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Modern gold deportments and its application to industry

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ABSTRACT

Modern gold deportment studies include physical, chemical and mineralogical assessments, combined to obtain a full understanding of the nature and variability of gold in a resource. The objective is to provide information which will allow cost effective and practical processing by informing decisions regarding resource evaluation, mining method and extraction process optimization.

The distribution of gold, based on speciation, grain size and mode of occurrence (liberation, exposure, and mineral association) is quantitatively determined by means of automated Scanning Electron Microscopic Techniques (QEMSCAN/MLA). Furthermore, general mineralogical characterization is undertaken in order to characterize the gangue components; with special emphasis on deleterious characteristics of the ore (e.g. cyanide consumers such as secondary Cu-species, preg-robbers/borrowers, passivation due to Sb-minerals or As-minerals and oxygen consumers such as pyrrhotite/marcasite).

Predictions based on the mineralogical observations are confirmed by physical and chemical testwork. These include grading analyses, gravity separation, direct cyanidation, and diagnostic (sequential) leach tests.

1. Introduction

The most efficient gold extraction processing route is directly related to the inherent mineralogical features of the gold ore being processed. The mineral assemblage determines the performance of all chemical and physical processes involved in gold extraction (e.g. Chryssoulis and Cabri, 1990; Marsden and House, 1992; Chryssoulis and McMullen, 2005). It is therefore crucial to accurately characterize the mineralogical nature of the ore to be processed; i.e. characterization of the precious metal phases (gold deportment) and gangue minerals. In the past, mineralogical testwork was often time-consuming, relatively expensive and the data obtained was qualitative rather than quantitative. Advances in automated mineralogy, by Scanning Electron Microscopy, revolutionized this field of study as the data became comprehensive and quantitative. Various examples of the use of automated analysis systems for gold deportment studies are found in the literature (e.g. Gottlieb et al., 2000; Butcher et al., 2000; Chryssoulis, 2001; Gu, 2003; Goodall et al., 2005; Goodall, 2008). It is therefore inexcusable for mineralogical factors to be overlooked by project metallurgists, resulting in unnecessary testwork, non-optimum processing flowsheets and decreased profitability.

The main aim of a gold deportment analysis is to locate and describe gold-containing particles in order to determine the gold speciation, grain size and mode of occurrence (gold liberation, exposure, and mineral associations) as well as to generally characterize the mineralogical composition of the ore. Two common problems affecting the results of a gold deportment study are representivity of the samples being analysed and variation in gold grade. Two main factors influence representivity namely (i) biased sample collection and (ii) the "nugget effect" caused by sparse and inconsistently distributed gold grains. Since a gold deportment study is based on a reasonable, but statistical number of observed gold grains (not always possible in very low grade material), the number of polished sections prepared for examination will depend on the grade of the sample. Variation in gold grade may result in difficulty in determining an adequate number of polished sections to prepare for examination. Thus reliable results are achieved by proper sample selection, sufficient sample mass, careful splitting, adequate number of replicate polished sections and proper data validation. The mineralogical data is validated by supporting chemical and metallurgical data (including gold mass-balances).

A wide range of metallurgical techniques are used to test the extractability of gold from gold ore. The most common metallurgical tests employed are direct cyanidation, gravity separation and diagnostic leaching. Diagnostic leaching is a procedure that involves the selective destruction of minerals, followed by a cyanide leach step to recover the newly exposed gold after each destruction stage. Various examples and adaptations of the application of diagnostic cyanide leach tests are found in the literature (e.g. Lorenzen and Tumilty, 1992; Lorenzen, 1995; Marsden and House, 1992; Henley et al., 2001; Goodall et al., 2005; Celep et al., 2009). The results of diagnostic leach tests are sometimes dif-

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ficult to interpret and often misleading, especially if additional mineralogical data is not available.

It is found that a combination of mineralogical and metallurgical tests provides the most cost- and time-efficient means to fully characterise gold-bearing samples. The data is used to predict the behaviour of the ore during processing and to recommend a cost-effective processing route.

This paper describes the methodology employed by the MetMin Section at SGS South Africa. A case study is discussed to demonstrate the applicability of the methodology. Generic reference is made to results obtained from other gold ore projects completed at SGS South Africa, during the last few years. SGS South Africa uses QEMSCAN[1] technology as an electron microscopic mineralogical tool, but an MLA[2] will give similar results. A full review of the QEMSCAN methodology has been provided by Gottlieb et al. (2000).

2. Methodology

Mineralogical characterization and gold deportment studies must be done on representative samples of the different or variable domains or zones within the ore body. The domains within an ore body are normally defined during the earlier stages of exploration. The domains are based on grade, lithology and mineralogical composition, degree of weathering or alteration and spatial distribution. Composite samples of each of the different domains usually comprise drill core, but could also be drill chips, coarse rejects from assayed samples or even bulk rock samples. A composite sample mass of about 10–50 kg is used for a full gold deportment study.

