

COMPOSITIONAL VARIATIONS OF Au-Ag TELLURIDE MINERALS OF ARINEM DEPOSIT, WEST JAVA

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Abstract

The epithermal Arinem veins system of gold-silver-base metal mineralization is located in the Arinem area in the southwestern part of Java Island, Indonesia. The veins are composed predominantly of quartz + calcite ± illite ± kaolinite with variable amount of manganese oxide and limonite and high amount of sulfides. The deposit contains a number of Te-bearing minerals, notably tellurides and tellurosulfide minerals. The tellurium mineral assemblages in the Arinem and Bantarhuni veins are similar in the presence of *hessite* (Ag_2Te), *petzite* (Ag_3AuTe_2), *stutzite* (Ag_5Te_3), *tetradymite* ($\text{Bi}_2\text{Te}_2\text{S}$) dan *altaite* (PbTe). The tellurium mineral assemblages vary from sample to sample and most of the observed telluride occurrences consist of at least 2 different phases (e.g. *petzite-hessite*, *tetradymite-hessite*, *petzite-hessite-altaite*). Gold concentrations measured in Te-mineral of petzite from the Arinem vein are in the range between 14.24 to 18.32 wt%. Some hessite and stutzite contain gold up to 3.48 and 1.10 wt%, respectively. Some of electrum are present as inclusions in Te-mineral patches in both veins.

Keywords : Electrum, petzite, sulfide, tellurides, Arinem, Bantarhuni

Sari

Mineralisasi epitermal emas-perak-logam dasar sistem Urat Arinem berlokasi di daerah Arinem di sebelah barat daya Pulau Jawa, Indonesia. Urat didominasi oleh kuarsa + kalsit ± illit ± kaolinit dengan kehadiran oksida mangan dan limonit dalam jumlah bervariasi dan kehadiran mineral sulfida yang melimpah. Endapan Arinem mengandung sejumlah mineral telurium yang sebagian hadir dalam bentuk sulfida telurium. Himpunan mineral telurium yang teridentifikasi di dalam Urat Arinem dan Bantarhuni memiliki kesamaan dalam hal kehadiran hessite (Ag_2Te), petzite (Ag_3AuTe_2), stutzite (Ag_5Te_3), tetradymite ($\text{Bi}_2\text{Te}_2\text{S}$) dan altaite (PbTe). Kehadiran mineral telurium bervariasi dalam sampel yang berbeda dan umumnya kehadiran telurium terdiri dari 2 fase atau lebih yang berbeda (seperti petzite-hessite, tetradymite-hessite, petzite-hessite-altaite). Kandungan Au dalam petzite dari Urat Arinem berkisar antara 14.24 sampai 18.32 wt%. Beberapa hessite dan stutzite juga mengandung Au mencapai 3.48 dan 1.10 wt%. Elektrum sebagian hadir sebagai inklusi dalam mineral telurium di kedua urat.

Kata kunci : Elektrum, petzite, sulfida, telurium, Arinem, Bantarhuni

Introduction

The Arinem deposit is located on the island of Java as a part of West Java Province of Indonesia. The deposit is found at the south of Mt. Papandayan active volcano and is situated about 200 km southeast of the capital city of Jakarta. Epithermal Au-Ag-base metal Arinem deposit occurs in volcano-plutonic arcs, i.e., transition between continental to island arcs of Sunda-Banda associated with subduction zones (Shulgin *et al.*, 2009; Figure 1).

So-far, unexploited low-grade gold-silver telluride mineralization at Arinem is an uncommon mineralization assemblage in West Java. The Arinem mineralization, to date has been regarded as epithermal quartz-sulfide vein deposit (Antam, 1993). Gold exploration in the Arinem area and its surroundings have started since the early 1980s by Antam, the state mining company.

Since 1990, a detail exploration including some drilling activities is on going to define the gold and base metal reserve as well as the deposit characteristics. The Arinem deposit comprises a set of veins such as Arinem, Bantarhuni and Halimun.

