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PROCESS MINERALOGY FOR EVALUATING MINERALOGY, PHYSICAL AND CHEMICAL CHARACTERS OF THE TAILINGS COMES FROM GOLD PROCESSING

MINERALOGI PROSES UNTUK MENGEVALUASI KARAKTER MINERALOGI, FISIKA DAN KIMIA LIMBAH PENGOLAHAN EMAS

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ABSTRACT

Based on mineralogy, physical and chemical analyses, character of gold-processing tailings from Pongkor showed relatively complex condition. Gold particles were normally included by either sulfide (pyrite, chalcopyrite, galena, arsenopyrite, sphalerite etc.) or silicate minerals (mainly quartz). The inclusion structure performed single, double or multiple forms. Single inclusion meant that gold particle(s) was encased by one mineral phase while double and multi inclusions implied that the gold was sheathed by two or more phases. Gold was distributed along the micro-cracks of either similar or different phase. Chemical analyses showed that Pongkor tailings were characterized by several elements that might be ineffective for gold leaching by cyanide. Preg-robbing solution might be occurred.

Keywords: mineralogy, physical and chemical analyses; tailings characters; Pongkor; inclusions

SARI

Pengujian sifat fisika, kimia dan mineralogi terhadap limbah emas yang diperoleh dari Pongkor menunjukkan kondisi yang relatif kompleks. Partikel emas umumnya terdapat sebagai inklusi baik oleh mineral sulfida (pirit, kalkopirit, sfalerit, galena, arsenopirit) maupun silikat, terutama kuarsa. Struktur inklusi dalam percontoh dapat bersifat tunggal, ganda atau multi. Inklusi tunggal berarti partikel emas hanya diselaputi oleh satu fasa mineral sedangkan inklusi ganda dan multi mengacu kepada kondisi emas yang ditutupi oleh dua atau lebih fasa. Selain inklusi, partikel emas juga dijumpai terdistribusi pada rekahan fasa yang sama atau berbeda. Dari pengujian kimia, XRF dan SEM-EDS diketahui bahwa percontoh limbah Pongkor mengandung unsur-unsur yang bersifat merugikan ketika partikel emas dilindi sianida. Kehilangan larutan kaya (preg-robbing solution) kemungkinan terjadi bila kehadiran elemen tersebut tidak diantisipasi.

Kata kunci: analisis mineralogi, fisik dan kimia; karakter limbah; Pongkor; inklusi

INTRODUCTION

Chemical analyses of bulk samples often provides incomplete information when the minerals will be processed notably to solve the problems related to contaminant removal within precious-low concentration minerals that causes low recovery of precious minerals. Referring to such a problem, Process Mineralogy is one of solutions that can be considered to overcome the problems. It bridges mineral processing and traditional mineralogy as well as a specialization within the field of applied

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mineralogy. The discipline is defined as the application of mineralogy to understand and solve the problems that occur during processing of the ore, concentrate, smelting related product (Grammatikopoulos et al., 2006). It is being applied in geometallurgy, ore characterization, process design and optimization and has objectives to identify, diagnose and predict ore characteristics that mineralogically control or affect the process. Its application is encouraged by new findings of complex ores as well as the rising pressure to reduce operational cost (Petruk, 2000; Baumgart et al., 1984; Baum et al., 2004). Mineralogy information of a certain ore, mainly the texture (Figure 1), can suggest how the ore should be optimally mined. Furthermore, the mineralogy information can also provide suggestion regarding environmental problems that might occur due to mining activities (http://www.minassist.com.au). The Process Mineralogy is a link between product characteristics and process performance. It determines and optimizes the process as well as evaluates the lost of precious mineral within a procesing plant (http://www.actlabs.com; Cashion and Brown, 1998).

Gold, belongs to strategic minerals, is still high demanded up to this point. The need of gold increases from time to time though its price is fluctuated (Lotter et al., 2011). Referring to such condition, a lot of research institutions, either private or state-owned, still develop such a metal extraction technology that performs more environmental friendly and provide optimum extraction. So far, gold extraction is still dominated by amalgamation and cyanidation (Chryssoulis et al., 2003). Of the two processes, artisanal mining activities mostly leached the gold by mercury that is started by crushing the run of mine ore and continued by putting the crushed ores into the trommel along with mercury and water. Trommel agitation produces the amalgam that can be separated from its tailings. However, not all gold change into amalgam. Some of them go to tailings along with mercury, mainly the fine gold. The tailings come from such gold processing is therefore interesting to be studied their mineralogy, physical and chemical characters. Therefore, factors affecting low gold extraction can be evaluated. Such evaluation helps improving gold processing performance to get desired results. Not only do the tailings need to be studied but also the raw materials for processing feed must be evaluated as a comparison data to the data derived from tailings.

Gold deposit at West Java, notably at the western part such as Sukabumi and Bogor, own both sulfide and oxide characters. Study conducted by Bayu Ningsih (2001) on Cigaru gold ores of Sukabumi shows that the ores are charcterized by chalcopyrite, pyrite, sphalerite, arsenopyrite, galena, limonite, gold, silver as well as gangue

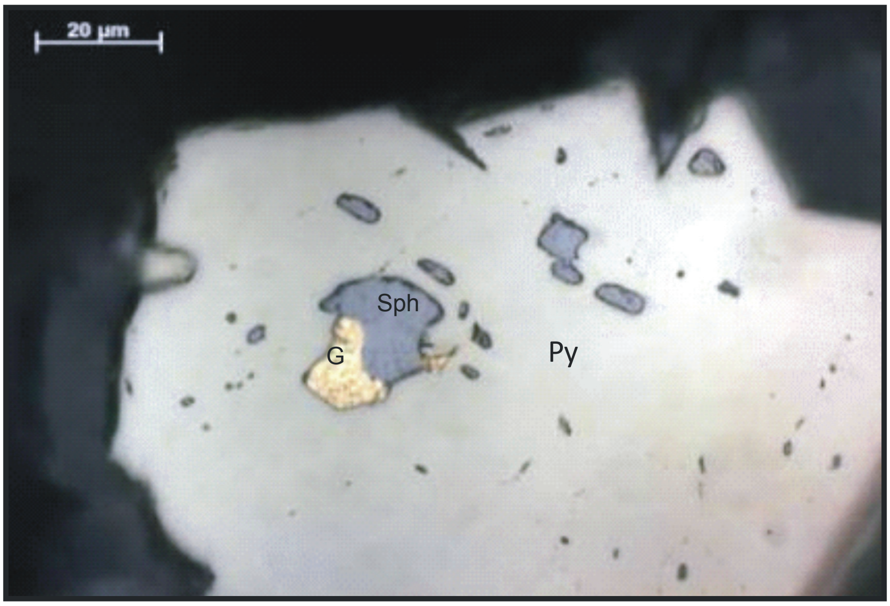

Figure 1. A complex mineralogical structure of Pongkor tailings. Gold (G) is associated with sphalerite (sph) and included by pyrite (Py)

