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Deportment of Gold and Silver in the Pinos Altos Composite and Leach Residues: Implications for Recovery Improvement

J. ZHOU*, R. MERMILLOD-BLONDIN† and P. COUSIN†

**Manager Mineralogy Consulting, JKTech Pty Limited, Australia*

†Agnico-Eagle Mines Limited, Canada

A mineralogical study was conducted on the feed (3.51 g/t Au and ~90 g/t Ag) and four leach residue samples (assaying 0.09 to 0.19 g/t Au and 30.0 to 61.5 g/t Ag) from the Pinos Altos silver-gold deposit in Mexico to determine the cause for gold and silver losses. A comprehensive mineralogical and analytical approach including fire assay, gravity pre-concentration, ore microscopy, mineral liberation analyser (MLA) and electron microprobe was used for the current study. Results showed that gold and silver lost in the leach residues occurred mainly as inclusions in quartz and silicates (accounting for over 80% for Au and 92% for Ag of the head assays, respectively), with a minor amount in iron oxide and other minerals. The amount of liberated gold and silver is negligible. Results also showed that gold and silver particles in leach residues are mainly ranged from 1 μm to 5 μm in size, which implies that ultrafine grinding is required to improve the recoveries of these two metals.

Keywords: mineralogy, gold deportment, silver deportment, silver-gold ore, leach residue, recovery improvement.

Introduction

The deportment of gold in various tailings is diverse, and its occurrence and distribution is influenced both by mineralogical factors and by the extraction process employed. The most important mineralogical factors affecting gold recovery are the locking of gold particles in sulphide and non sulphide minerals, the presence of preg-robbers, cyanide and oxygen-consuming gangue minerals, and the presence of slow-dissolving gold minerals (Zhou, Jago and Martin, 2004). Processing inefficiencies that can affect gold recovery are the fineness of the grind achieved in the mill, the gold leaching process selected (almost universally cyanide, although other lixiviants are being investigated) and the gold extraction process selected (i.e. solid/liquid separation followed by Merrill Crowe and absorption on activated carbon being the most common processes) (Zhou and Fleming, 2007).

Compared to gold, silver mineralogy is more complex and silver extraction is more challenging to metallurgists. Over 200 Ag-bearing minerals have been identified and a silver rich ore body would typically contain 5 to 10 different silver minerals (Gasparrini, 1984). Like gold, silver occurs not only as visible silver in epithermal Ag and Au Ag ores but also as submicroscopic silver in Cu-Au and Pb-Zn-Ag ores (Zhou and Zhou, 2008). Knowing the deportment of silver in the ore being treated and its metallurgical products is important in plant design and optimization.

Pinos Altos is Agnico Eagle's new project in Mexico and is expected to begin production in mid 2009. The Pinos Altos silver-gold ore contains 3.5 g/t Au and ~90 g/t Ag. Sulphide content in the ore is low. Gold and silver are recovered by cyanide leaching (see the following section for details). During the cyanide leaching, gold was recovered efficiently (residues ranged from 0.02 to 0.15 g/t Au), but silver recovery was much lower than expected (residues assayed 33 to 65 g/t Ag). What has caused the silver and gold losses and how to improve recoveries are the questions to be answered.

The ultimate goal of a mineral processing plant is to recover as much of the target mineral(s) as possible from the ore being treated to achieve the best economics. This is particularly so at Agnico Eagle Mines. At Agnico Eagle, the company has a strong interest in mineralogy and understands the benefits it can bring. To determine the cause for silver and gold losses, a deportment study was proposed by Agnico Eagle Mines and the testwork was conducted at JKTech. This paper presents the major results acquired from the mineralogy study and indicates how the recovery can be improved.

Geological setting

Location

Pinos Altos is located in the Sierra Madre gold belt, 280 km west of Chihuahua, the state capital (Figure 1). The mineral rights total, approximately, 11 000 hectares, which are directly accessible by paved highway.

History

The Pinos Altos property was acquired by Agnico Eagle Mines in 2006 upon receiving encouraging results from a drilling campaign Agnico Eagle conducted under an option agreement in place at the time. Since initiating exploration, it has significantly increased gold grades and reserves, and expanded gold zones on the property. In August 2007, a favourable feasibility study led to the decision to commence construction of the Pinos Altos mine.

Figure 1. Location of the Pinos Altos deposit

Initial production is scheduled for mid 2009, beginning with ore from the open pit. Underground mining will be phased in over four years. The gold will be processed by conventional milling although a heap leach option is also being contemplated. Gold production is estimated to average 190, 000 ounces per year over a 11-year mine life, with expected total cash costs averaging US$210 per ounce. Preliminary capital cost estimates to bring the project into production are approximately US$230 million.

Geology

Approximately 60% of the Pinos Altos mineral resource is located in the Santo Niño zone, along a regional fault zone that holds a number of other known deposits in the area. This Santo Niño zone has thicknesses of up to 45 metres over a length of 2 km, and a vertical extent identified to be over 750 metres. It remains open to the west and at depth.