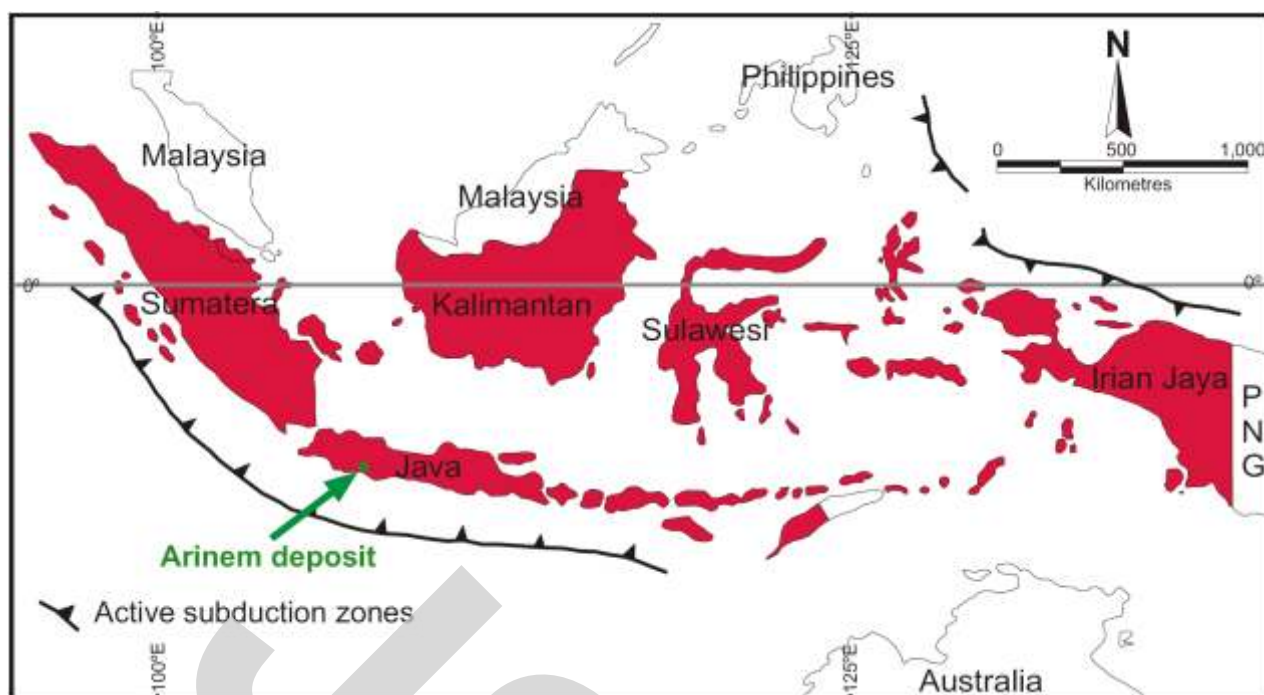


Figure 1. Map of the Indonesia region and the location of the Arinem deposit noted by the green arrow.

The main gold mineralization is represented by the Arinem Vein with total length around 5,900 m with strike 160 to 190° and dip around 68 to 83°. The Bantarhuni Vein has zone length about 2,300 m and width 3-5 m. The Halimun Vein is divided into east and west parts, with length up to 1,500 m and width 2-10 m (Antam, 1993). Some detail studies of Arinem and Bantarhuni veins show that these veins contain variable amount of gold and silver associated with tellurides. The occurrence of telluride minerals are variable within a single ore shoot but much less than sulfides and are restricted to small concentrations within mineralized area.

Afifi *et al.* (1988a) concluded that among other factors, the stability of metal tellurides with respect to their corresponding native elements, sulfides and oxides is a function in part of the activity of tellurium in the system. For tellurides, Te_2 ideal gas is adopted as the most appropriate reference state, because $Te_2(g)$ is the most abundant gaseous species over geologically significant ranges in temperature. The most common occurrence of native tellurium and telluride minerals is within epithermal quartz veins

associated with volcanic or subvolcanic rocks. Epithermal deposits also contain variable amounts of the common base metal sulfides and sulfosalts.

Sampling and Analyses

This study focuses on two veins from Arinem deposit such as Arinem and Bantarhuni veins, in which Te-bearing minerals are present. The aim is to characterize the compositional variations of the tellurium minerals within these veins. Detailed sampling of the mineralized veins was undertaken from the drill core as well as from outcrops. For the Arinem vein, most of the data used are collected from 14 diamond drill holes during the drill-out phase of the exploration program. Six drill core data of Bantarhuni Vein are also analyzed to support the study. These drill cores provide samples at intervals over a strike length of up to 2,000 m and depth extend to 575 m for Arinem vein (L440m to L-60m), and over a length of 1,000 m and depth of 290 m for Bantarhuni vein (L300m to L10m). Thus those are present an opportunity to investigate mineralogical of an epithermal vein system.

The oldest rocks exposed around the Arinem vein are andesitic tuff, tuff breccia and aphanitic-porphyritic

lavas. This unit is part of the Late Oligocene to Middle Miocene Jampang Formation which has been intruded by phaneritic-porphyrific andesitic rocks (Alzwar *et al.*, 1992). Towards the top, it was gradually covered by andesitic tuff and tuff breccia which are younger than the Jampang Formation. The volcanic rock of Jampang Formation is host for the mineralization within the area.

The ore minerals of the Arinem deposit are mainly as banded-massive quartz-sulfide with occurrences of tellurium minerals of hessite (Ag_2Te), tetradyomite ($\text{Bi}_2\text{Te}_2\text{S}$), petzite (Ag_3AuTe_2), stutzite (Ag_5Te_3) and altaite (PbTe). Microscopic study observed the intimate association of Ag-Au tellurium minerals with sulfide minerals of sphalerite, galena, pyrite and chalcopyrite (Figure 2).

The quantitative chemical analysis of the compositions of ore minerals from the Arinem and Bantarhuni veins were determined with JEOL 733 electron microprobe at the Hokkaido University. Standards used are natural chalcopyrite, InP, MnS, CdS, FeAsS, Sb_2S_3 , PbS, SnS, HgS, ZnS and elemental Se, Au, Ag, Te. The probe was operating at 20 kV voltage and the beam currents of 10 nA was focused to 1-10 μm diameters with peak counting times was 20s. The X-ray lines measured were As, Se, Te, Cd, Ag, Bi and Sb (L), S, Cu, Zn, Fe and Mn (K) and Pb, Au and Hg (M). The raw data was corrected by ZAF correction.