minerals of quartz. Field observation on Cigaru ores shows that the ores are similar to the Pongkor ones. It belongs to sulfide and oxide ores. Table 1 illustrates the Au and Ag content of Cigaru ores. Such a condition is interesting to be studied if related to gold response to the lixiviants either mercury or cyanide (Marcoux et al., 1996). Marcoux et al. (1996) found that Pongkor gold Deposits consisted of 4 (four) lodes, namely Pasir Jawa, Ciguha, Kubang Cicau and Ciurug that contained (total) 98 g/t Au and 1026 g/t Ag but the average contents of gold and silver from 4 lodes were 6.4 g/t Au dan 171.2 g/t Ag. Those figures were valid only for the upper part of the layer at the depth of 200 – 250 m. In reality, the layer continued to the depth of >500 m. Under the tropical climate; Pongkor sulfide gold deposit altered intensively, however, the oxidation process on the bed rocks less developed compared to those occurred within lodes that vertically showed 250 m extensive lateritic alteration. Mineralogy available within the altered lodes was calcite ($CaCO_3$) that then developed into rhodochrosite ($MnCO_3$), kutnahorite ($CaMn[CO_3]_2$) and ankerite ($CaFe[CO_3]_2$). Other minerals were adularia, ($KALSI_3O_8$), electrum (Au, Ag) and sphalerite (ZnS) associated with galena (PbS), chalcopyrite ($CuFeS_2$) and Ag sulphosalts. Galena commonly includes hessite ($AgTe_2$)

Tabel 1. The content of gold silver from Cigaru ores

Sample code	Content	
	Au (g/t)	Ag (g/t)
Oxide	10.56	22.96
Sufide	8.13	25.47
Tailngs	9.36	05.66
Consentrate	41.64	46.40

Artisanal mining at Cineam, Cigaru and Pongkor employs mercury for extracting the gold and produces mercury-containing tailings. The processed gold ore at Cineam comes from sulfide type while artisanal mining at Pongkor treats both sulfide and oxide gold ores but mostly the oxide one. Limitation of their knowledge and technology often initiate their low recoveries of the extracted gold. It requires seeking the factors that affect low recovery that can be performed by studying mineralogy, physical and chemical properties of the ores. Different from the artisanal mining, PT ANTAM - Pongkor processes the gold ore using cyanidation technique, followed by carbon in leach (CIL). Yet, it also needs studying the tailings to get information regarding the effect of mineralogy, physical and chemical characters on the leaching.

The objective of this study is to examine characters of gold-processing tailings by identifying its mineralogy, physical or chemical natures. Such information can be used as a reference in selecting appropriate and efficient processing method in terms of improving gold recovery.

METHODOLOGY

Sampling to obtain tailing samples was conducted at Pongkor. The samples were derived from tailings pond of PT ANTAM and discard tailings of artisanal mine (Figure 2). They comprised cyanidation tailings of PT ANTAM as well as amalgamation and cyanidation tailings of artisanal mine. Due to their wet condition, the samples were dried using sunlight for 3 days and then prepared through riffle divider, cone and quartering to get representative samples. Prepared samples were then sent to each testing laboratory for characterizing their properties including chemical, physical and mineralogical characters. Laboratory of Chemistry analyzed chemical composition using Atomic Absorption Spectroscopy (AAS), Spectroscope instruments as well as gravimetry method. Laboratory of Mineral Physics including Optical Microscope, Scanning Electron Microscope, and XRD Laboratories analyzed mineralogical characters within samples while XRF Laboratory tested element composition of the samples as a comparison to chemical analysis. Sieving analysis was conducted at Physical Property Laboratory while Transmission Electron Microscope tests were conducted at Integrated Research and Testing Laboratory (LPPT) - Gajah Mada University. Fire assay tests were analyzed the Au/Ag content of the samples. The tests were conducted at Center of Geological Resources - Bandung. The basic procedure for fire assay involves mixing an aliquot of powdered sample (10, 15, 30 or 50 g are the common sizes used) with soda ash (sodium carbonate), borax (sodium borate), litharge (PbO), flour (baking flour used to add carbon as a reductant), silica, and possible niter (potassium nitrate). The well mixed material is fired at temperatures ranging from 110 to 120°C. As the Pb and Ag in the melt settle to the bottom of the crucible, it scavenges the Au (+/- Pd, Pt) from the

Figure 2. Tailing pond of PT ANTAM; the site for sampling the tailings

melt. The lead button is cupelled at 950°C in a magnesia cupel. A tiny Ag bead which contains Au, Pt and Pd can be dissolved and analyzed by atomic absorption spectroscopy - AAS.

Preparing the samples for optical microscope and scanning electron microscope tests uses a series materials such as polishing alumina1 μ Buehler, polishing alumina 0.05 μ Buehler, entelan new for microscopic 7961, resin + catalyst Buehler 8681, xylene EP, bromoform ($CHBr_3$)and a series of abrasive grit from 120 (the coarsest) through 1000 (the finest one). Tailing samples; coded as AG (amalgamation tailings from artisanal mining), AS (cyanidation tailings from artisanal mining and AT (cyanidation tailings from PT ANTAM); are fractioned using specific sieve (normally -100-mesh) and mixed with resin media and molded within mounting machine. The molded materials are then polished several times to get proper polished sections that can be analyzed in both optical microscope and scaning electron microscope.

RESULTS AND DISCUSSION

Study of mineral characters has been conducted in mineral processing operations to model comminution and concentration processes. The objective of this study is to comprehend mineralogy characteristics of the particles in relation with comminution, concentration and smelting processes of the minerals. Concerning gold processing, Process Mineralogy evaluates gold characters during its beneficiation, recoveries and precious metal reactions, reaction of mineral phases throughout metallurgical process as well as developed phases in the process that cause environmental problems. As an interdisciplinary, it does not only evaluate problems that relate to mineral processing but also comprehends all problems that associate with mine and mineral exploration (Brough et al., 2013; Celep et al., 2009; Evans et al. 2011).