Ore minerology

Based on the microscopic examination and XRD analysis, the Pinos Altos ore is consisted mainly of non-sulphide minerals (i.e. quartz, potassium feldspar, plagioclase, illite, kaolinite, chlorite, and montmorillonite), with minor amounts of goethite, hematite, ilmenite, magnetite, rutile, calcite (see Table I) and trace amounts of sulphide minerals and gold-silver minerals. Sulphide minerals include pyrite, chalcopyrite, galena, sphalerite, covellite and bornite. Gold and silver minerals include native gold, electrum, kustelite, acanthite, native silver, iodyrite and bromyrite.

Metallurgical work

Ore Grade

The mean grades of the probable mineral reserve are 2.85 g/t of gold and 79.10 g/t of silver for the open pits and 2.95 g/t of gold and 88.00 g/t of silver for the underground. The ore is variability tested and is relatively large ranging from 0.5 to 6 g/t of gold and from 20 to 160 g/t of silver.

Flowsheet

A part of the Pinos Altos ore is processed by heap leaching. The mill is designed for 4,000 metric tons per day and implements a conventional Merrill Crowe precious metals recovery plant, including one stage crushing, SAG and ball mill grinding (P80 = 75 μm), gravimetric separation, thickening, leaching and recovery systems, cyanide destruction, and dry tailings impoundment (Figure 2). Based on laboratory test work performed by KCA Laboratories, the metal extraction rates established were above 90% weighted average recovery for gold and around 50% weighted average recovery for silver.

Cyanide leaching

Cyanidation is the most efficient and widely applied process for extracting gold from various ores, and high recoveries (>80%) are, usually, expected and commonly achieved. The gold left in the tailings is often encapsulated in sulphide, oxide and/or silicate minerals that are impervious to the cyanide leach solution. Encapsulation of gold in sulphide minerals (and non sulphide minerals to a minor extent) is considered to be the major factor causing gold losses to tailings in the gold industry, and will be one of the greatest challenges in the future, as more and more new gold discoveries fall into this category. Gold locked in minerals that are impervious to cyanide leach solution occurs as both microscopic (visible) inclusions and submicroscopic (invisible) gold in sulphide and non sulphide minerals.

Gravity separation using a Knelson concentrator 3' and cyanide leaching using the bottle roll test were implemented to produce the leaching residues studied in this paper. The gold and silver overall recoveries vary, respectively, from 95 to 97% wt and 25 to 65% wt.

Methodology

A comprehensive mineralogical and analytical approach including fire assay, gravity pre-concentration, ore microscopy, mineral liberation analyser (MLA) and electron microprobe was used for the current study.

Samples and sample preparation

One composite sample (-300 μm) and four leach residual samples (RE-2027, RE-2030, RE-1924 and RE-1932) were used for the current study. Representative sub-samples were riffled out from each as received sample for (a) Au, Ag and S^{2-} assays, and (b) preconcentration by heavy liquid separation, followed by superpanning.

Table I
Mineralogical composition of the Pinos Altos ore

Mineral name	Mineral content%
Quartz	66.1
Orthclase	15.5
Albite	4.9
Illite	3.6
Kaolinite	3.5
Clinochlore	2.7
Montmorillonite	1.4
Hematite	1.0
Calcite	0.8
Ilmenite	0.5

The semi quantitive analysis of EVA is performed on the basis of relative peak hights and I/Icor values of those detected crystalline phases with PDF files. Amorphous or crystalline mineral species present in trace amounts may go undetected.