Results

Hessite is the dominant silver-telluride mineral in the deposit. Hessite mostly occurs as small patches of fine-crystalline inclusions in sphalerite and galena or in association with pyrite and chalcopyrite. Some of hessites found along grains boundaries between sphalerite, galena and chalcopyrite, and in association with petzite and altaite. Others are co-exists with tetradyomite as inclusion in chalcopyrite. The composition of silver in hessite minerals ranges from 57.31-63.05 wt% Ag and tellurium contents are around 31.26-37.48 wt% Te.

Stutzite is found as inclusions in sphalerite and galena together with hessite. It is sometimes difficult to recognize stutzite from hessite microscopically since those are very similar. The silver content in

stutzite is in the range of 54.86-61.03 wt% and tellurium 36.68-41.70 wt%.

Petzite is the only gold-bearing tellurium mineral identified. Mostly it is present as fine-crystalline inclusions in sphalerite and galena together with hessite as of irregular patches up to 10 μm . Some of petzites are overgrown with hessite in the form of inclusions in sphalerite. EPMA measurement concludes that petzite contain 47.96-52.74 wt% Ag; 30.83-34.89 wt% Te; and 14.24-18.32 wt% Au, respectively.

Tetradyomite with 5-20 μm in size together with hessite is observed as inclusions in chalcopyrite. Some of the co-existence tetradyomite-hessite are associated with the calcite and quartz gangue. These composite inclusions indicate crystallization from a melt under equilibrium conditions. Tetradyomite contains 55.70-58.08 wt% Bi, 33.83-35.79 wt% Te, and 3.12-4.26 wt% S.

Altaite is the sole Pb-telluride observed in the Arinem and Bantarhuni veins and contains 61.55-64.29 wt% Pb and 32.45-36.20 wt% Te.

A very small grains of *electrum* (2-6 μm) are found as inclusions in chalcopyrite, galena and sphalerite. These inclusions which are fine to medium-grained (~1.0 μm) appear to be texturally co-depositional with the host sulfides. Even some of electrum grains are indicated under microscopic observation but it was too small to be used for further analyzed by microprobe.

Ranges of some elements contain in the tellurium minerals from Arinem and Bantarhuni veins are presented in Table 1. Table 1 only preserved nine elements content of Te, Ag, Au, Pb, Bi, Se, S, Hg and Cd from fifteen elements measured, since other elements are under the detection limit.

The X-ray energy-dispersive and backscatter electron image with JEOL JSM-5310 scanning electron microscope were used to mapping the co-existence occurrences of hessite with tetradyomite and petzite, and co-existing of hessite with electrum as inclusion in pyrite (Figure 3 to 5).

Table 1. Microprobe Measurement of Elemental Contents in the Te-Bearing Minerals of Arinem and Bantarhuni Veins

Te-bearing Minerals	Element content (wt%)									
	Te	Ag	Au	Pb	Bi	Se	S	Hg	Cd	
Arinem vein										
Hessite [*] ₍₁₈₎	31.26 - 36.35	57.31-63.05	0.02-3.48	0.00-1.69	mdl	0.00-0.86	mdl	0.00-0.65	0.03-0.28	
Stutzite ⁽⁴⁾	36.68-41.70	60.47-61.03	0.00-1.10	0.00-0.83	0.00-0.24	mdl	mdl	0.20-0.41	mdl	
Petzite ⁽⁶⁾	30.83-34.89	47.96-52.74	14.24-18.32	mdl	mdl	mdl	mdl	0.00-0.22	0.02-0.11	
Tetradymite ⁽⁴⁾	34.81-35.79	mdl	0.00-0.39	mdl	55.70-58.08	0.08-1.31	3.12-4.26	0.00-0.59	mdl	
Altaite ⁽¹⁾	32.45	0.67	0.55	63.04	mdl	mdl	mdl	0.52	0.05	
Bantarhuni vein										
Hessite ⁽⁷⁾	35.88-62.58	61.30-62.58	0.00-0.78	0.00-0.25	0.00-0.18	mdl	mdl	0.00-0.31	0.09-0.20	
Stutzite ⁽²⁾	40.18-40.58	54.86-55.08	0.47-1.95	0.00-0.05	mdl	mdl	mdl	1.28-1.88	0.00-0.11	
Tetradymite ⁽²⁾	33.83-34.67	mdl	0.00-0.02	mdl	56.14-56.54	1.52-1.98	3.51-3.95	mdl	mdl	
Altaite ⁽⁷⁾	33.61 36.20	0.00 0.75	0.00 0.60	61.55 64.29	mdl	mdl	mdl	0.00 0.20	0.00 0.19	

* Number in parenthesis is a number for EPMA measurement
 mdl : minimum detection limit