Problems related to gold extractive metallurgy mostly concern with mineralogy factors such as particle size, association of gold with other minerals, coating, cyaniside materials within the ores, solution preg-robbing, refractory ores, inclusion of sub-microscopic gold within sulfides sulfarsenides, oxygen consumption by undesired minerals (http://www.minasist.com.au). Process mineralogy of gold correlated to its processing is studied from ore and plant-product samples to be used for feasibility study, process development and trouble-shooting in solving problems arisen during mineral processing and hydrometallurgy operation (Chen et al., 2002; Zhou et al., 2004). Based on gold recovery and processing technique, the gold ores are categorized into free-milling and refractory. The former refers to the ores at which 90% of gold are recovered through conventional cyanidation while the later belongs to those that yield low recovery although cyanidation process has used significant cyanide strength when leaching the ores or the ores undergo early, complex treatment.

Optical microscope observation showed that Samples AG, AS and AT contained gold, quartz, chalcopyrite, sphalerite and pyrite. Gold was distributed as free and included particles or available along the micro-crack of two phases (Figure 3). Sample AG, an amalgamation sample derived from artisanal mine, showed a 10-micron gold particle included by quartz. It is asumed that the amalgamated material contains few gold particles. Liberated gold particle was found excessively in Sample AS that came from cyanidation tailings of artisanal mine showing the gold particle size between 80 - 200 microns. Gold inclusion is the most common texture within Sample AT. The gold is included by sulfide minerals such as pyrite, chalcopyrite and sphalerite. Such inclusions occur either single or multi-inclusions. The former means that gold is included by one mineral while the later suggests that the gold is embraced by two or more minerals either sulfides or silicates.

Figure 4 illustrates the SEM-EDS analysis for Sample AG. Photomicrograph analysis shows that the sample consists of two materials, namely silicate (grey color) and sulfide (bright color) minerals as shown by EDS analysis which affirms that the grey color belongs to silicate minerals. Two elements that represent silicate minerals are aluminum (Al) and silicon (Si). The fact that the silicates perform sheet character suggests that the silicates belong to kaolinite. Manganese (Mn) and iron (Fe) stand for sulfide although the sulfur (S) is not detected. Washed out phenomenon is supposed to be the reason that sulfur is not available in detected area. Gold is not detected within this sample from either mapping analysis, spectrum or quantity table.

SEM-EDS analysis on Sample AS detected metal (silver - Ag) and sulfide (molybdenite - MoS and cinnabar - HgS) minerals (Figure 5). Iron and silicon comes from silicate minerals while manganesse is supposed to be from rhodochrosite. Silver is normaly associated with gold, however, such gold is not mapped. The gold is known from its pectrum curve and quantity table. Sample photomicrograph shows that metal minerals are included within silicate minerals.

SEM photomicrograph for Sample AT shows sulfide minerals (white color) that are distributed along the micro-crack of quartz (Figure 6). The EDS analyses detect 6 elements within the samples. Those are silicon, iron, molybdenum, aluminum, sodium and potassium. Of the six detected elements; silicon, iron, molybdenum and aluminum are well-mapped while the rest elements are quite good. Silicon is one of silicate mineral components either quartz or other clay minerals. The existence of clay minerals is shown by detected sodium, potassium and aluminum. Observation on specimen outside detected area indicates some clay minerals that perform layer

