Using Mineralogy to Optimize Gold Recovery by Flotation

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Gold is an important by-product of many porphyry copper ore deposits. Precise mineralogical characterization of the unfloated gold in what is typically very low grade (i.e., <0.1 g/t Au) flotation tails provides a clear picture of the carriers and causes for gold losses in these large tonnage operations, thereby identifying the means to reduce such losses. Analyzing quantitative gold deportments in flotation tails enables the carriers of unfloated gold to be ranked, the most appropriate carrier identified, and test work designed to address specific causes of gold losses. Typically, 10–20% of the gold in the tails can be recovered without additional grinding or by regrinding a rougher or cleaner scavenger concentrate.

INTRODUCTION

The gold content in final tails from Cu-Au operations typically ranges from approximately 0.010 to 0.250 g/t Au. Because unfavorable associations, such as with pyrite or silicate minerals, are the single most important cause of gold losses, finer grinding appears to be the sole remedy to the problem. In large-tonnage operations, however, throughput always wins over gold recovery, so finer grinding is usually not a viable option. However, two situations exist that can result in gold loss to the tailings: the preferential association of gold with pyrite and the unfloated free gold grains.

Accurate gold mineralogical balances of flotation tails samples, referred to as gold deportments, identify the forms and carriers of gold and provide the necessary information on the amount of gold contained within each carrier. Form refers to the different chemical states of gold, such as alloys, minerals, and submicroscopic gold; carrier refers to the mineral particles that carry gold in one or more forms. Gold contained within each carrier is determined independently and not by difference. Thus, the sum of all fractions of gold compared to the tails gold assay provides a measure of the completeness of the gold deportment. The same exercise also determines the causes of gold flotation losses, including: gold grain sizes outside normal floatable size classes; incompatible collector/gold grain composition; inadequate activation; excessive depressants; unfavorable association; and submicroscopic gold in arsenopyrite, pyrite, and iron oxyhyd-roxides.

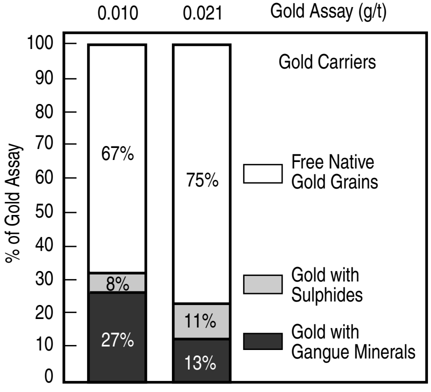

Figure 1. The deportment of unfloated gold at Los Pelambres (hydrothermal breccia ore).

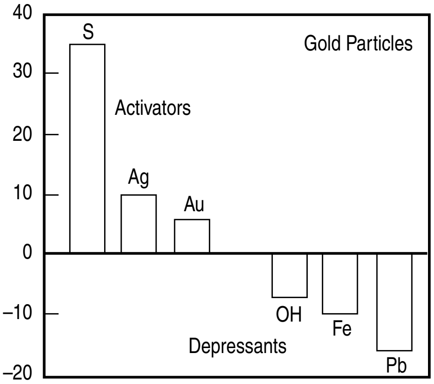

Figure 2. The activators and depressants of gold at Los Pelambres. The size of the bar is proportional to the difference in concentration between floated and rejected gold particles.

Based on this information, it is possible to target specific carriers of lost gold, determine the means to recover the targeted gold, and establish the percentile of overall improvement in gold recovery.

In this article, two examples are provided. In one example, the targeted gold is in the form of unfloated free gold particulates and, in the other, it takes the form of fine-grained gold inclusions in pyrite.

MINERALOGICAL CHARACTERIZATION

The study of the deportment of unfloated gold is a three-step process, namely: developing a detailed gold deportation of a tailing sample; comparing floated with rejected free gold particles; and comparing this tailing sample with other tailing samples. In the first step, the forms and carriers of gold are identified, the gold content of each carrier is quantified independently, and the fractions of gold represented by each carrier are then tallied and compared against the assayed value. In the second step, comparing floated and rejected free gold particles enables significant differences to be identified in mineralogical and process-related parameters from which the cause(s) for the experienced losses are determined. In the third step, consistency in the forms, carriers, and causes of gold losses is established by studying tailing samples from other streams or samples of tailings spaced in time. Metallurgical testwork is then specifically designed to remediate the cause of loss while targeting a particular carrier of unfloated gold. To illustrate the approach, two examples are presented, the first from Los Pelambres in Chile and the second from El Bajo de Alumbrera in Argentina.