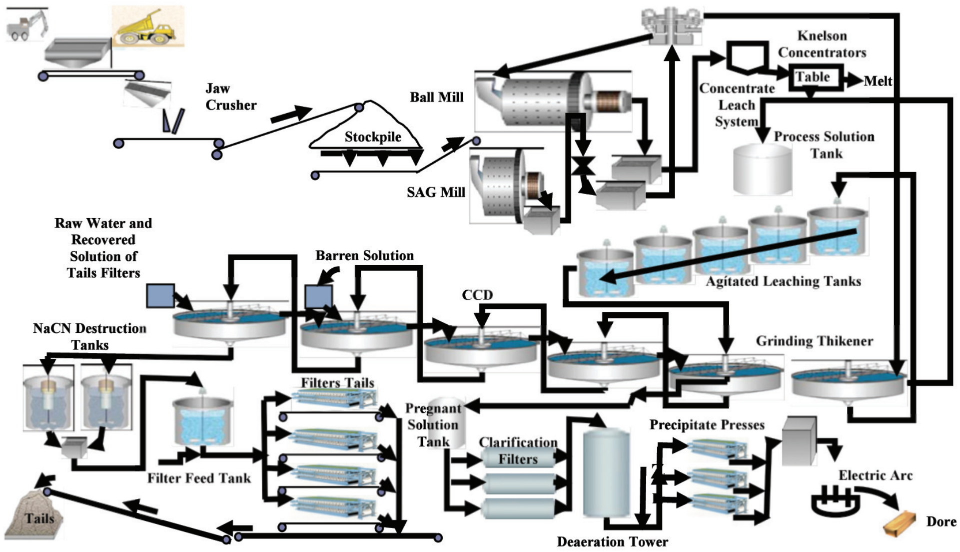

Figure 2. Pinos Altos flowsheet

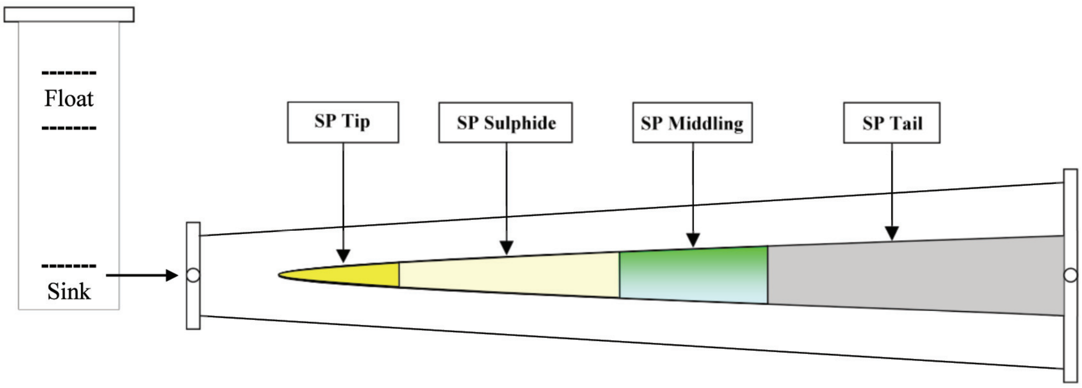

Figure 3. Preconcentration flowsheet for gold and silver deportment study

Approximately 900 g of Composite and 470 to 550 g of each residue material were preconcentrated by heavy liquid separation (HLS) at S.G. 2.75 to produce a sink fraction consisting, mainly, of sulphides, oxides and heavy silicate minerals and a float fraction consisting mainly of silicates, or silicates with disseminated sulphides. The sink fraction was further concentrated by superpanning (SP) to separate liberated gold and silver minerals from other minerals. By employing such a flowsheet (Figure 3), all of the liberated gold and silver grains would be separated, and minerals with large silver and gold inclusions would be concentrated.

Gold and silver scan

Gold and silver scan was carried out using both optical microscope and MLA.

Reflected light microscopy is used in gold and silver search for a Composite sample. Optical microscope is the most common and widely used tool in many mineralogical labs. The advantage of using optical microscopy is its high efficiency when operated by an experienced mineralogist. It also provides visual images showing the occurrences of gold and silver minerals (Zhou, Jago and Martin, 2004).

The MLA system was used in this study for gold and silver search in leach residue samples. Polished sections made from gravity products were systematically scanned using MLA for gold and silver minerals. MLA is a scanning electron microscope based system, and uses back scattered electron images to define the mineral grains in the samples and then uses X-ray spectra to identify the mineral in each grain. The X-ray spectra can be collected by a point, area or X-ray mapping technique. Mineral identification is done through a library of mineral standards, and involves the collection of a high quality X-ray spectrum for each mineral in the sample. The building of a standards library directly from the sample ensures that measurement conditions are reflected in the standards, such as beam energy, and it also provides for an elemental deportment that better reflects the chemistry of the sample.

Various measurement modes are offered by the MLA to accommodate many different mineralogical information requirements. For this study, the sparse phase liberation analysis (SPL) technique was used to investigate the submitted samples. The SPL measurement mode was developed to analyse samples where the mineral(s) of interest are present at low levels, typically in the range of 0.01 to 1.0%. It searches BSE images for particles containing phases of interest using a BSE grey scale range and then performs an XBSE analysis on those particles (XBSE implements area X-ray analysis to efficiently and effectively analyse ore samples containing phases with sufficient BSE contrast to ensure effective segmentation). The SPL technique does not provide bulk mineralogy information, as only selected particles in the sample are analysed. The selectivity of the SPL measurement is designed to efficiently measure liberation of trace minerals in tailings and low grade feed samples, such as precious metal ores and tailings where the properties of the trace phase are the focus of the investigation. Typical applications of the SPL technique are: looking at sulphide liberation in a base metal sulphide tailing stream, assessing the deportment of penalty elements in concentrates or the deportment of gold, silver, or PGM in various tailings. The benefits of using the SPL measurement mode is that by only measuring particles which contain the target mineral(s), the MLA system is able to measure a greater number of grains of those phase than other measurement modes (such as a standard XBSE or GXMAP) would in a given time period.

Analysis of gold and silver

Gold analysis was done by fire assay with gravimetry measurement. Silver analysis was conducted by four acids leaching with atomic absorption reading of the solution.

Electron microprobe analysis

Chemical composition of gold and silver minerals was analyzed by CAMECA SX-100. In addition to Au and Ag, Cu, Pb, Zn, Fe, Ni, Hg, Sn, S, Se, Sb, Bi and Te were also analysed.

Deportment of gold and silver in composite

Gold deportment

Gold speciation and association

A total of over 320 gold grains were observed and measured in Pinos Altos Composite. Based on the classification of gold minerals (Zhou, Jago and Martin, 2004), gold in the Pinos Altos Composite occurred mainly as native gold and electrum, with a minor amount of küstelite. Electron microprobe analysis of gold grains showed that the content of Au in three gold minerals ranged from 25.1% to 25.9% in küstelite, 53.7% to 74.7% in electrum and 75.2% to 99.0% in native gold, with an average of 71.1% Au.

Like many other Au-Ag ores in South America, Au in the Pinos Altos ore is intimately associated with Ag. In addition to forming Ag-rich electrum and küstelite, gold minerals are closely associated with silver minerals (Figure 4).