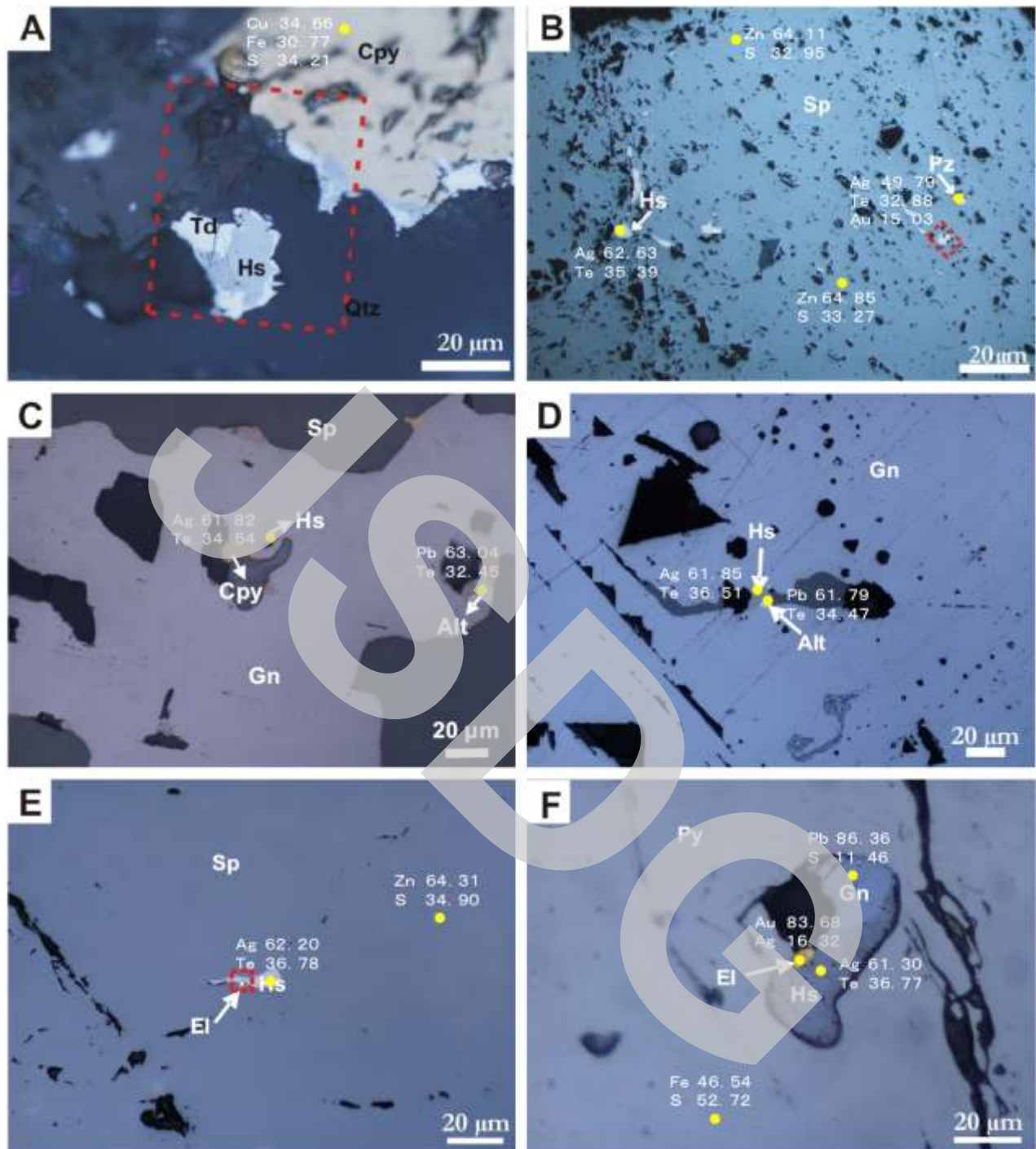


Figure 2. Reflected light photomicrographs showing the association of sulfides and Te-bearing minerals from the Arinem Vein [A-C] and the Bantarhuni Vein [D-F]. [A] hessite (Hs) and tetradymite (Td) as isolated crystals and some as inclusions in chalcopyrite (Cpy); [B] sphalerite (Sp) with inclusion of fine-crystalline hessite (Hs) and petzite (Pz); [C] hessite (Hs) and altaite (Alt) as inclusions with chalcopyrite (Cpy) in galena (Gn); [D] hessite (Hs) and altaite (Alt) as inclusions in galena (Gn); [E] hessite (Hs) and electrum (El) as inclusions in sphalerite (Sp); [F] hessite (Hs), electrum (El) and galena (Gn) as inclusions in pyrite (Py). Some elements concentrations (wt%) in individual spot analyses are given. Red inset in Figs. 2 [A], [B], and [E] are location of back scattered electron image mapping (see Figs. 3, 4 and 5).

