**Introduction**

Gold losses during mineral processing can be assigned to a variety of mineralogical, textural and processing controls. Variation in the gold mineralogy, association, textural setting, grain size, gangue mineralogy, and also the mineralogical reactions that occur during processing, can all impact recoverability.

Characterization of such features is of increased importance for ore types that contain refractory gold. Gold can be largely split into two distinct types; “refractory” and “free milling.” The description “Free Milling” is generally used where cyanidation can be employed to extract >90% of the contained gold, whereas “refractory” is used when gold is more difficult to extract through conventional cyanidation. In addition, deposits can exhibit a more complex gold population exhibiting a spectrum of refractoriness.

A short summary table below outlines the key causes of refractoriness in gold ores (Goodall and Scales, 2007).

<table>
<thead>
<tr>
<th>Cause</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold Mineralogy</td>
<td>Change in mineralogy/gold mineral composition. Typical examples include gold being present as an alloy (i.e., telluride).</td>
</tr>
<tr>
<td>Grain Size</td>
<td>Variation in the grain size: to produce liberated or sufficiently exposed gold grains the required grain size must be adjusted</td>
</tr>
<tr>
<td>Host Mineralogy</td>
<td>Mineralogical variation of the gangue can cause a change in the textural setting of the gold in the deposit.</td>
</tr>
<tr>
<td>Passivation</td>
<td>Insoluble coatings can form over the surface of the gold grains. These coatings inhibit cyanidation and reduce recovery. Carbonates, sulfides, and oxides can have this effect.</td>
</tr>
<tr>
<td>Decomposition</td>
<td>Increased reagent consumption, as achieved through reactions with copper, zinc, lead, antimony, and arsenic-bearing minerals leading to a decrease in cyanide leaching efficiency.</td>
</tr>
<tr>
<td>Preg-robbing</td>
<td>A process for removal of the aurocyanide complex from solution – usually by carbonaceous material.</td>
</tr>
</tbody>
</table>

*Table 1 Summary table of the causes of refractoriness in gold ores (Goodall and Scales, 2007).*
Gold deposits are often variable in terms of their gold mineralogy, textural complexity, and gangue mineralogy. To maintain a successful and consistent operation, data on the mineralogy is required to understanding the likely processing response of the variable ore types.

In many ways, the mineralogy characteristics, rather than the assay, is the key analysis parameter to understand as this dictates the overall recovery. Examples such as the increased content of carbonates or carbonaceous material can all have detrimental effects to gold recovery and increase operational costs. In addition, changes in gold mineralogy, gold grain size and gold host mineralogy can all mean that gold is lost to tailings.

Failure to understand these mineralogical-driven variables can reduce gold recovery, increase recovery costs, and reduce the profitability of the operation. To combat these adverse outcomes, ZEISS offers:

- Automated Quantitative Mineralogy (AQM) with Mineralogic Mining
- ZEISS MinSCAN for mine site automated quantitative mineralogy deployment
- Xradia Versa for detailed 3D tomographic analysis.

All of these tools can be used to acquire much-needed data that increases understanding of the deposit, supports correct management, and optimizes the operation.

### Key Solutions in Gold Extractive Metallurgy – Lab-Based ZEISS Mineralogic Mining for Geometallurgy and Troubleshooting

As a precursor to the design of any processing plant, conducting thorough geometallurgical studies are advisable as a means to understand the mineralogy of the ore and its subsequent responses during mineral processing. Such studies require the collection of samples and automated mineralogy analysis to provide mineralogy data. Combining the mineralogy data with processing performance data creates distinct geometallurgical domains.

ZEISS Mineralogic software provides key mineralogy and textural data to improve ore deposit knowledge, as described in Table 2:

