CHRYSOS CORPORATION
Assays at the speed of light

TECHNICAL WHITE PAPER

Validation of PhotonAssay™ precision and accuracy for gold analysis

Summary

Precision and accuracy are important parameters for any analysis technology. Precision refers to the repeatability of the measurement process – a precise analysis will consistently give the same result when tested on the same material. The term accuracy is used to refer to the deviation between the reported grade and the true value. An accurate analysis method is necessarily precise, but the reverse does not have to be true: a method may report consistent values (high precision), but the results may be incorrect.

This paper describes performance validation tests carried out using a prototype PhotonAssay™ facility on a large suite of experimental test samples.

Methodology

Tests were conducted on approximately 130 separate samples, comprising:

- A wide range of materials sourced from around Australia and prepared for us by a company that specialises in the manufacture of fire-assay standards. These samples included a wide range of matrices, including silicate ores, copper-gold ores and concentrates, and various polymetallic ores
- Commercially purchased fire-assay standards, comprising finely pulverised and homogenised materials with gold contents in the range 0-35 parts-per-million (ppm), generally certified with an accuracy of better than 1%. These samples include materials with both oxide and sulphide matrices.
- A variety of gold-bearing copper concentrates from various Australian mining operations. These materials, which are produced during the initial stages of refining copper and gold from ore, contain very high levels of copper minerals (approximately 90% chalcopyrite, $CuFeS_2$) and gold levels of several tens of ppm.
- Dried carbon pulp samples, produced during leaching of gold from ore. These contain gold levels up to several thousand ppm.

Sample materials were finely ground and dried and packed into standard 300 mL sample jars. Sample weights varied from about 200 g (carbon pulps) to over 600 g (copper concentrates).

All samples were individually analysed using a prototype PhotonAssay™ facility. The analysis involves alternately activating the sample using a high-power X-ray source and measuring the signal from excited gold atoms. Our patented external reference correction method is used to increase measurement precision.

Gold measurement precision and detection limits

Measurement repeatability is dominated by the statistical fitting error of the gold signal determination. This error can be calculated straightforwardly for an individual sample during the data analysis process, and provides an immediate indication of the uncertainty of the gold concentration determination.

Figure 1 plots the statistical measurement errors as a function of gold grade for all samples with grades up to 200 ppm; the y-axis indicates both absolute errors in ppm (downwards pointing arrows) or relative fractional errors (upwards pointing arrows) on the same scale. The inferred 3-sigma detection limit is 60-75 ppb.

The measurement sensitivity at very low concentrations is dominated by background, arising from activation of other naturally occurring elements, notably uranium and thorium. The majority of our test samples contain low levels of these elements. Elevated concentrations can be expected to reduce measurement precision. For example, we estimate that uranium and thorium present at levels 50 times that of gold would double the repeatability errors shown in figure 1.

Planned design improvement for the PhotonAssay™ Max, Mine and Mobile platforms are expected to improve both the detection limit and measurement precision approximately 2-fold over the results shown in figure 1.

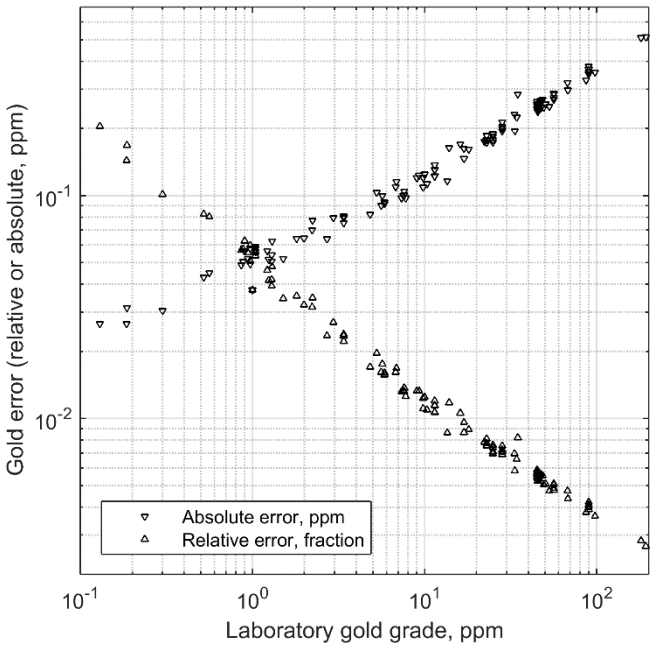

Fig 1. Gold measurement precision using PhotonAssay™.

Gold Analysis Accuracy

Figure 2 compares the PhotonAssay™ and laboratory analysis results. The left-hand plot shows results for low-grade samples (those below 3 ppm gold content) on a linear scale; the right-hand plot shows results for all samples on a log-log scale, running from 0.1 to several thousand ppm.

The different symbols in figure 2 denote different sample types: gold standards, prepared for us by a commercial standard laboratory; gold-copper concentrates from an Australian mining company; commercial reference materials, used to establish the PhotonAssay™ calibration; and carbon pulp samples. The intrinsic insensitivity of the PhotonAssay™ method to the physical and chemical form of the samples means that a single-parameter calibration can be used for all test materials.