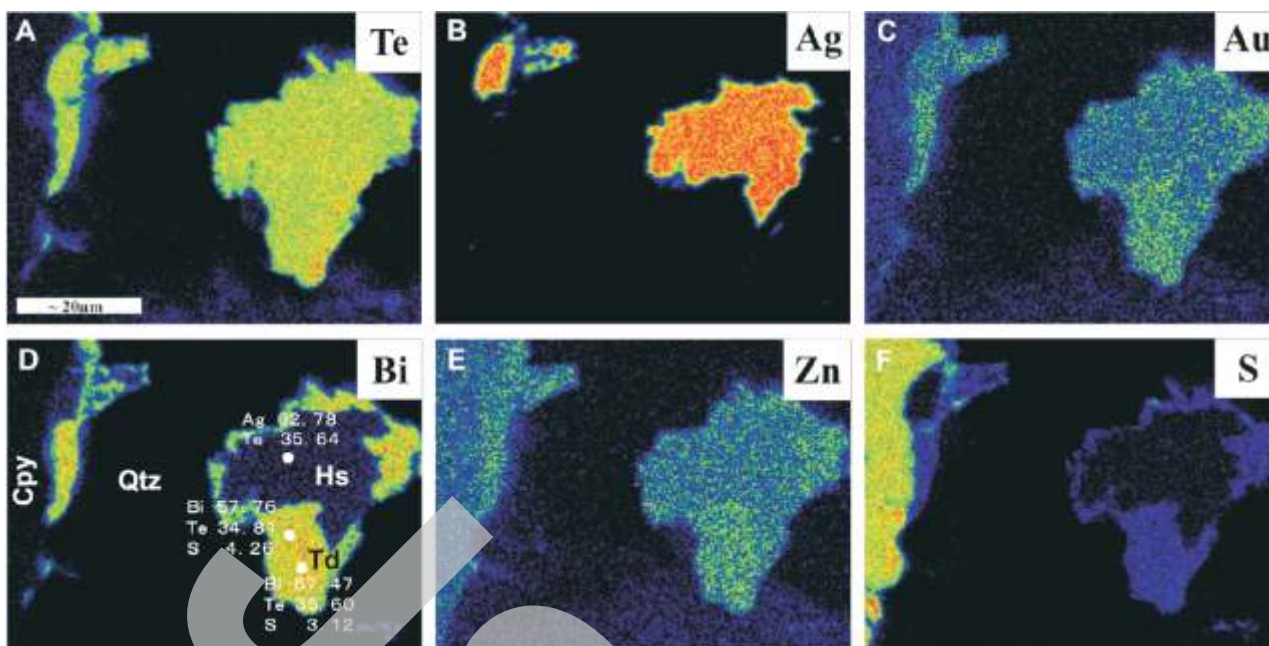


Figure 3. Characteristic X-ray images of tellurium [A], silver [B], gold [C], bismuth [D], zinc [E] and sulfur [F] of tetradymite (Td) and hessite (Hs) minerals, sample from the Arinem Vein (see Figure 2A). Some elements concentrations (wt%) in individual spot analyses are given.

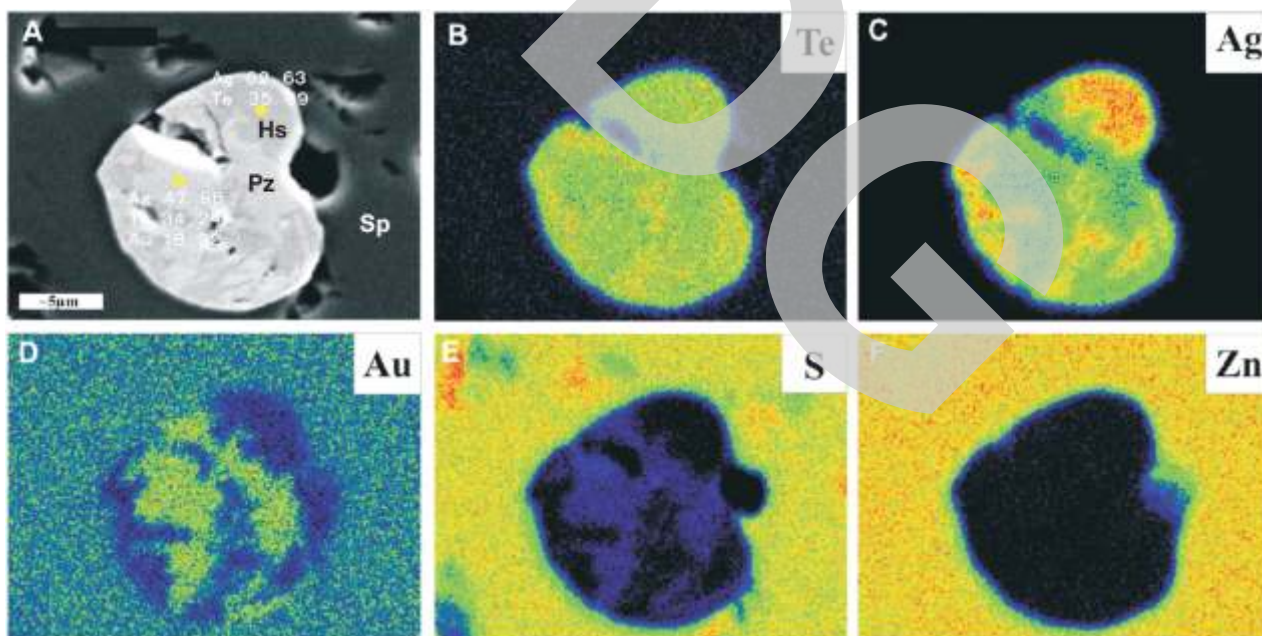


Figure 4. [A] Back scattered electron image shows the occurrence of hessite (Hs) associated with petzite (Pz) as inclusions in sphalerite (Sp) and its X-ray images characteristics for tellurium (Te) [B], silver (Ag) [C], gold (Au) [D], sulfur (S) [E] and zinc (Zn) [F], sample from the Arinem Vein (see Figure 2B). Some elements concentrations (wt%) in individual spot analyses are given.