<table>
<thead>
<tr>
<th>Data Output</th>
<th>Summary</th>
<th>Data Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modal Mineralogy</td>
<td>Provides a quantitative summary of the mineralogy contained in the sample (i.e., % content of minerals in sample)</td>
<td>Understanding the different geometallurgical packages and the variation in the mineralogy can impact operational performance. The identification of these variations in the mineralogy, such as the amount of carbonate content, variation in gold mineralogy species, or the appearance of elevated levels of carbonaceous material allows for predictive operational management by the creation of specific geometallurgical domains.</td>
</tr>
<tr>
<td>Quantitative Composition</td>
<td>Provides the chemical composition of the minerals identified</td>
<td>This data output is important for refractory ores whereby the gold may be contained in solution in other minerals (i.e., pyrite). Having a unique and thoroughly quantitative elemental analysis provides a valuable insight into gold distribution. This is also critical data for identifying deleterious elements such as Sb, Zn, Pb, As, etc.</td>
</tr>
<tr>
<td>Morphochemical Analysis</td>
<td>Provides a combination of mineral composition with textural analysis</td>
<td>Mineral composition alone may not be enough. The combination of a chemical composition with a textural signature can provide valuable information to understand recovery performance that might be controlled by the texture of the minerals. This understanding can be critical for quantifying gold mineralogy contained in fine/two-elongate grains that are difficult to liberate.</td>
</tr>
<tr>
<td>Lithology</td>
<td>Provides an understanding of the particle types in the sample, i.e. 90% of the gold found is located in quartz</td>
<td>Lithology provides a particle-based classification to understand particle types and enhance further understanding of subsequent geometallurgical responses. If 90% of the gold is &lt;5 microns in size and always contained in quartz, this can be valuable data to look at for more advanced grinding to liberate the gold.</td>
</tr>
<tr>
<td>Assay &amp; Distribution</td>
<td>Provides a measured assay on the sample and also a distribution of target elements</td>
<td>The gold assay is valuable data. However, conventional assay methods do not provide an understanding of the distribution of the gold within the minerals. This data output allows you to understand the mineralogical location of the gold to improve recovery. This can also be valuable data for identifying and locating deleterious elements in the samples.</td>
</tr>
<tr>
<td>Liberation</td>
<td>Provides a liberation output to understand how well exposed target minerals</td>
<td>Cumulative liberation curves provide a valuable understanding of the liberated nature of the milled ore. A high degree of liberation is most beneficial for the floatation response of the highest-grade concentrates. If the grain size, mineralogy, or mineral associations change, this can impact the liberation of the target minerals.</td>
</tr>
<tr>
<td>Partial Particle Perimeter</td>
<td>Free exposure of the perimeter of the mineral grains of interest</td>
<td>This data is applicable for leaching applications and cyanide consumers. If particular samples contain a high exposure of carbonate material, you can expect higher cyanide consumption.</td>
</tr>
<tr>
<td>Contact &amp; Locking Association</td>
<td>Data to understand the mineralogical contact and locking associations</td>
<td>Associations can provide valuable data into understanding the complex relationships of the target minerals with other gangue phases. If the gold has a high association with chlorites and clays, this could be a textural relationship that will lead to slow floatation performance.</td>
</tr>
</tbody>
</table>

Table 2 Summary table describing the types of the data output and example application value of this data.
Sampling the ore deposits can be undertaken using the lab-based ZEISS Mineralogic Mining system. A Scanning Electron Microscope (SEM) equipped with multiple Energy-Dispersive Spectrometers (EDX) is used in concert with the Mineralogic Mining software plug-in to collect and analyze the relevant data.

These studies provide a good initial understanding of the ore deposits and can be useful as a troubleshooting instrument in a central lab facility. This allows for a highly detailed troubleshooting study to be undertaken to investigate the mineralogical and textural drivers of any issues that may arise during processing (such as higher than expected losses to tailings).

However, issues remain around:

- The delay in getting results back to the mine site.
- Plant performance troubleshooting being reactive and based on “bad days” or “bad ore” response.
- Due to the reactive response, there is a missed opportunity to improve operational management and improve plant recovery performance, resulting in increased OPEX and reduced profits.

To circumvent these issues, on-site instruments using the mine-site deployable MinSCAN can provide a cost effective means of delivering a routine and proactive approach to plant performance to produce a more profitable and consistent operation.

**MinSCAN for Mine Site Operational Management**

ZEISS MinSCAN is a deployable and ruggedized SEM that is able to tolerate the tough conditions of the mine site and can be commissioned on-site to provide a routine analysis of the mineralogy that is passing through the plant.