Grain size and liberation of gold minerals

The grain size of gold particles ranged from 1 to 212 µm. By frequency, approximately 76% of the gold was liberated, 6% was attached to acanthite, iron oxide and non-opaque minerals (NOP), and 18% occurred as inclusions in acanthite, goethite, pyrite and NOP (Figure 4). In terms of the surface area, liberated gold accounted for 92% and attached and locked gold only accounted for 8%. The higher percentage of liberated gold by surface area is because of its larger grain size comparing to locked grains. Figures 5 and 6 show that liberated gold grains distributed within a fairly large size range and coarse grains accounted for a large portion, while locked gold grains were all below 50 µm with over 85% below 10 µm. Size distribution of gold minerals shows that a high recovery of gold by cyanidation can be achieved when the ore is ground finer (below 75 µm).

It should be noted that the liberation and locking data for gold minerals presented above is based on the frequency and or observed surface area and should not be considered as gold balance by association. It can only be used for determining the relative gold distribution. This is because only a part of the locked gold will be exposed during

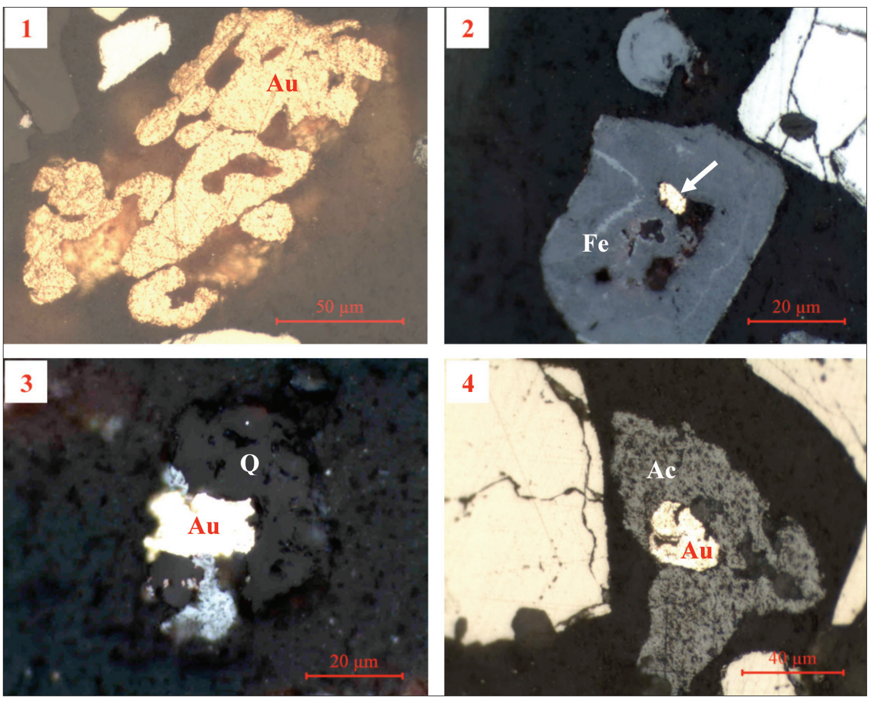

Figure 4. Gold in Composite sample. 1: Liberated gold (Au); 2: Gold (indicated by white arrow) locked in iron oxide (Fe); 3: Gold (Au) locked in quartz (Q) with native silver (white); 4: Gold (Au) locked in acanthite (Ac)

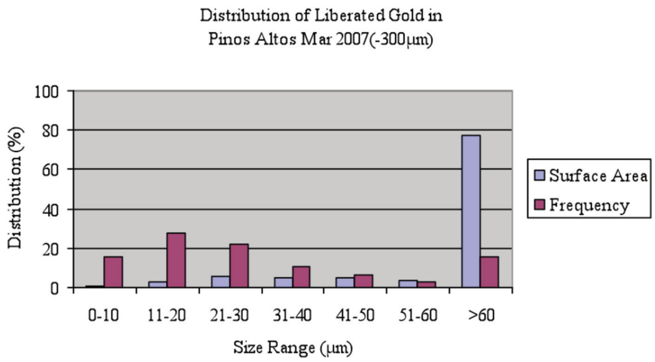

Figure 5. Size distribution of liberated gold in the composite sample

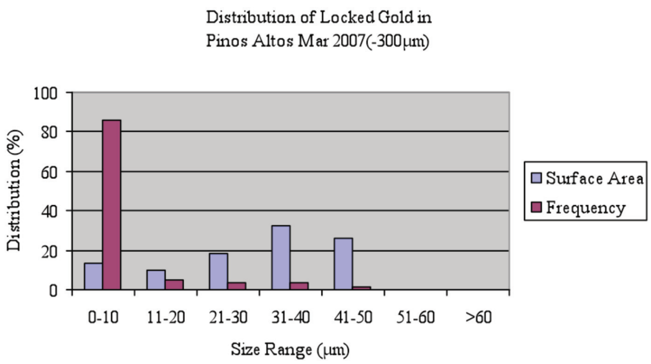

Figure 6. Size distribution of locked gold in the Composite sample

polishing and will be observed under microscopy or using any other techniques. The liberation/locking data of gold (and silver) will be biased if the frequency or measured surface area is used. Fire assay should always be used in gold balance calculation.