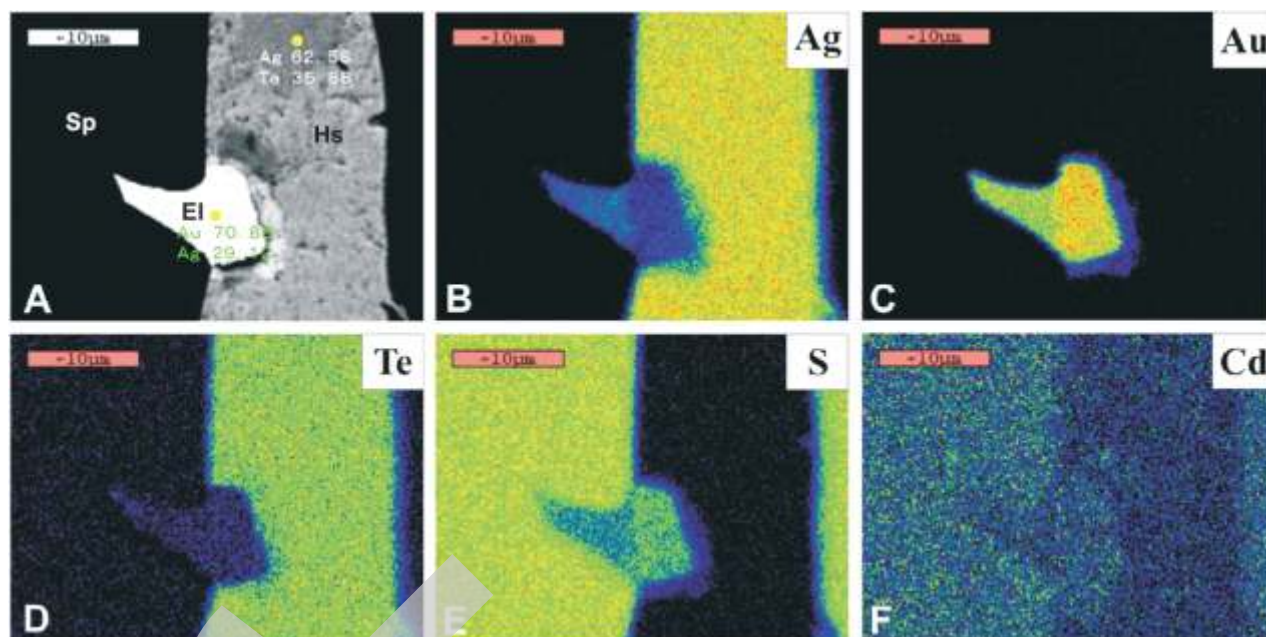


Figure 5. [A] Back scattered electron image shows the occurrence of hessite (Hs) associated with electrum (EI) as inclusions in sphalerite (Sp) and its X-ray images characteristics for silver (Ag) [B], gold (Au) [C], tellurium (Te) [D], sulfur (S) [E] and cadmium (Cd) [F], sample from the Bantarhuni Vein (see Figure 2E). Some elements concentrations (wt%) in individual spot analyses are given.

Discussion

Gold and silver distribution in the Arinem deposit is controlled by different Au-Ag-tellurides minerals, including petzite (Ag_3AuTe_2), stutzite (Ag_5Te_3) and hessite (Ag_2Te). Electrum is a minor phase while tetradymite ($\text{Bi}_2\text{Te}_2\text{S}$) and altaite (PbTe) are subsidiary phases. The telluride assemblages mostly occur as droplet-shaped inclusions in sphalerite, galena, pyrite and chalcopyrite. Only a small part was found along grain boundaries between sulfide minerals, or associated with the calcite and quartz gangue. Most of the observed telluride occurrences consist of at least 2 different phases (e.g. petzite-hessite, tetradymite-hessite, petzite-hessite-altaite). The average calculation formula for the Te-bearing mineral within the Arinem deposit from the quantitative chemical analysis using the electron microprobe analyzer (EPMA) of ore minerals from the Arinem and Bantarhuni veins are presented in Table 2.

The phase relation in the system of Au-Ag-Te is plotted based on the experimental work (Cabri, 1965, Figure 6). In addition to mineral stable along the binary Au-Te and Ag-Te joins, this system contains the minerals electrum (Au, Ag), krennerite ($\text{Au, Ag} \text{Te}_2$), sylvanite (AuAgTe_2) and petzite (AuAgTe_2)

and the naturally unquenchable phases $x(\text{Ag}_{1-x}\text{Au}_{1+x}\text{Te}_6)$ and $((\text{Ag,Au})_{2-x}\text{Te})$; $x = 0.09-0.12$). Hessite is stable in three structural modifications from room temperature to its melting point at 960°C . Stutzite is stable in at least two structural modifications to its final melting point at 420°C . The phase is stable over the temperature range 120° to 460°C , but it decomposes rapidly on cooling below 120°C into a mixture of hessite and stutzite, which accounts for its apparent absence from natural telluride ores (Afifi *et al.*, 1988a).

The system of Bi-Te-S contains several minerals derived by regular alternation of sulfur, bismuth, and tellurium layers within a common substructure (Figure 7). These include joseite-A ($\sim\text{Bi}_4\text{Te}_2\text{S}_2$) and joseite-B ($\sim\text{Bi}_4\text{Te}_2\text{S}$), tetradymite ($\text{Bi}_{14}\sim\text{Te}_{13}\text{S}_8$), ingodite (Bi_2TeS) and sulphotsumoite ($\text{Bi}_3\text{Te}_2\text{S}$).