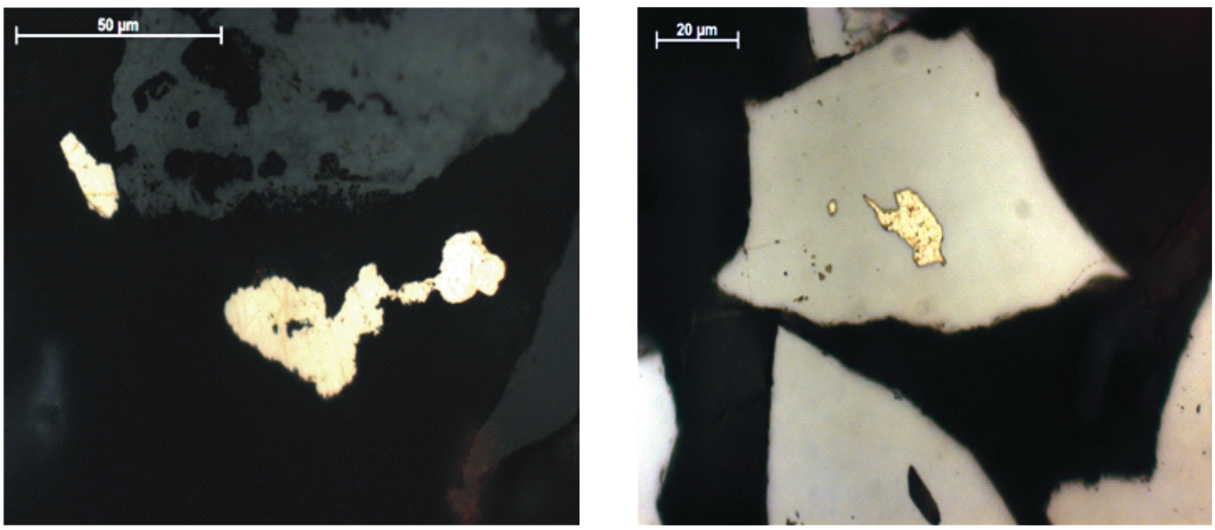

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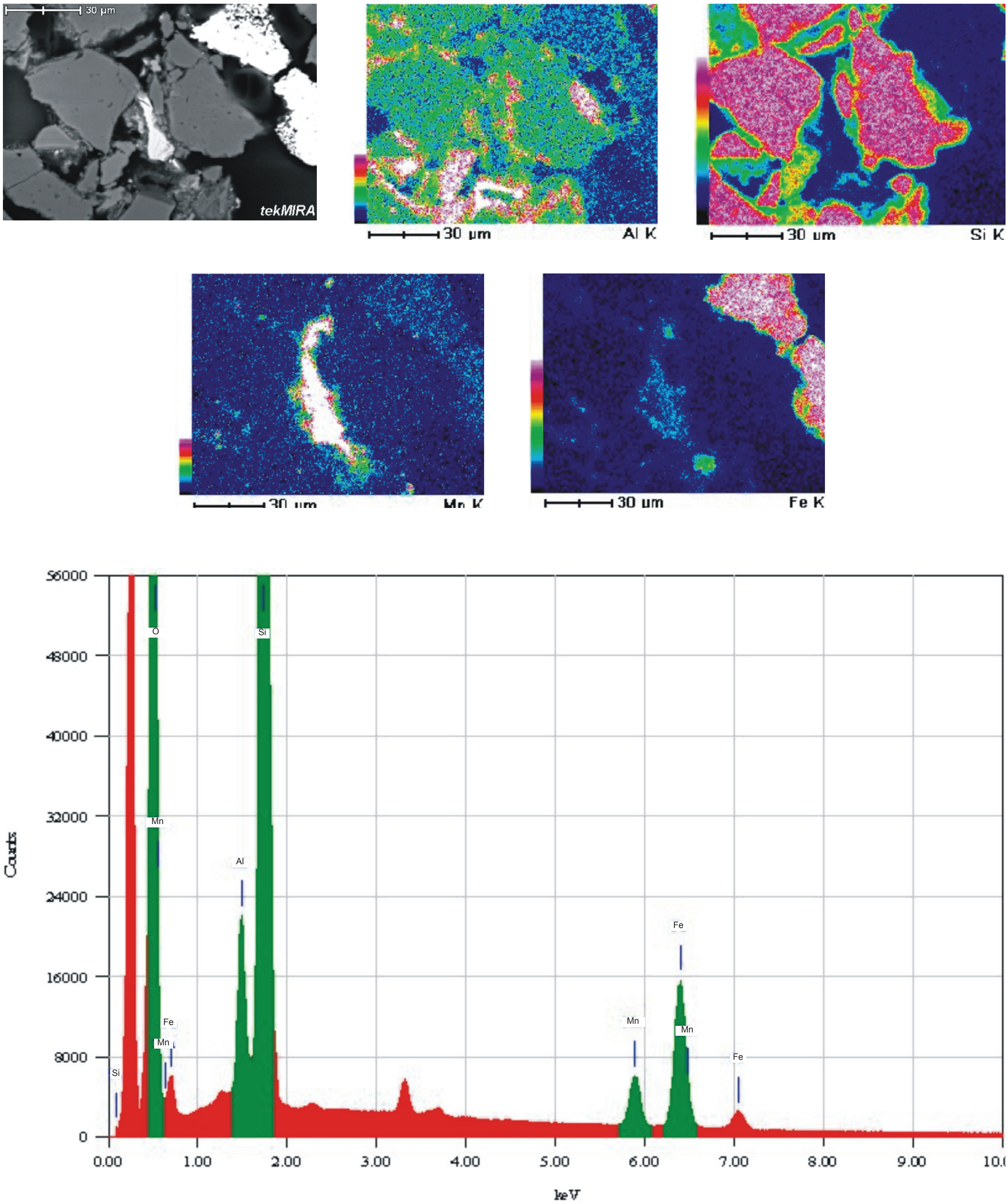
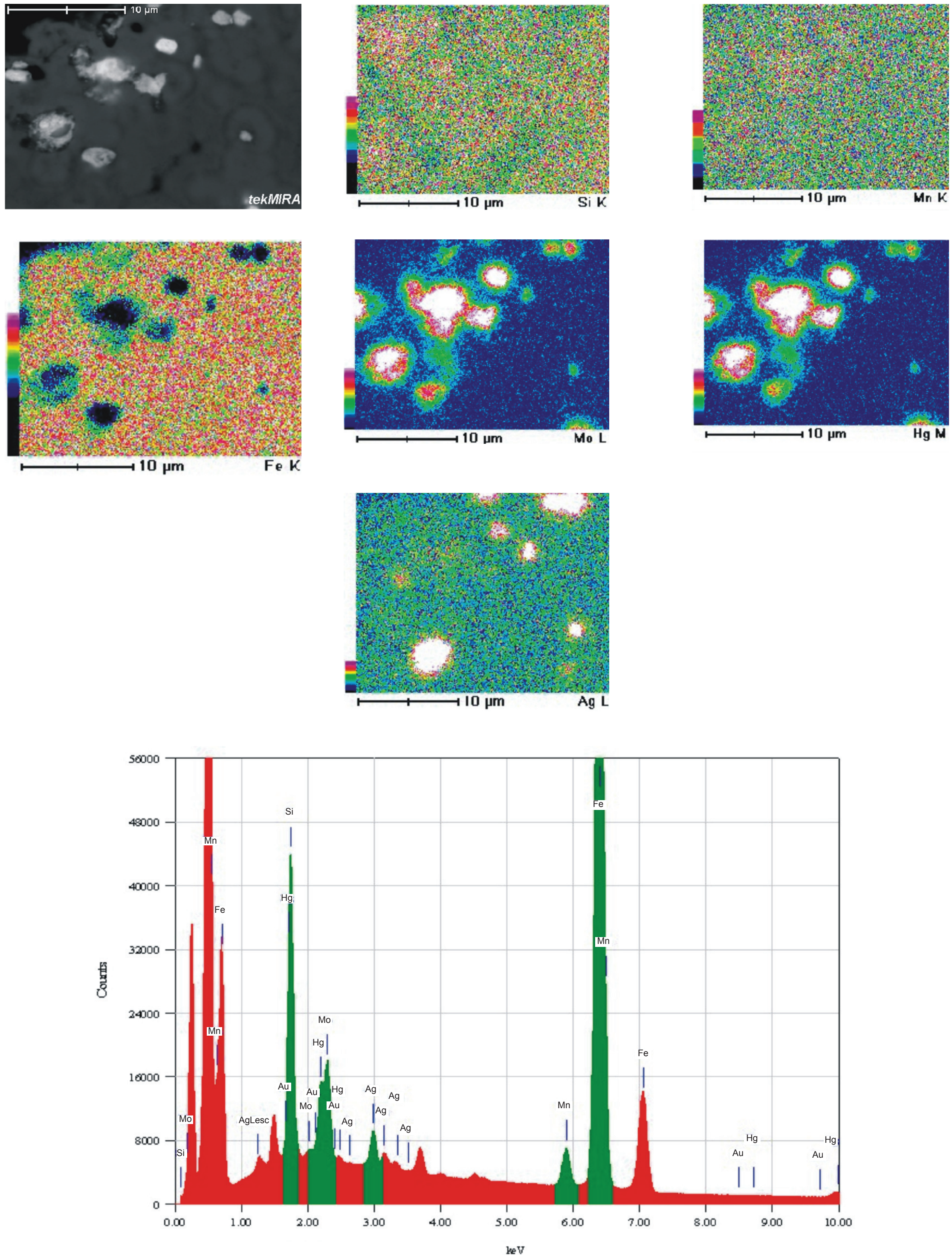
Figure 3. Results of optical micoscope test showing free gold in Sample AS (a) and included gold within pyrite in Sample AT (b)