By having daily or weekly sampling and analysis on-site, a higher resolution and more complete understanding of the mineralogy and metallurgical can be gleaned. Such sampling and the data-intensive nature of ZEISS MinSCAN means a highly detailed mineralogy and metallurgical response can be developed and used to drive continuous improvement and improve recovery and profitability.

ZEISS MinSCAN, launched in 2014, is a deployable and ruggedized SEM that is engineered to tolerate harsh conditions. It can be commissioned, on-site, to provide routine analysis of the mineralogy of the ore that is passing through the plant. Having daily or weekly sampling and analysis on-site offers a higher resolution and more complete understanding of the mineralogy. This highly detailed mineralogy can be gleaned to improve ore deposit knowledge and refine the geometallurgical model. The frequent sampling and data-intensive insights into the metallurgical response can, in turn, be used to drive continuous improvement and improve both recovery and profitability.

The example in Figure 1b outlines how, over time, the liberation profiles of the gold and electrum change. Figure 1B portrays gold deportment changes during a 3-week analysis cycle. It is impossible to capture such variation without deploying a mine site solution due to the long feedback times when utilizing offsite centralized or service laboratories.

Deploying an on-site mineralogical analysis system provides the plant with a means of performing predictive optimization and improving operational management.

Additional benefits include:

- Rapid time-to-results for efficient and effective responses to challenging mineralogy.
- Routine sampling and analysis helps provide a highly detailed understanding of the mineralogy. More importantly, insight into the metallurgical responses to the variable mineralogy enabled by this data drive can lead to much more proactive operational management capability.

Having an on-site system is highly advantageous and is a proven solution to improve processing performance. To further improve ore body knowledge the deployment of additional analytical equipment can help deliver even more value to the mine site.

Figure 1 Ruggedized ZEISS MinSCAN. A) Cumulative liberation data to understand gold liberation over a period of time; B) Gold distribution data to understand the location across mineralogy.
XRM for Trace Mineral Analysis

Additional analytical techniques can be further deployed to streamline the process of generating the data that can be used to improve recovery in gold circuits. Perhaps the most crucial analysis is to understand the losses to the tailings. The information on these losses can then be used to rectify the issues occurring in the plant and thereby improve recovery.

While this kind of analysis is possible with automated mineralogy, it requires preparing a large number of samples, at regular intervals. These samples often need lengthy analyses and high resolution to locate the fine gold particles. The above-described issues with sampling and representivity are compounded further when the gold mineralogy becomes coarser and more “nuggety” in its texture. This results in the gold grains becoming more elusive within the 2D samples and more challenging to intersect in a 2D surface of the resin-mounted samples.

3D volumetric analysis is statistically more viable, representative, efficient, and cost-effective in data acquisition. As such, it is therefore a more time-efficient and effective way to understand gold losses to tailings.

Figure 2 displays an example of the data output available from the XRM. This data can also be extended to supply modal mineralogy, liberation, and perimeter exposure to provide additional valuable insights into understanding tailings losses.

Summary

A thorough understanding of the mineralogy needs to be generated and matched with vetted metallurgical test work to ensure the most efficient and optimum recovery of gold. While this effort might be made initially as part of a geometallurgical program, it seldom has the correct sampling resolution to be able to fully understand daily (or even weekly) operational performance across the ore body. When issues in recovery do arise, typically samples are sent to external labs for troubleshooting studies. Relying on analysis from external labs represents a missed opportunity to improve recovery. Due to the constant ore variation, the lab-based analysis represents only a snapshot in time -- the time taken to produce the results means the issues have likely passed.

The deployment of the ZEISS MinSCAN system on-site, at the mine, offers a continuous mineralogy analysis tool that can be used to provide routine mineralogy assessment as well as contribute to better operational management.

In addition, recent developments in X-ray technology with the XRM mean that a high-throughput volumetric analysis solution is available to provide a fast and effective means to understand gold losses to tailings.

The ZEISS Microscopy Solutions for Gold ore analysis, therefore, represent a comprehensive solution that can help:

- Increase project value and operational effectiveness through the generation of mineralogical data to develop robust geometallurgical domains and improve ore deposit knowledge.
- Develop a more proactive operation based on routine, on-site mineralogy analysis in support of a continuous improvement framework that leads to improved operational performance and gold recovery.
- Deliver rapid 3D tailings analysis for improved understanding of losses to tailings.