides. Galena [PbS]: Galena occurs as minor constituent in the mineralized vein in the advanced argillic-altered rocks. It generally formed as irregular mineral forming as matrix in disseminated anhedral pyrite grains and intergrown with tennantite, chalcopyrite and enargite (Figure 4i).

***Emplectite [$CuBiS_2$].*** Emplectite is generally associated with enargite and luzonite. It commonly found as irregular patches or speck within the large enargite and luzonite grain

 

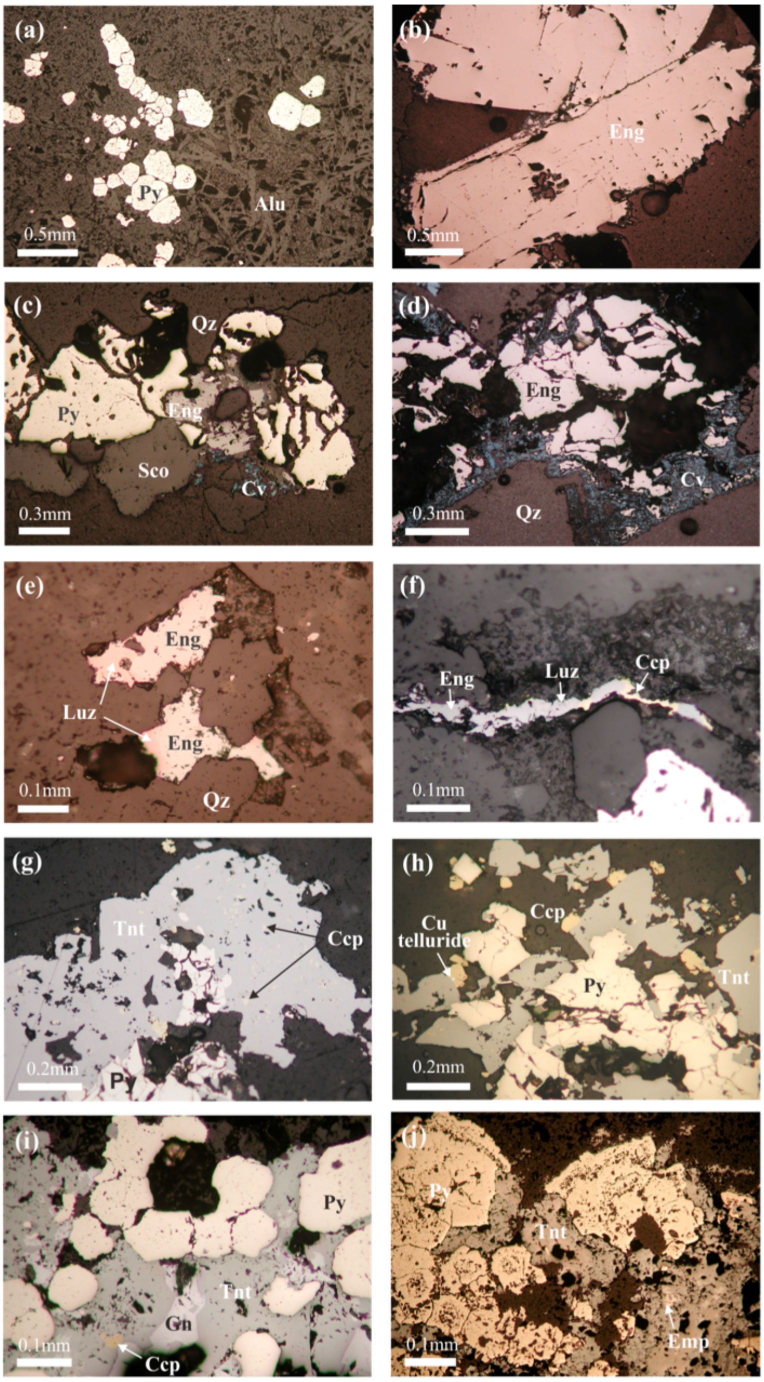


Figure 4: Photo-micrographs illustrating ore mineral assemblages at Cijulang prospect: (a) euhedral pyrite within laths of alunite (Dcjl04-282.8) (b) two large subhedral enargite crystals in the vug of silica alteration (c) pyrite-enargite-covellite and late covellite in the vug (d) enargite replace by covellite in the vug (e) intergrowth of enargite and luzonite (f) enargite-luzonite-chalcopyrite micro-veinlet in the silica alteration (g) spec of chalcopyrite in the massive tennantite (h) tennantite-chalcopyrite-telluride assemblage (drill core DCjl01-340) (i) Intergrowth of tennantite, galena, and chalcopyrite cementing the early formed pyrite of advanced argillic (Dcjl03-327.45); Alu-Alunite, Ccp-chalcopyrite, Cv-covellite, Eng-enargite, Emp-emplectite, Gn-galena, Luz-luzonite, Qz-quartz, Tnt-tennantite.