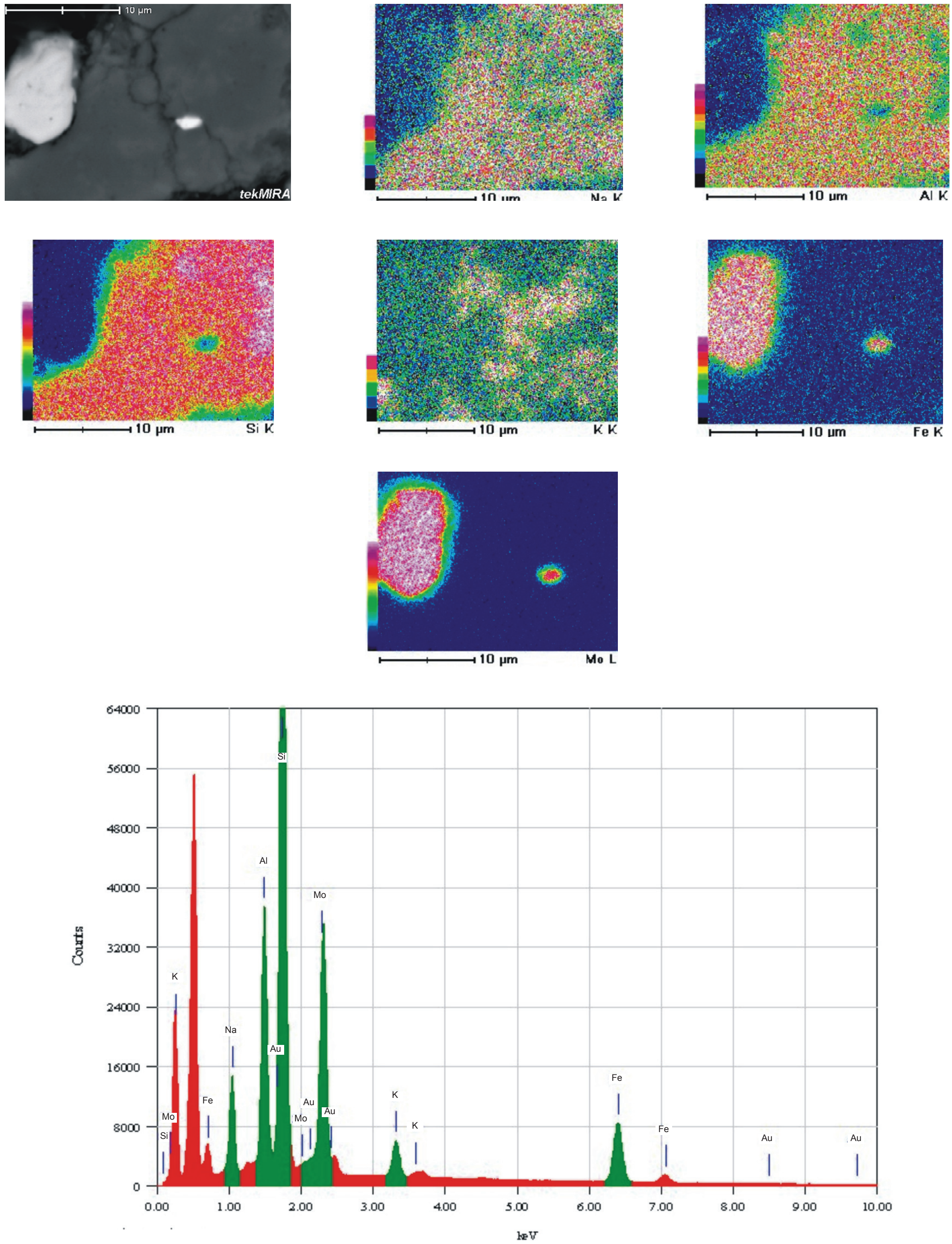
Element	(keV)	mass%	Error%	At%	Compound		mass%	Cation	K
O		46.11							
Al K	1.486	3.25	1.28	3.85	Al2O3	6.14	1.00	4.8998	
Si K	1.739	33.64	1.21	76.61	SiO2	71.97	9.98	59.3755	
Mn K	5.894	3.82	2.74	4.45	MnO	4.93	0.58	7.9010	
Fe K	6.398	13.18	2.83	15.09	FeO	16.95	1.97	27.8237	
Total		100.00		100.00		100.00	13.52		

Figure 4. SEM-EDS analysis to Sample AG showing silicate and metal minerals



Element	(keV)	mass%	Error%	At%	Compound		mass%	Cation	K
O		24.15							
Si K	1.739	4.11	0.79	11.51	SiO2	8.79	2.33	3.7526	
Mn K	5.894	1.73	1.40	2.48	MnO	2.23	0.50	2.3651	
Fe K	6.398	56.33	1.44	79.38	FeO	72.47	16.04	79.1195	
Mo L	2.293	3.96	1.85	3.25	MoO3	5.94	0.66	4.2252	
Ag L	2.983	1.87	1.14	0.68	Ag2O	2.01	0.28	2.1304	
Au M	2.121	1.98	1.90	0.39	Au2O3	2.22	0.16	1.9239	
Hg M	2.195	5.87	1.70	2.30	HgO	6.34	0.47	6.4834	
Total		100.00		100.00		100.00	20.42		

Figure 5. SEM-EDS analysis to Sample AS showing silicate, metal and sulfide minerals. The metal and sulfide minerals are included by silicate mineral



Element	(keV)	mass%	Error%	At%	Compound		mass%	Cation	K
O		39.50							
Na K	1.041	3.66	0.64	6.83	Na2O	4.93	1.55	4.9434	
Al K	1.486	6.25	0.62	9.94	Al2O3	11.80	2.25	9.0329	
Si K	1.739	15.81	0.61	48.36	SiO2	33.82	5.47	26.1658	
K K	3.312	1.49	0.58	1.64	K2O	1.79	0.37	2.9195	
Fe K	6.398	7.35	1.35	11.30	FeO	9.45	1.28	15.1516	
Mo L	2.293	24.01	1.62	21.50	MoO3	36.03	2.43	38.9095	
Au M	2.121	1.94	1.68	0.42	Au2O3	2.17	0.10	2.8773	
Total		100.00		100.00		100.00	13.45		

Figure 6. SEM-EDS analysis to Sample AT, showing silicate, metal and sulfide minerals. The metal and sulfide minerals are included by silicate mineral

structure. It is assumed that such minerals refer to kaolinite. Indication regarding quartz mineral is shown by trigonal structure. Compared to iron, molybdenum is better when mapped, perform by bright red color. In nature, such an element is always found with pyrite as molybdenite (MoS). Similar to Sample AG and AS, inclusion and distribution along the crack are the common structure found in this sample. Referring optical microscope analysis, a lot of gold particles is in free condition. From metlugical point of view, such condition is an advantage. The gold can be recoverable through flotation or direct cyanidation techniques while the locked gold particles require a pre-treatment prior to processing them, either grinding the ores to fine particles or roasting them. Study on microscopic gold by Zhou et al. (2004) indicated that 90% gold-bearing sulfides belong to size of 20 - 100 μm. Such condition implies that re-grinding to 20 μm is sufficient to liberate the included gold.