Gold distribution

Based on the mass balance and assays, it is determined that approximately 50% of gold was carried in the heavy liquid sink fraction (Table II), with 46.5% of gold being concentrated into SP Tip, SP Sulphide, SP Oxide, and SP Middling (collectively accounting for 0.23% of the total mass) and considered to be mainly liberated. Gold in the SP Tail and Float fraction, which is mainly locked in NOP, iron oxide and pyrite, accounted for approximately 3.1% and 50.4% of the head assay, respectively. This indicates that the ore needs to be ground finer to achieve high gold recovery by cyanidation.

Silver deportment

Silver speciation

A total of 368 silver grains were observed in the Composite sample. According to microscopic scan and microprobe analysis, silver in the Pinos Altos composite occurred mainly as acanthite (Ag_2S) and native silver (Ag) (Figure 7), with a minor amount of Ag being carried by gold minerals (native gold, electrum and kustelite as presented above) and silver halides. Electron microprobe analyses showed that the average Ag content in acanthite and native silver are 87.3% and 95.7%, respectively.

Grain size, liberation and association of silver minerals

The grain size of the silver particles ranged from 1 to 316 µm. By frequency, approximately 78% of the silver mineral was liberated, 7% was attached to gold, NOP, pyrite, and goethite, and 15% was found as inclusions in pyrite, gold, iron oxide and NOP. Silver associated with covellite was also observed. In terms of the surface area, however, liberated silver accounted for 95%, and attached and locked gold only accounted for 5%. Like gold, this is because liberated silver grains were much coarser than locked silver grains. Based on the microscopic observation of the Sink fraction, acanthite and native silver were mainly liberated single phases, although binary grains of these two minerals were fairly common. Silver halides were mainly liberated, with some grains carried gold and/or other mineral inclusions. Figures 8 and 9 show that both liberated and locked silver minerals are coarser than gold grains, which indicates that recovering silver by cyanidation will require higher cyanide concentration and or longer retention time. Figure 9 also shows that to achieve high silver recovery, the ore needs to be ground to 60 µm or finer.

Silver distribution

Table II shows that less than 31% silver occurred in the heavy liquid sink fraction, with over 69% of silver being carried in the Float fraction at the grinding fineness of 300 µm. Considering that silver is fairly coarser than gold, and more silver is locked in NOP, the ore needs to be ground much finer to achieve the same silver recovery as gold.

A calculation using grain size, mineral and liberation identification, leads to the silver mass for each grain via pure mineral density and a spherical grain hypothesis. The table below, (Table III) emphasizes the silver liberation distribution using each grain mass and regarding the different fractions weighted via the global silver distribution from assays in Table II.

Table II
Mass balance and distribution of gold and silver in Composite sample

Sample ID		Wt. (g)	Wt. (%)	Grade (g/t)		Distribution (%)	
				Au	Ag	Gold	Silver
Head		858.6	100.0	3.51	84.8	100	100
Float		838.80	98.31	1.80	59.8	50.4	69.3
Sink	SP Tip	0.39	0.05	**709.6	**10,029	*46.5	*27.2
	SP Sulfide	0.42	0.05				
	SP Oxide	0.50	0.06				
	SP Mid	0.60	0.07				
	SP Tail	12.53	1.47	7.50	203.0	3.1	3.5

* and **: calculated from head grade.

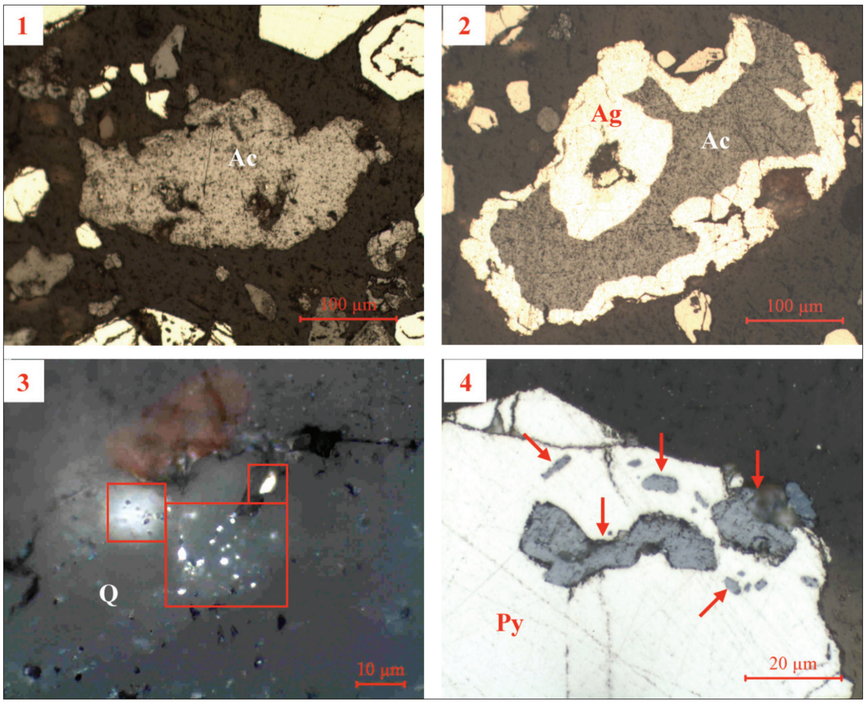

Figure 7. Silver in Composite sample. 1: Liberated acanthite (Ac); 2: Liberated acanthite (Ac) with native silver (Ag); 3: Native silver (white particles inside red boxes) locked in quartz (Q); 4: Acanthite (indicated by red arrows) locked in pyrite (Py)