A full gold deportment study includes:

(a) Crushing and milling to achieve the required particle size distribution.
(b) Head chemical analysis and gold assays.
(c) Modal mineralogy.
(d) Grading analysis.
(e) Heavy liquid separation analysis.
(f) Gravity separation analysis.
(g) Gold deportment of particulate gold in the head sample and/or gravity concentrate and/or heavy liquid separation (HLS) sinks fraction.
(h) Direct cyanidation of the head sample.
(i) Diagnostic leach analysis of the head sample and/or gravity tailings.

Gold deportment testwork options are illustrated in Fig. 1. A full gold deportment study may not always be done on the head material, due to grade, time and cost constraints. A “Modified Gold Deportment” is then performed on a concentrate, where the gold grains are pre-concentrated by gravity separation. This has similarities to the method described by Lastra et al. (2005), where the gold concentrated by hydroseparator is described. The concentrate only represents a certain proportion of the total gold in the sample, and therefore, a diagnostic leach test is done on the gravity tailings in order to obtain a full picture of the gold deportment.

2.1. Crushing and milling

Most gold ores should be milled to at least ~50–80% passing 75 μm for effective gold exposure (Marsden and House, 1992). Therefore, at least 10 kg of each representative composite sample is milled to ~50% passing 75 μm for the initial testwork (grading, heavy liquid separation and/or gravity separation). A split aliquot of ~1 kg is milled to ~80% passing 75 μm for head chemical analyses (including gold assays), mineralogical characterization, gold deportment and cyanidation testwork. If it is known that the ore contains very fine-grained gold, then finer grinding down to ~80% passing 53 μm may be required.

2.2. Head assays and chemistry

Split aliquots of each composite sample (~50% passing 75 μm) are analysed by X-ray Fluorescence (XRF) for major elements, by Leco for total *S* and organic C, and by Inductively Coupled Plasma Spectroscopy (ICP-OES/MS) for specific trace elements (Cu, Ni, Pb, Zn, Sb, Te, Hg, and Bi). The arsenic and silver grades are determined by Atomic Absorption Spectroscopy (AAS). Multiple gold analyses are done by fire assay AAS finish (30 g split aliquots).

2.3. Grading analysis

A split aliquot of ~500 g to ~1 kg of each sample (~50% passing 75 μm) is screened into six size fractions, and each fraction is assayed for its gold and sulphur content. The 212 μm, 106 μm, 75 μm, 53 μm, and 25 μm screens normally give a good indication of the gold-by-size distribution, but different size intervals may be used if very coarse or very fine gold is suspected. The grading analysis gives an indication of the gold grain association with predominantly coarse-grained or fine-grained particles. If a large proportion of the gold reports to the coarse fractions, then there is a strong possibility that the ore contains coarse gold. Some ores display a bi-modal distribution, indicating the possible presence of both fine-grained and coarse-grained gold. In tailings samples, however, grading analyses may sometimes be misleading as gold reporting to the coarse fractions is often fine-grained and locked in coarse gangue particles.

2.4. Heavy liquid separation

Gold may be upgraded by means of heavy liquid separation (HLS). HLS analysis is conducted on a ~500 g to ~1 kg sub-sample (~50% passing 75 μm), deslimed at 25 μm, using TBE @ 2.96 SG. The distributions of gold and sulphur across the slimes-, floats- and sinks fractions are determined. The result of the HLS gives an indication of the amenability of the ore to gravity recovery. However, since the sample must be deslimed for HLS to be effective, a certain proportion of the gold that would be amenable to gravity separation (grains >10 μm in size) might report to the slimes fraction and not to the HLS sinks.

Gold reporting to the floats fraction is usually fine-grained and associated with light gangue, such as silicates and carbon. Entrainment of liberated gold grains is not uncommon, especially for very fine-grained samples. Gold reporting to the sinks fraction is mostly liberated and larger than 25 μm in size or associated with heavy gangue minerals like oxides and sulphides, larger then 25 μm in size.

2.5. Gravity concentration

In order to achieve a mass pull of ~2.5–3%, two split aliquots of ~4 kg from each composite sample (~50% passing 75 μm) are processed by means of Falcon or Knelson concentrator to produce two gravity concentrates and gravity tails. The two gravity concentrates are combined as are the two tails. The gravity tails are assayed for their gold content and the gold distribution is calculated. Polished sections are prepared from the gravity concentrate and these sections are examined by means of optical microscopy and electron microscopy in order to establish the gold deportment of the particulate gold reporting to the concentrate fraction. Gold recoveries

[1] Quantitative evaluation of minerals by scanning electron microscopy.
[2] Mineral liberation analyzer.