Chemical analyses for gold-bearing tailings of PT ANTAM and Cikaret artisanal mining were conducted using AAS, gravimetry and spectrophotometer methods. Table 2 illustrates the results of all detected elements, quartz seems the dominant one. It is likely that the quartz includes some gold particles. The existence of iron, lead, copper, zinc is supposed to be came from sulfide minerals such as pyrite (FeS_2), galena (PbS), chalcopyrite ($CuFeS_2$) and sphalerite (ZnS) while manganese might be came from rhodochrosite ($MnCO_3$) or kutnahorite ($CaMn[CO_3]_2$). The presence of TiO_2 implies that the sample may also contain ilmenite ($FeTiO_3$) while phosphor may serve as trace element. Table 3 illustrates XRF analyses of Sample AG, AS and AT. The results show 20 detected elements and 13 of them are similar to those analyzed by chemical test though their concentrations are relatively different. Some detected element such as arsenic, manganese, copper and iron are supposed to affect cyanidation process (Li et al., 2010).

XRD instrument identifies four minerals within three samples (AG, AS dan AT), namely quartz, orthoclase, calcite and pyrite (Table 4). Of the three samples, only Sample AT contains gold-bearing sulfide mineral (pyrite). The fact that specimen AG and AS for XRD analyses were not treated to separate heavy and light minerals by concentrating the samples results in unidentified

Table 2. Chemical composition of 3 tailing samples from Pongkor area

Tested Elements	Units	Sample Code		
		AG	AS	AT
SiO_2	%	82.0	81.0	73.9
Al_2O_3	%	4.63	3.64	8.19
CaO	%	1.29	1.81	4.42
K_2O	%	1.03	0.60	3.31
Na_2O	%	0.14	0.21	0.45
Fe	ppm	2.76	2.84	2.61
Mn	ppm	2.15	2.53	0.19
Pb	ppm	0.009	0.042	0.016
Cu	ppm	23	40	33
Zn	%	0.052	0.080	0.058
TiO_2	%	0.093	0.20	0.38
P_2O_5	%	0.053	0.014	0.052
LOI	%	3.54	3079	4.79
H_2O	%	0.53	0.55	0.36

Table 3. Results of XRF tests to Sample AG. AS and AT

Tested Elements	Units	Sample Code		
		AG	AS	AT
SiO_2	%	82.15	82.30	70.09
Al_2O_3	%	4.68	3.61	8.20
Fe_2O_3	%	3.53	3.58	3.35
MnO	%	2.33	2.78	0.21
MgO	%	0.49	0.34	1.15
CaO	%	1.46	2.08	5.42
Na_2O	%	0.012	0.081	0.57
K_2O	%	1.22	0.72	4.09
TiO_2	%	0.040	0.13	0.28
P_2O_5	%	0.041	0.059	0.080
As_2O_3	%	0.037	0.014	0.006
Cr_2O_3	%	0.011	0.015	0.030
CuO	%	0.017	0.017	0.005
NiO	%	0.001	tt	0.008
Rb_2O	%	0.005	0.003	0.017
SO_3	%	tt	0.039	1.43
SrO	%	0.011	0.011	0.014
ZnO	%	0.013	0.038	0.014
ZrO_2	%	0.002	0.004	0.011
PbO	%	0.003	0.043	0.009
LOI	%	3.96	4.14	5.03

Table 4. Mineral composition of three samples from Pongkor, tested by XRD.

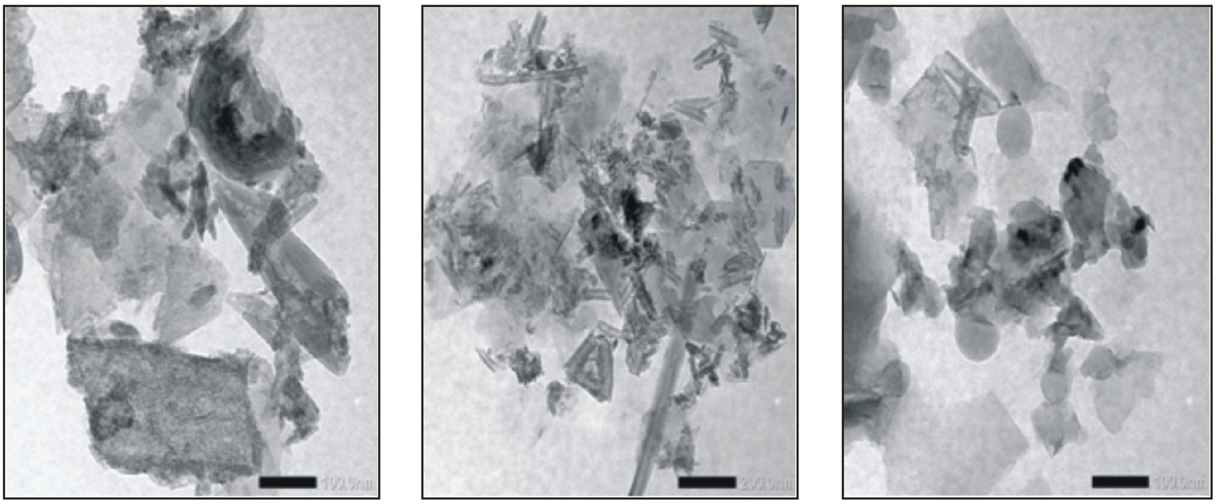
Sample Code	Mineral Compositions
AG	Quartz, calcite, orthoclase
AS	Quartz, calcite
AT	Quartz, orthoclass, calcite, pyrite

some gold-bearing sulfide minerals. Marcoux et al. (1996) stated that Pongkor gold deposit had carbonaceous characters. The detected calcite within sample confirms such a statement. Carbonaceous ores belong to refractory ores that contains carbon element, organic acid and hydrocarbon. The dissolved aurocyanide complex is robbed by adsorption of carbonaceous matter, which is similar to activated carbon in cyanide leaching of gold. Pretreatment is required to handle this type of ores, including high temperature roasting, bio-oxidation, chemical oxidation, competitive adsorption, barrier inhibition and microwave roasting. Recently, bio-oxidation was developed rapidly due to its advantages such as mild conditions, simple processes, low energy consumption and friendly environment.