Phase relations in the system Au-Ag-Te (Cabri, 1965), coupled with fluid inclusion thermometry study of quartz minerals associated with sulfides (Yuningsih *et al.*, in publ.) indicate that temperature of tellurides deposition within the Arinem deposit were around average $200^\circ-270^\circ\text{C}$, and the salinity is dilute (less than $4.34 \text{ wt}\% \text{ NaCl}_{\text{equiv}}$). The temperature is similar with other observation among other telluride-bearing deposit around the world, in general

less than 354°C (melting point of hypogene sylvanite) and typically below 250°C and waters associated to telluride deposition is in the range < 1 to 6 wt% NaCl_{equiv.} (Afifi *et al.*, 1988b). However, Thompson *et al.* (1985) reported saline H₂O-CO₂-Na-K-C1 fluids (>40 wt% NaCl_{equiv.}) from inclusions nearly quartz at Cripple Creek, Colorado, which they inferred to be magmatic in origin.

Based on the study of chemical and isotopic from some other telluride-bearing epithermal deposits indicate at least partial derivation of some components, such as H, O and C, from an igneous source (Afifi *et al.*, 1985; Porter and Ripley, 1985; Ahmad *et al.*, 1987). Tellurium is transported preferentially in the vapor rather than in the aqueous phase, in the form of Te₂(g) and H₂Te(g), precious metals telluride complexes or even tellurium-sulfur, tellurium-alkali metals and halide elements species (McPhail, 1995; Larocque *et al.*, 1997; Cooke and McPhail, 2001). Cooke and McPhail (2001) predicted that the only mechanism capable of tellurium deposition is condensation of Te₂(g) and H₂Te(g) into precious metal chloride waters.

Otherwise, gold and silver are generally considered to be transported in an aqueous phase in the epithermal environment as bisulfide or chloride complexes, or as thio, hydroxyl-bearing, carbonate and tellurium-bearing complexes *i.e.*, Ag(HTe)₋₂ and Au(HTe)₂ (Seward, 1984; Romberger, 1988; Gammons and Barnes, 1989; Shenberger and Barnes, 1989; Zhang and Spry, 1994; Gammons and Williams-Jones, 1995; Stefánsson and Seward, 2003). However, recent secondary ion mass spectrometry studied by Kesler *et al.* (2007) of the Au, Te and Ag compositions of arsenian pyrite in Carlin and epithermal-type gold deposits show Te/Au ratios of ~0.1 or less suggesting that Te was not sufficiently abundant to complex Au.

Moreover, trace element compositional data from vapor-rich fluid inclusions (Heinrich, 2005) and recent experiments (Williams-Jones *et al.*, 2002) show that gold may also be carried in significant amounts in the vapor phase of some ore-forming systems. The elevated partial pressures of carbon dioxide (log *f*CO₂ of -0.2 at 300°C) also would increase the solubility of metals and metalloids (Williams-Jones *et al.*, 2002).

Table 2. Average Calculated Formula for the Te-Bearing Minerals from Arinem and Bantarhuni Veins.

Te-bearing minerals	Calculated Formula
Arinem vein	
Hessite ¹⁾	(Ag _{1.98} Fe _{0.01} Cu _{0.01} Zn _{0.01} Au _{0.01}) _{2.02} (Te _{0.97} S _{0.01}) _{0.98}
Petzite ²⁾	(Ag _{3.17} Cu _{0.01} Fe _{0.02} Zn _{0.06}) _{3.26} (Au _{0.68} Cd _{0.01}) _{0.69} (Te _{2.01} S _{0.03}) _{2.04}
Stutzite ³⁾	(Ag _{5.12} Zn _{0.03} Au _{0.01} Hg _{0.01}) _{5.17} (Te _{2.80} S _{0.01}) _{2.81}
Altaite ⁴⁾	(Pb _{1.00} Au _{0.01} Hg _{0.01}) _{1.02} (Te _{0.93} S _{0.03}) _{0.96}
Tetradymite ⁵⁾	(Bi _{1.93} Cu _{0.03} Fe _{0.04}) _{2.00} (Te _{1.95} Ag _{0.02} Au _{0.01}) _{1.98} (S _{0.95} Se _{0.06}) _{1.01}
Bantarhuni vein	
Hessite ¹⁾	(Ag _{1.96} Fe _{0.01} Cu _{0.01} Au _{0.01}) _{1.99} (Te _{0.99} S _{0.01}) _{1.00}
Stutzite ³⁾	(Ag _{4.78} Cd _{0.01} Au _{0.06} Hg _{0.07}) _{4.92} (Te _{3.06} S _{0.02}) _{3.08}
Altaite ⁴⁾	Pb _{1.01} (Te _{0.96} S _{0.02}) _{0.98}
Tetradymite ⁵⁾	(Bi _{1.90} Zn _{0.03} Cu _{0.01} Fe _{0.03} Pb _{0.01}) _{1.98} (Te _{2.05} Ag _{0.02}) _{2.07} (S _{0.85} Se _{0.11}) _{0.96}

* On the basis of ¹⁾ 3 a.p.f.u, ²⁾ 6 a.p.f.u, ³⁾ 8 a.p.f.u, ⁴⁾ 2 a.p.f.u, ⁵⁾ 5 a.p.f.u