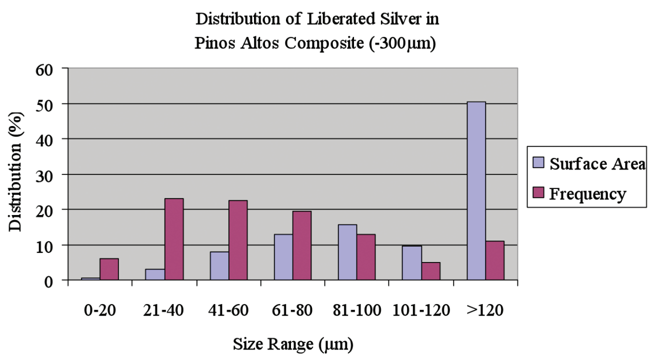

Figure 8. Size distribution of liberated silver in Composite sample

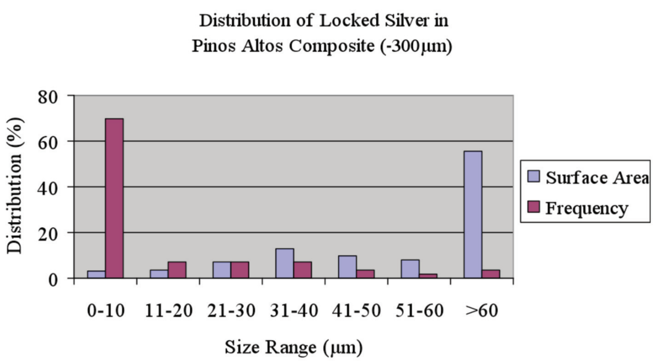

Figure 9. Size distribution of locked silver in Composite sample

Table III shows about 60% of silver is locked and may be lost in cyanide tails at the particular size of the studied sample (-300 µm).

The liberated fraction shows a maximal recovery of 28% Ag would be expected with gravity separation regarding the particle size distribution at Figure 6, and assuming particle above 60 µm would be recovered by gravimetric concentration.

Table III
Silver distribution regarding liberation and products

<table>
<tr><th>Fraction</th><th>Liberated</th><th>Attached</th><th>Locked</th></tr>
<tr><td>SP Tip</td><td rowspan="4">26.7</td><td rowspan="4">0.3</td><td rowspan="4">0.2</td></tr>
<tr><td>SP Sulphide</td></tr>
<tr><td>SP Oxide</td></tr>
<tr><td>SP Middling</td></tr>
<tr><td>SP Tail</td><td>3.5</td><td>0.0</td><td>0.0</td></tr>
<tr><td>Float</td><td>2.7</td><td>8.1</td><td>58.5</td></tr>
<tr><td>Total</td><td>32.9</td><td>8.4</td><td>58.7</td></tr>
</table>

These results are in the order of magnitude of the metallurgical tests done by Agnico Eagle and confirm the metallurgical behaviour of the Pinos Altos ore.

Deportment of gold and silver in leach residues

Gold deportment

In leach residues, gold occurred mainly as native gold and electrum. Silver occurred mainly as acanthite, and to a lesser extent, as native silver. A minor amount of chlorargyrite and a trace amount of AgHg were also observed.

Gold lost in the residues was extremely fine, ranging from <1 µm to 19 µm in size with the majority being below 5 µm (Table IV). Gold occurred mainly as inclusions in quartz and silicate (Figures 10 and 11), and to a lesser extent, in sulphides and iron oxides. Liberated gold particles were also observed but accounted for a negligible portion.