There are two terminologies regarding the gold ores that are difficult to treat, namely preg-robber and complex ores. The former relates to the ores that are leached by cyanide and lost to fine carbonaceous materials due to adsorption process (Cabri, 2004; Yang et al. 2013; Wan, 2001; Wang, 1994). The carbonaceous material will be activated in the same way as the carbon materials used in cabin in leach (CIL) or carbon in pulp (CIP). The later (complex ores) refers to those that contain two or more economic minerals such as gold associated with arsenic, antimony or sulfide minerals. Due to its complexity, this type of gold is difficult to be processed due to cost consuming (http://www.insidemetals.com/index.php?view=mining_glossary). XRD analyses of Pongkor samples detect carbonate mineral (calcite) while chemical and XRF analyses also notice some components of silicate and sulfide minerals such as Ca, Mg, Na, Mn, Cu and Ti. All will result in preg-robbing solution as stated by Marcoux (1996). From the metallurgy point of view, the inclusion gold belongs to refractory and is not easy to be treated in order to get reasonable recoveries. Commonly, gold recovery from this ore type is less than 90% even in some cases only <50%. In the past, refractory gold was treated by roasting the material. However, the SO_2 release to the air results in negative impacts to the environment. Bio-oxidation by microorganism (bacteria) or pressure oxidation currently has been applied as a new technology to treat such the ores. The two techniques provide environmental friendly characters (Vaughn, 2004)

In terms of gaining more mineralogy data, the samples would previously be analyzed by Electron Probe Micro Analysis (EPMA). The instrument has a capability to probe fast, accurately and non-destructively 1 to 2-micron tested material and provides adequately quantitative element analyses. EPMA applies wavelength-dispersive spectroscopy or known as WDS. Unfortunately, only few institutions have EPMA instrument such as Research Center for Science and Technology - Serpong (Puspiptek Serpong) and National Atomic Energy Agency (BATAN). The instruments at both institutions were out of order at that time. Referring to such condition, the EPMA analyses were then replaced by TEM testing at the Integrated Research and Testing Laboratory, Yogyakarta. Figure 8 refers to TEM analyses for three Pongkor samples (AG, AS and ATD) and the results show that diffraction patterns of the three samples did not correspond with difraction patern of the gold. It seems that TEM analyses of the three samples only detected silicate materials (Figure 7). No concentration treatment to separate heavy and light minerals of the samples may the reason that TEM analyses did not detect gold particles. The fact that the instrument was not completed by EDS method may also suggest no detected gold.

Inclusion is the most common feature found within Pongkor samples. Gold is included by silicate (normally quartz) and sulfide minerals (pyrite, chalcopyrite, sphalerite and arsenopyrite). Such inclusions occur as single or multi-characters. The former refers to gold particles that are concluded by one mineral, either silicate or sulfide minerals while the later shows gold particles are embraced by two or more mineral phases. Distribution of gold between micro-cracks of the phases is another structure found within Pongkor samples. The cracks occur within same phases (either silicate or sulfide minerals) or different phases (silicate - sulfide minerals). From metallurgical point of view, gold inclusion belongs to refractory ore and is normally difficult to treat in terms of gaining high recovery.



a b c

Figure 7. TEM analyses of sample AG (a), AS (b) and AT (c) showing glass minerals gelas (silicate)

Related to complex gold ore, Vaughn (2004) describes that such the ores is ready to be cyanide-leached on one condition, namely all gold particles are relatively liberated. However, the presence of deleterious minerals needs to be wary as they will affect the process in two ways - absorb cyanide solution (known as cyaniside materials or oxygen absorber) and re-absorb gold from Au-cyanide solution (Bradshaw et al., 2011). The complex gold ores commonly belong to Cu-Au ores that occur in various geological conditions and contain copper, gold, cobalt, uranium, bismuth as well as rare earth elements. Copper was found in Pongkor samples along with Cr, Mn, Rb, Sr and Zn (Table 2) though their quantities within detected samples were insignificant (Cashion and Brown, 1998; Li et al. 2010)

Sieving analysis was accomplished to examine the quantity of each fraction. One kilogram of each sample was fractionated into +60, -60+100, -100+140, -140+200 and -200 meshes. Figure 8 illustrates the sieving results. The majority of Sample AG particles belong to +60# and -200# as many as 58.30 and 30.34% respectively. Sample AG came from amalgamation tailings of artisanal mining. Sieving analysis for Sample AT shows that most particles go to -200# (52,44%) and they mostly consist of included gold in either silicate or sulfide minerals . Sample AT originated from PT Pongkor tailing dam. The fact that a lot of included gold particles within coarse fraction of Sample AG and AT goes to tailings relates to some of them is unliberated. Similar condition also occurs fine fraction as revealed by optical microscope tests. Fine gold is covered by sulfide (pyrite, chalcopyrite etc.) and silicate (mostly quartz) minerals. Due to its inclusion character; when processed, such the gold particles cannot be reached by lixiviants. Around 52.44% of Sample AS (cyanidation tailing from artisanal mining) belongs to -200# fraction. Referring to optical microscope analyses, a lot of free gold particles go to the tailings though the included gold and those distributed within crack are also available. Based on liberation classes as stated in www.minassist.com.au, the lixiviants will reach the liberated particles unrestricted. It reacts easily, however, the fact that a lot of free

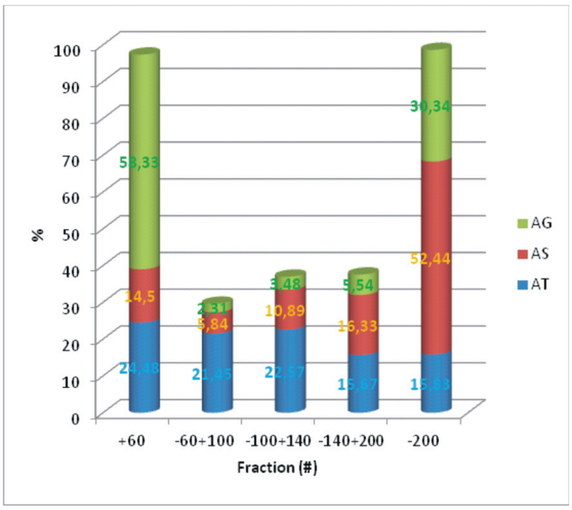


Figure 8. Sieving tests of 3 tailing samples from Pongkor

gold particle goes to tailings is understandable. Perhaps, human error from the operator of the artisanal mine due to lack of experience and technology is the reason.

Assaying Pongkor samples was conducted to fractions of -140+200 and -200 meshes (Table 5). It shows that the average Au and Ag contents are 2.668 and 121 g/tons respectively. Such figures does not show the real content as the detected samples came from fractionated samples. To get real amount, sample for fire assay should come from the intact one (http://www.actlabs.com). However, there was a technical problem to use such undisturbed samples for fire- assay test.