 

which generally fill along the fractures and replacing pyrite (Figure 4j).

***Gold [Au].*** Gold, on the deposit scale, generally occurs within the massive silica zone and advanced argillic alteration. High grade gold is generally confined to the silica zone with massive pyrite-enargite ores. Native gold has not been observed from the ore microscopic study and this would probably due to its very fine-gained micron size which is impossible to be seen by a microscope.

### 5.2 Paragenesis of mineralization

Paragenetic sequence of mineralization (Figure 5) was developed for Cijulang prospect based on the characteristic of alteration, mineralization, and textural relationships among ore and gangues minerals. Four main stages were identified and described as follow:

**State I** represents hydrothermal alteration and characterized by intense acid-leaching of host rocks forming vuggy silica alteration. The successive formation of quartz+pyrophyllite+dickite/kaolinite±alunite and quartz+kaolinite+illite+smectite alteration zones appeared to have developed penecontemporaneous with vuggy silica alteration. Pyrite was introduced during this alteration stage and occurs mainly as dissemination. Pyrite is also seen as pseudomorph replacement of mafic minerals and as euhedral grain occurring together with alunite and native sulfur throughout the quartz-alunite alteration at greater depth. Early formed vuggy silica rocks and advanced argillic-altered rocks were followed by later ore deposition. State II and III represent the metal stage. An early Fe-As-S stage.

**Stage II,** comprises pyrite, enargite-luzonite-covellite and represents high-sulfidation state of fluids. This mineral assemblage commonly occurs in the vugs of silica alteration zone. Early formed pyrite is generally replaced by enargite/luzonite. Covellite tends to replace enargite suggesting later in its development with respect to enargite and pyrite. The paragenetic relations among enargite and luzonite are not well defined. The intergrowth of these two ore minerals are common and suggest that they were developed from contemporaneous deposition.

**Stage III** is represented by a later Cu-Fe-As-S stage. It is associated with intermediate-sulfidation state sulfides and comprises tennantite, chalcopyrite with minor emplectite and tellurides. In the Cu-Fe-As-S stage, tennantite appears to be deposited together with tellurides and chalcopyrite. Gold and silver is appeared to be associated with tennantite in this state. Enargite/luzonite-pyrite is generally formed in the upper level setting and tennantite-chalcopyrite-emplectite-telluride assemblage generally occurred at greater depth.

**Stage IV** is an oxidation stage and primary sulfide mineral assemblages from ore stages were replaced pervasively by hematite and goethite. Iron oxides and oxyhydroxides formed as staining and encrusting, vug-filling throughout the mineralized rocks and ore zones. Scorodite is also formed as late minerals in the vugs as a result of oxidation of primary enargite/luzonite ores.

## 6 Conclusion

Cijulang prospect is a typical of high-sulfidation system characterized by pyrite+enargite-gold mineralization and accompanying acid sulfate alteration. Hydrothermal activity in the Cijulang prospect involves two stages: an early event of acid leaching which was responsible for vuggy silica and advanced argillic alteration with disseminated pyrite which is followed by a later period of ore (Cu±Au±Ag) deposition. The mineralogical and paragenetic study has revealed the existence of two metal stages in the Cijulang prospect as observed in other high-sulfidation gold districts (e.g. El Indio, Lepanto). An early Cu-rich, Au-poor stage, characterized by high-sulfidation-state sulfides such as enargite/luzonite and a

 