GOLD DEPORTMENT AND OPTIMIZATION AT LOS PELAMBRES

The concentrator at Los Pelambres processes a porphyry copper ore assaying 1.0% Cu, 0.02% Mo with 0.03–0.05 g/t Au, using a standard Cu-Mo flotation circuit[1] at a rate of 120,000 tpd. The plant is currently undergoing an expansion to mill 180,000 tpd. Copper recoveries are in the 92–94% range, with a final concen-

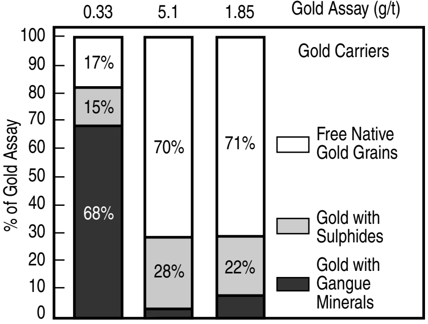

Figure 3. The averaged deportment of unfloated gold in rougher (RT), cleaner (CT), and cleaner scavenger tails (CST) of Alumbrera.

Table I. Gold Recovery from Tails of Los Pelambres

Feed	Feed Au (g/t)	Tails Au (g/t)	Mass Pull (%)	Refloat Ro. (g/t)*	Au Recovery (%)
RT**	0.013	0.009	1.3	0.28	29.3
First CST***	0.031	0.018	3.9	0.35	45.3

* Conc. Grade
** Rougher Tails
***Cleaner Scavenger Tails

trate grade of 38% Cu. Gold is an entirely different case, given that with such low head grades, it is a real challenge to monitor and optimize, let alone maintain the gold grade of the copper concentrate consignments above the 1 g/t threshold set for gold credits. Therefore, a program was initiated to establish the deportment of unfloated gold in order to identify the potential and means for improving gold recovery.

Composite samples of the rougher and first cleaner scavenger tails and the combined Cu-Mo concentrate collected over a 12 hour period were studied to establish the deportment of unfloated and recovered gold. The gold grade of the samples was determined based on quadruple one-assay tonne fire assays with atomic absorption finish at a limit of detection of 0.001 g/t. The gold deportment was established using a comprehensive mineralogical and analytical approach specifically designed for samples assaying less than 0.1 g Au/t. The three gold deportments came to within –3 and +16% of the assayed value (Figure 1).

In the hydrothermal breccia ore, gold occurs in three forms, of which native gold is the most important followed by submicroscopic gold in the crystal structure of the sulfide minerals. Electrum is uncommon. Native gold grains are characterized by their small (median 15 mm), relatively uniform size and their consistently low silver content (10±1 wt.% Ag). As shown in Figure 1, in both tails, free, fully liberated gold grains are the principal carrier of unfloated gold (indicated by the unshaded segment). In the rougher tails, which assayed 0.010 g/t Au, a total of 143 gold grains were observed and sized representing 67% of the rougher tails gold. In the first cleaner scavenger tails (0.021 g/t Au) 282 free gold grains were observed accounting for 75% of the gold losses in this stream. With approximately one half of the unfloated free gold being of floatable size classes, this gold became the prime target for improving recovery. Comparative surface analysis of floated and rejected free gold particles revealed that the surfaces of rejected gold grains had systematically less sulfur and silver while they were enriched in lead and iron oxyhydroxides (Figure 2).

Using this information, a flotation test program was developed to activate gold flotation using NaHS and Ag ions. Thirty to 45% of the unfloated gold could be recovered from the rougher and cleaner scavenger tails, respectively (Table I), without additional grinding into a concentrate assaying 0.3–0.4 g/t Au. NaSH, which provided best results, sulfidized surface lead and silver, thereby facilitating collector loading. Surface lead on the originally rejected gold grains was present as lead carbonate. Following plant trials, overall gold recovery was improved by seven percent.

GOLD DEPORTMENT AND OPTIMIZATION AT EL BAJO DE ALUMBRERA

The concentrator at Alumbrera processes a porphyry copper ore containing an average 0.80% Cu and 1.0 g/t Au using a gravity/flotation circuit at a rate of 80,000 tpd.[2] Chalcopyrite is the principal copper mineral with pyrite averaging about 6%. Chalcocite and covellite are significant in some sectors of the mine. Ore is ground to P_{80} of 150 mm. A nominal 30% of the gold is gravity-recoverable in four Knelson concentrators treating about 15% of the primary cyclone underflow. Gold recovery in the flotation circuit ranges between 65–70% from flotation feeds that assay 0.70–0.75 g/t Au. Hence, overall gold recovery is about 75% (with copper recoveries standing at 90%). Of the unrecovered gold, which constitutes 25% of the mill feed, 4/5 are lost to the rougher tails and 1/5 to the cleaner scavenger tails.

In late 1998, a six week sampling campaign was initiated to acquire a total of six sets of rougher, cleaner, and cleaner scavenger tails, representing three days of low and three days of high tails for a gold deportation study. Low tails assayed 0.16 g/t Au [rougher (RT)] and 0.98 [cleaner scavenger (CST)], with high tails assaying 0.25 g/t RT and 1.48 CST.

The study procedure involved three steps. In the first, the gold occurrence in the RT, cleaner tails (CT), and CST of one set was determined in every detail. In the second, a comparison of gold mineralogical parameters between the tails and the final concentrate revealed pertinent differences. In the third, a comparison with two other sets of tails documented the consistency of the forms, carriers, and causes for gold losses. The following mineralogical parameters of gold were evaluated: grain size, composition and surface modifiers present on free gold grains, associations, grain size distribution of gold associated with pyrite and coarse gangue mineral particles, size-by-size distribution of gold in gangue minerals, and concentration of solid solution gold in the sulfides.