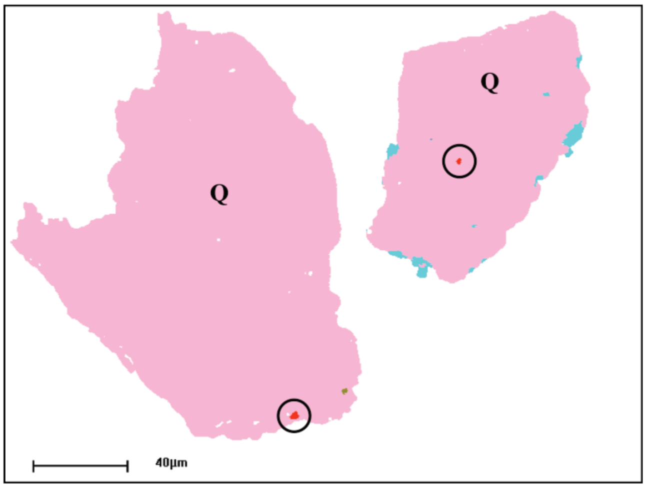

Figure 10. Gold (inside black circles) locked in quartz (Q) in Leach Residue

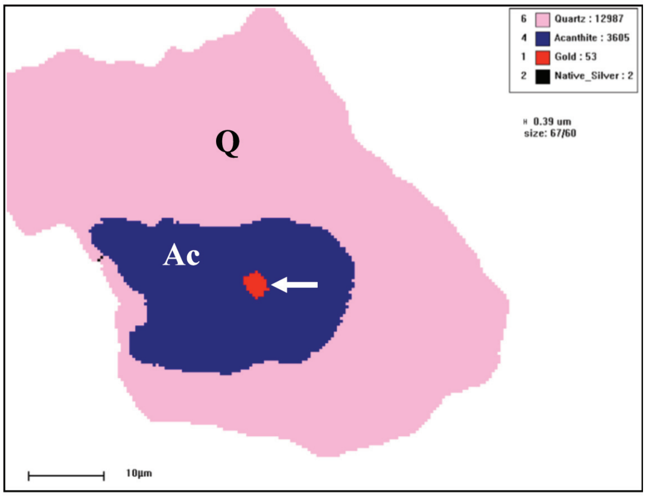

Figure 11. Gold (indicated by white arrow) locked in acanthite (Ac) within quartz (Q) in Leach Residue

It is well known that liberated gold can be lost to cyanidation tailings for various reasons. This generally occurs when some of the gold (coarse native gold or electrum particles) in the ore is too slow-leaching to dissolve to completion in the time allocated to the leaching process. Studies have indicated that a spherical gold particle with a diameter of 44 µm will take approximately 13 hours to dissolve under normal cyanide leach conditions, while particles with a diameter of 150 µm will take 48 hours or more (Fleming, 1992). Generally, when an ore contains large liberated gold particles, the flowsheet will incorporate a gravity circuit to recover these particles, so it is not necessary to design for excessively long leach times. An average gold plant would have a 24 hour leach residence time (Fleming, 1998). In addition, gold losses from cyanide leach circuits can be caused by the formation of surface coating and rimming on the surface of gold particles during cyanide leaching, which retards the rate of leaching. Certain gold alloy compounds are also very slow-leaching, and this, too, is believed to be due to the formation of passive films on the surface of the particles (Chryssoulis and McMullen, 2005; Zhou and Fleming, 2007). Finally, losses of liberated gold to tailings can occur when the ore contains gangue minerals that rapidly consume the leaching chemicals (cyanide and or oxygen), leaving the leach liquor starved of the reagents needed to dissolve the gold, or when the ore contains natural carbonaceous and or graphitic or shale material that is able to re-adsorb the gold cyanide complex after the gold has been leached. This phenomenon is quite common in the gold mining industry, and is known as preg-robbing (Zhou and Fleming, 2007).

In the case of the Pinos Altos, there were no refractory gold minerals or coating/rimming on the surface of liberated gold grains was observed. Therefore, the presence of liberated gold grains was considered to be due to the presence of coarse gold in the leach feed and insufficient leaching time.

Gold distribution (Table V) shows that gold in the leach residues was mainly carried in the Float which is consisted of silicates, accounting for over 62% of the head assay.

Silver deportment

Like gold, silver in the four leach residues occurred mainly as micron-sized inclusions in non sulphide minerals

Table IV
Grain size, liberation and association of gold and silver

Sample ID	Item	Silver						Gold	
		Float	SP Tip	SP Sulphide	SP Oxide	SP Mid	SP Tail	Float	Sink
RE-2027	Frequency (#)	109	336	N/A	105	123	240	2	15
	Size Range (µm)	<1 - 7	<1 - 14	N/A	<1 - 7	<1 - 14	<1 - 7	1 - 5	<1 - 19
	Host Mineral	Q	FeOx>>Q	N/A	FeOx>Q	FeOx>Q	Q>FeOx	Q	Q>FeOx
RE-2030	Frequency (#)	89	101	112	244	120	314	1	15
	Size Range (µm)	<1 - 19	<1 - 38	<1 - 38	<1 - 106	<1 - 10	<1 - 27	1 - 2	1 - 14
	Host Mineral	Mainly Q	Lib, Py & FeOx	Lib, Py & FeOx	Lib>Q> FeOx	Q>FeOx> others	Q>lib	Q	Py, lib, Q, FeOx
RE-1932	Frequency (#)	185	370	377	N/A	454	460	0	11
	Size Range (µm)	<1 - 10	<1 - 53	<1 - 38	N/A	<1 - 19	<1 - 38	N/A	<1 - 5
	Host Mineral	Q	Lib & FeOx	Lib & FeOx	N/A	Lib, FeOx & Q	Q>FeOx	N/A	FeOx & Q
RE-1924	Frequency (#)	48	138	N/A	53	67	69	0	1
	Size Range (µm)	<1 - 4	<1 - 10	N/A	<1 - 10	<1 - 7	<1 - 5	N/A	4
	Host Mineral	Mainly Q	Mainly FeOx	N/A	FeOx>>Q	FeOx>>Q	FeOx>Q	N/A	FeOx

Table V
Mass balance and distribution of gold and silver

Sample ID	P	80 (mμ)	Wt. (g)	Wt. (%)	Assay (g/t)		Distribution (%)	
					Au	Ag	Gold	Silver
RE-2027	Head	73	548.7	100.0	0.19	65.7	100	100
	Float		536.8	97.8	0.16	61.8	82.4	92.0
	Sink		11.9	2.2	1.06	88.8	12.3	3.0
RE-2030	Head	84	522.9	100.0	0.09	33.2	100	100
	Float		489.4	93.6	0.06	29.9	62.4	84.3
	Sink		33.5	6.4	0.36	37.8	25.6	7.3
RE-1932	Head	72	528.8	100.0	0.09	39.7	100	100
	Float		517.4	97.8	0.12	36.2	(90.0)	89.2
	Sink		11.4	2.2	0.41	55.6	10.0	3.1
RE-1924	Head	50	467.5	100.0	0.09	40.2	100	100
	Float		459.6	98.3	0.07	37.5	76.5	91.7
	Sink		7.89	1.7	0.19	44.4	3.6	1.9