Table 5. Results of fire assay tests to 6 fraction tailing samples from Pongkor

Sample Code	Contents (g/t)	
	Au	Ag
AS-140+200	2,536	190
AS-200	2,654	200
AG-140+200	2,538	23
AG-200	2,556	23
AT-140+200	2,888	140
AT-200	2,837	150
Average	2,668	121

CONCLUSIONS AND SUGGESTIONS

Conclusions

Optical microscope testing along with SEM, XRD, XRF and chemical analyses illustrates that Pongkor gold ores retain refractory and complex characteristics. Gold inclusion within sulfide and silicate minerals is the common feature. Its nature might be single or multi-inclusion. The former relates to those coated by single phase while the later covered by more than one phases. XRD, XRF and chemical analyses confirm that Pongkor gold ore has preg-robber characters as shown by the existence of carbon, arsenic, copper, clay minerals etc.

When analyzing three types of Pongkor tailing samples, each testing method does not always provide similar results. For example, optical microscope tests provided photos of gold particles from each sample tests while the gold from SEM analyses can only be detected by its spectrum and quantity tables. Detected elements from chemical analyses are lesser than that of XRF. The fact that each method and technique of the instruments owns advantages and disadvantages are supposed to be the cause.

Suggestions

Three sample types are not enough for figuring out characters of the samples. At least, it requires minimum 15 sample types instead of three that are selectively sampled to get a representative data. It is also suggested performing TEM completed with EDS analyses, electron probe micro-analyses (EPMA), Fourier transform infrared spectroscopy (FTIR), Raman spectroscope and Auger electron spectroscopy (AES) to derive more complete data. However, not all mentioned instrument are available in Indonesia.

The study only analyzed tailing samples that are already mixed within tailing dam. Such condition has consequences a difficulty to evaluate sample source, whether it comes from raw material A, B, C etc. as its mineralogy, physical and chemical characters of the tailing samples do not reflects sample source. Analyzing the original samples help comprehending the nature of the ores and its tailings.

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REFERENCES

Baum, W., Lotter, N.O. and Whittaker, P. J. 2004. Process mineralogy – A new generation for ore characterization and plant optimization. *SME Annual Meeting Feb. 23-25*, Denver, Colorado

Baumgart, Wolfgang, Dunham, A.C., Christian Amstutz, G. 1984. *Process mineralogy of ceramic materials*. Ferdinand Enke Publishers Stuttgart.

Bayu Ningsih, Yunita Rr., 2001. Studi perbandingan pemakaian sianida dan thiourea sebagai pelindi bijih emas Cigaru, Sukabumi. *Skripsi sarjana strata 1*. Universitas Sriwijaya.

Bradshaw, D.J., Triffett, B., Kashuba, D., 2011. The role of process mineralogy in identifying the cause of low recovery of chalcopyrite at KUCC. *Presented at the 10th International Congress for Applied Mineralogy*, 1-5 August 2011, ICAM, Trondheim, Norway, p. 73–80.

Brough, C. P., Warrender, R., Bowell, R. J., Barnes, A. and Parbhakar-Fox A. 2013. The process mineralogy of mine wastes, *Mineral Enginering v. 52*. p.125-135.

Cabri, L.J., 2004. New developments in process mineralogy of platinum-bearing ores. *Proceedings of the 36th Annual Meeting of the Canadian Mineral Processors*. Ottawa p. 189-198.

Cashion, J. D. and Brown, L.J., 1998. Gold mineralogy and extraction. *Hyperfine Interactions v. 111*, Issue 1-4, p. 271-280.

Celep, O., Alp, I., Deveci, H. and Vicil, M., 2009. Characterization of refractory behaviour of complex gold/silver ore by diagnostic leaching. *Trans, Nonferous Met, Soc, China* v. 19, p. 707 - 713.

Chen, T.T., Cabri, L.J. and Dutrizac, J.B., 2002. Characterizing gold in refractory sulfide gold ores and residues. JOM, v. 54, n. 12, p. 20-22

Chryssoulis, S., Venter, D., Dimov, S., 2003. On the floatability of gold grains. *Proceedings of the 35th Annual Meeting of the Canadian Mineral Processors* (Ottawa, Canada), p. 455-472

Evans, C. L., Wightman, E. M., Manlapig, E. V. and Coulter, B. L., 2011. Application of process mineralogy as a tool for sustainable processing. *Minerals Engineering*, v. 24, n. 12, p. 1242-1248.

Grammatikopoulos, T.A., Kapsiotis, A., Liu, M., Tsikouras, B., Hatzipanagiotou, K., Zaccarini, F. and Garuti, G. 2006. Process mineralogy of low grade PGM-bearing chromitites from the Vourinos ophiolite complex, northern Greece. *Geophysical Research Abstracts*, v. 8, 04661,

http://www.actlabs.com accessed on 23 July 2014 at 13.30

http://www.insidemetals.com/index.php?view=mining_glossary accessed on 10 July 2014 at 09.30

http://www.minasist.com.au accessed on 16 July 2014 at 10.00

Li, Yu-liang, Jian Liu, Wei-sheng Guan, 2010. *Cyanidation of gold clay ore containing arsenic and manganese*. Issue 2 v. 17. p. 132-136.

Lotter, N.O., Kormos, L.J., Oliveira, J., Fragomeni, D., Whiteman, E., 2011. Modern process mineralogy: two case studies. *Miner. Eng. v.24*, p. 638–650.

Marcoux, E., J.P. Milesi, Sitorus, T. and Simanjuntak M., 1999. The epithermal Au-Ag (Mn) deposit of Pongkor (West Java, Indonesia). *Indonesian Mining Journal*, v.2, n.3, p. 1-17. Directorate General of Mines, Department of Mines and Energy

Petruk, W., 2000. Applied mineralogy in the mining industry. Elsevier Science B.V. pp. 51-57

Vaughn, J.P., 2004. The process mineralogy of gold: the classification of ore types. *Journal of the Metals, Minerals and Mineral Society*. v. 56, issue 7 p. 46-48

Wan, Rong-Yu, 2001. Importance of metallurgical research on refractory gold ore processing. *Mining Engineering*: November v. 53, n. 11, pp. 41-46.

Wang, K. 1994. *Study on the gold occurrence from several typical carlin-type gold deposits in China*. Hefei, Japan: Publishing house of University of Science & Technology of China.

Yang, Hong-ying, Qian Liu, Xiang-ling Song dan Jinkui Dong, 2013. Research status of carbonaceous matter in carbonaceous gold ores and bio-oxidation pretreatment. Trans. *Nonferrous Met. Soc. China* v. 23, pp. 3405− 3411. Elsevier

Zhou, Joe Y. and Louis J. Cabri., 2004. Gold process mineralogy: Objectives, techniques, and applications. *Jounal of Metal*. v. 56, Issue 7, pp 49-52