Unfloated gold occurs in three forms: native gold, the most significant; submicroscopic gold, in pyrite and the secondary copper sulfides; and electrum, which is insignificant. The fraction of the tails gold assay accounted for by each of the three carriers of unfloated gold (free gold, pyrite, and gangue mineral particles) is depicted in Figure 3. In the rougher tails, poor liberation from gangue minerals is the principle cause of gold losses, accounting for 68% of the RT assay, with 39% being in the plus 100 μm fraction. Free gold losses representing 17% of the gold lost to the rougher tails are attributed to the same degree to two factors: very small particle sizes (below optimum floatable size classes) and depression induced by surface-bound calcium and hydroxyl ions. The gold deportments of the cleaner and cleaner scavenger tails are remarkably similar (Figure 3), indicative of no preferential recovery (or losses) of any particular gold carrier between these two streams. The principal carrier of gold lost in both streams is free gold grains, which account for 70% of

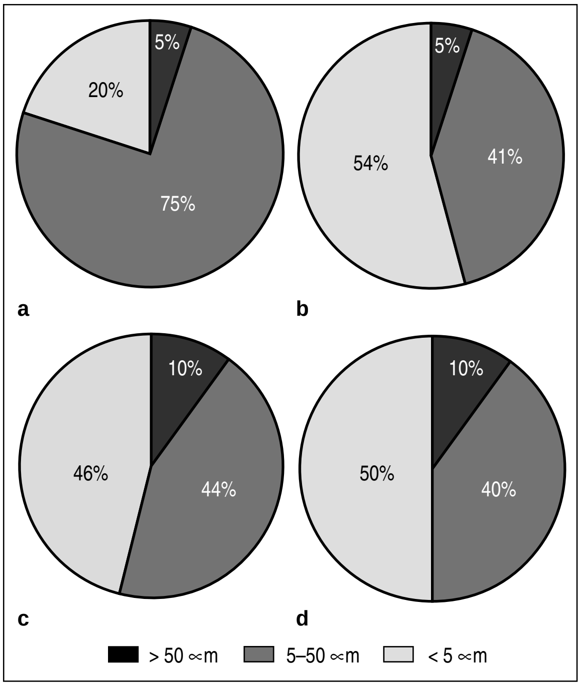

Figure 4. The size distribution of floated and rejected free gold particles at Alumbrera in (a) final concentrate, (b) rougher tails (43 gold grains), (c) first cleaner tails (1,195 gold grains), and (d) cleaner scavenger tails (736 gold grains).

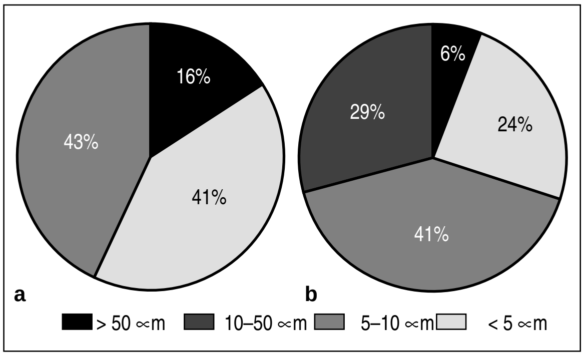

Figure 5. The size distribution of gold associated with (a) pyrite particles and (b) free, in the cleaner scavenger tails of Alumbrera.

the CT/CST gold assays, followed by pyrite (22–28%).

The main cause for free gold rejection in the cleaner scavenger circuit are excessive amounts of depressants coupled with inadequate collector loading and, to a lesser extent, small particle sizes. The greater proportion (~50%) of smaller size gold particles in the CT and CST compared to the final concentrate (20%), as shown in Figure 4, is an unmistakable indication of the preferential loss of smaller gold grains in the cleaner and cleaner/scavenger circuits.

Although the silver content of native gold grains ranging between 5 and 15% Ag has no bearing on their floatability, electrum grains (30–40% Ag) were rejected selectively. Gold in pyrite is present mostly as discrete gold grains, with only 4–9% of the CT/CST gold assay being confined in the crystal structure. Based on the deportments, two opportunities for improving gold recovery by flotation emerge. The most promising option is reduction/better control of the lime addition or use of a lime/soda ash blend, as high pH and surface calcium depress free gold. The alternative is to recover more efficiently the smaller gold grains or to allow more of the pyrite host of these tiny gold grains (Figure 5) to float in the final concentrate. The choice between the last two alternatives depends on the potential to reduce tiny free gold losses in the cleaner and cleaner/scavenger circuits, and the available room for pyrite dilution of the final copper concentrate. An indirect benefit of allowing more pyrite in the final concentrate will be the increase in copper recovery by reducing losses of free chalcocite and covellite.

References

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