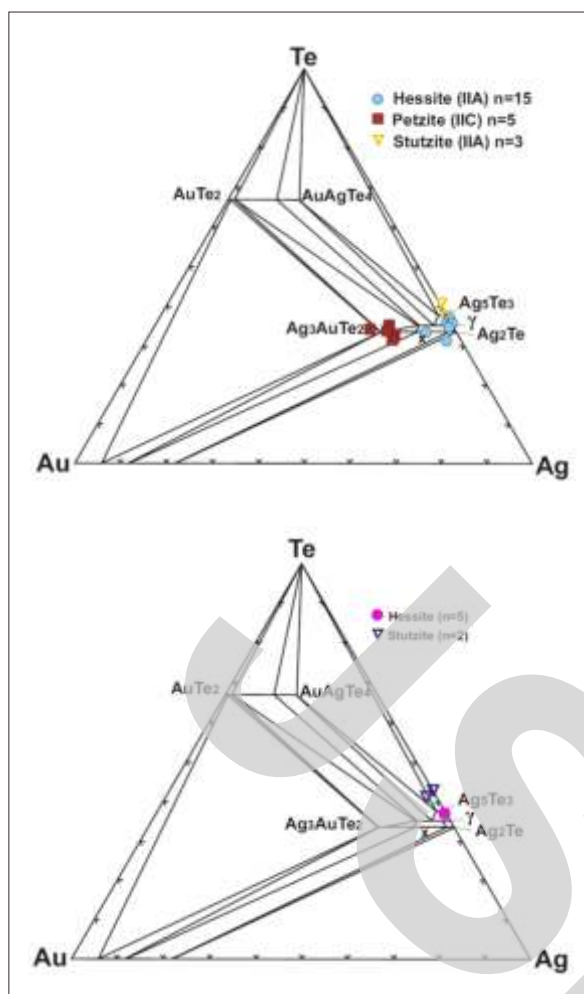


Figure 6. Chemical compositions of hessite, petzite and stutzite of Arinem (left) and Bantarhuni (right) veins in comparison with ideal composition of mineral phases plotted on Au-Ag-Te diagram between 120° and 280°C (Cabri, 1965).

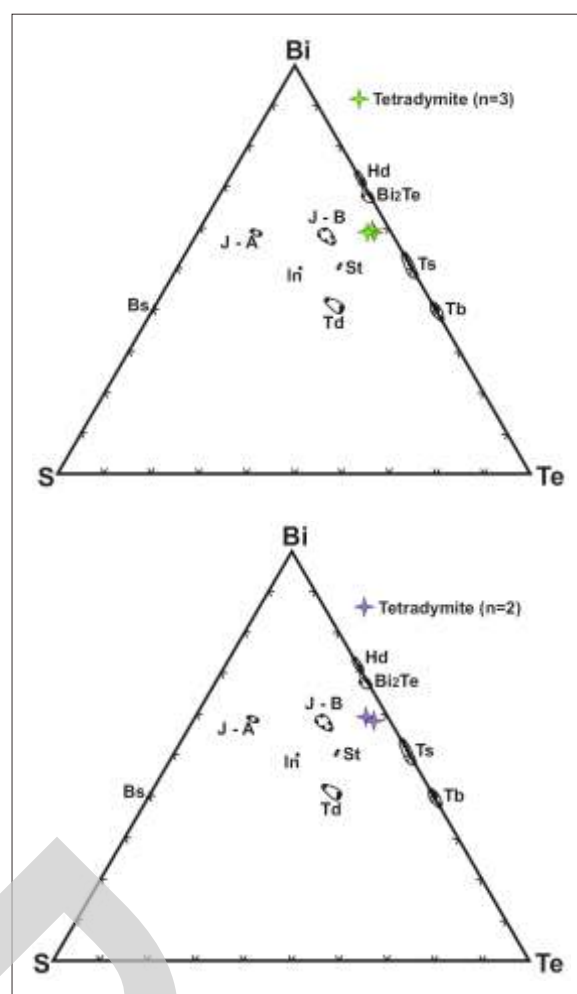


Figure 7. Chemical composition of tetradymite of Arinem (left) and Bantarhuni (right) veins in comparison with ideal composition of mineral phases plotted on Bi-Te-S diagram. (Arifi, 1988a). Bs=bismuthinite, Hd=hedleyite, In=ingodite, J-A=joseite-A, J-B=joseite B, St=sulfotsumoite, Tb=tellurobismuth, Td=tetradymite, Ts=tsumoite (= wehrlite), and unnamed = Bi_2Te .

Conclusions

Microscopic observation of the samples from Arinem and Bantarhuni veins shows the intimate association of Au-Ag bearing tellurium minerals with sulfides minerals of sphalerite, galena, pyrite and chalcopyrite. Very little difference in mineralogy composition for tellurium minerals and the lack of definite trend data of Te-bearing mineral horizontally and vertically obtained from Arinem and Bantarhuni veins (more than length 1,000 to 2,000 m with depth 290 to 575 m for Bantarhuni and Arinem veins) suggested that the hydrothermal system was relatively large.

The close proximity and similarity of geochemical characteristics of the Arinem and Bantarhuni veins such as the paragenesis of ore minerals, the association of Te-bearing minerals with sulfide and

compositions of the Te-bearing minerals indicates that the mineralization occurred as part of a single hydrothermal system. Enrichments of certain trace element contents in the Arinem hydrothermal system (e.g., Te and Bi) also suggest that there was contribution in the mineralizing fluid from the magma or surrounding rock.

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