(primarily in quartz) (Figures 12 and 13), accounting for 84% to 92% of the head assays (Tables IV and V). The remaining silver was carried by sulphide minerals (pyrite, sphalerite and galena), iron oxides and liberated silver minerals (up to 106 μm in size). Coatings were observed on some liberated silver grains, but were not analysed for composition due to the thinness. Presence of residual liberated silver grains in the Pinos Altos leach residues could be caused by the same reason as for gold, i.e., some silver grains in the ore were too coarse in size to dissolve during the original leaching period and, in other words, the leaching time might be insufficient for those large silver grains. It was observed, in the Pinos Altos Composite sample, that 38 grains out of the total silver grains (368) were over 100 μm in size, with the largest one being 316 μm. To dissolve these large silver mineral grains, extended leaching time and/or higher cyanide concentration will be required.

Implications for recovery improvement

The gold and silver deportment study of the Pinos Altos Composite sample showed the presence of coarse gold and silver minerals. It also indicated, that to achieve high recoveries for gold and silver, finer grinding (50 to 60 μm) is required. The prediction has been proved by cyanidation testwork and subsequent deportment study of gold and silver in leach residues. Deportment study of leach residues indicated that liberated gold and silver have been effectively recovered by cyanide leaching. Residual liberated gold and silver minerals can be recovered by increasing the cyanide concentration and/or retention time.

The presence of the lost gold and silver in silicate minerals as fine-grained inclusions indicated that finer to ultrafine grinding is required to improve gold and silver (particularly silver) recoveries.

Concluding remarks

Gold and silver can be lost to tailings for various reasons, and the mineralogy can have a significant impact on the recoveries of both metals. In the case of Pinos Altos, locking of gold and silver in silicate minerals is considered to be the major mineralogical factor that have impacted the recoveries of gold and silver (particularly silver), although the large grain size of liberated gold and silver minerals may have also contributed to the losses of these two metals. To improve the recoveries of gold and silver, finer grinding (<50 μm) is required.

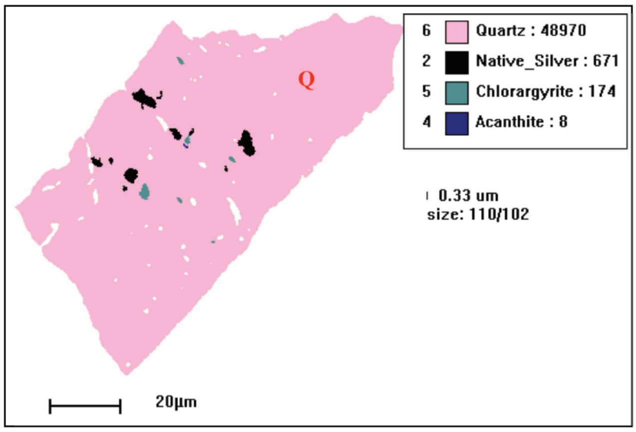

Figure 12. Native silver, chlorargyrite and acanthite locked in quartz (Q) in Leach Residue

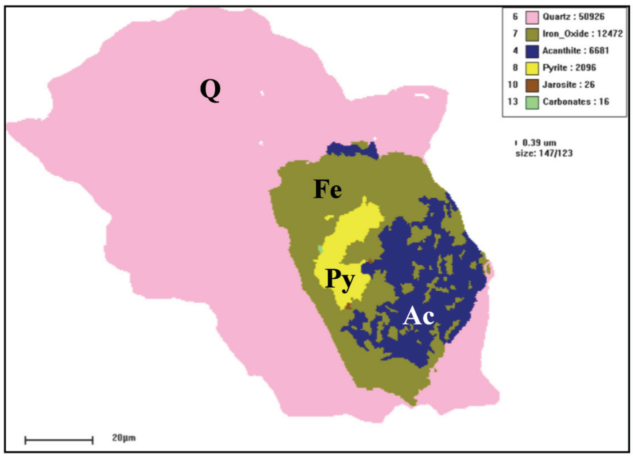

Figure 13. Acanthite (Ac, deep blue) locked in iron oxide (Fe) within quartz (Q) in Leach Residue. Yellow inclusion within iron oxide (Fe) is pyrite (Py)

A deportment study of gold and silver in composite ore samples is often used to diagnose and predict metallurgical response of the ore to various mineral processing techniques, to identify potential issues that may impact gold and silver recoveries, and help in the process design. This is usually conducted at the early stage of a metallurgical programme. A detailed deportment study of tailing samples can help quantitatively determine the forms and carriers of gold and silver in the tailings and identify the problems that have caused losses in the plants. Such a deportment study should be considered whenever gold and/or silver losses occur.

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J. Zhou

Manager Mineralogy Consulting, JKTech Pty Limited, Australia