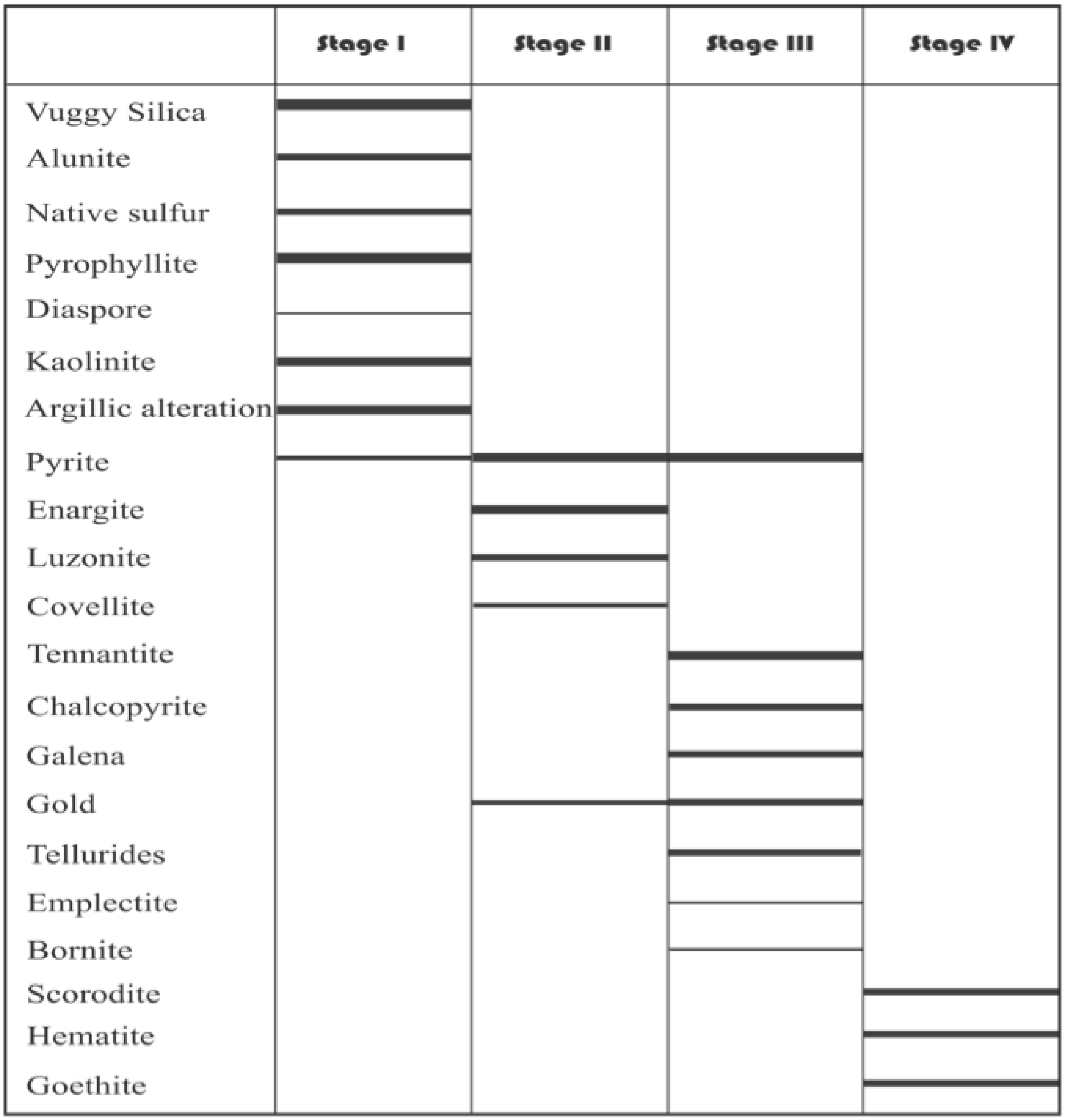


Figure 5: Paragenetic sequences of mineralization for Cijulang high-sulfidation epithermal prospect. Gold is introduced with stage II pyrite-enargite/luzonite mineralization and more abundant in the stage III associated with tennantite-chalcopyrite-emplectite-telluride assemblage. Line thickness represents the relative importance of minerals in each stage.

 

later Au-rich, Cu-poor stage characterized by intermediate-sulfidation-state sulfides of tennantite+ chalcopyrite assemblage. A transition from early acid-leaching to enargite-pyrite and finally to tennantite-chalcopyrite indicate that the hydrothermal fluids progressively more reduced and become less acidic in condition.

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