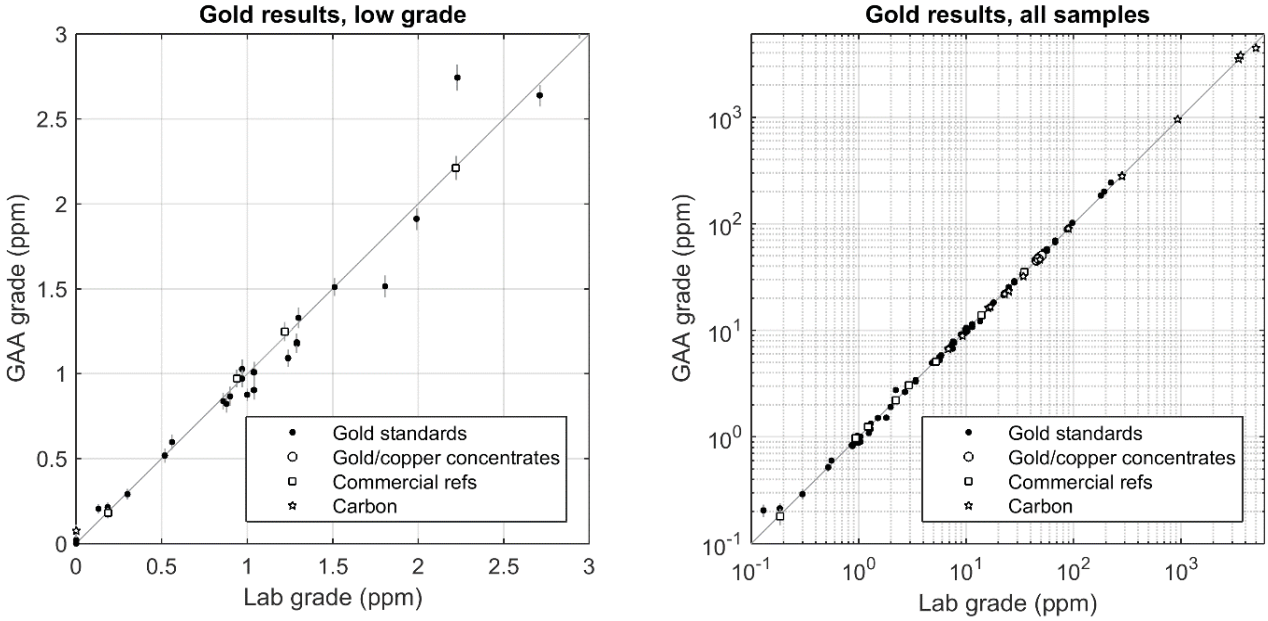

Figure 2. Comparison of PhotonAssay™-inferred gold grade and laboratory grade for all samples. One standard- deviation statistical errors on the PhotonAssay™ grade are indicated.

For lower-grade samples with gold contents below 3 ppm, measurement errors are dominated by statistical uncertainty; these range from about 2.5% relative at 3 ppm to 10% relative at 0.3 ppm (see figure 1). All errors are quoted at one standard deviation.

At higher grades, the contribution of systematic error components becomes increasingly important. Table 1 summarises analysis performance for the different sample suites for materials containing more than 3 ppm of gold; here accuracy is defined in terms of the difference between the PhotonAssay™-inferred gold content and that reported by the samples' manufacturer. As such, our reported accuracy numbers also include an error component arising from the uncertainty on the true gold content.

Table 1. Accuracy of PhotonAssay™ method for various sample groups, including and excluding outliers.

Group	**Number of Samples**	**Relative accuracy (%) of all samples**	**Number of outliers**	**Relative accuracy (%) excl. outliers**	**Average statistical error (%)**
Gold standards	74	3.2	10	1.9	1.1
Au/Cu concentrate	10	0.6	0	0.6	0.5
Commercial refs	3	2.5	0	2.5	1.4
Carbon	6	5.5	1	2.6	0.4
Total	93	3.4	11	2.1	0.9

Although the agreement for most samples is very good, we observe a number of 'outliers', defined as those samples where the PhotonAssay™ and reported laboratory grades differ by more than 5%. For non-outliers, the root-mean square deviation between PhotonAssay™ and laboratory grades is 2.1% relative, making a 5% cut-off equivalent to about 2.5 standard-deviations; less than one sample in the full set of 93 should show such a large discrepancy if the PhotonAssay™ and laboratory errors were normally distributed.

We have systematically investigated these outlying samples, including conducting repeat measurements, but have been unable to find any obvious flaws in our results or analysis. In terms of sample mass and matrix composition, the samples are entirely typical and similar to other materials in the calibration suite. We note that materials from the gold/copper concentrate and commercial reference suites do not show any outliers. We tentatively assign the error to the reported laboratory gold grades for the outlier samples, and are working with the sample manufacturer to resolve this question.

Summary

Using a prototype PhotonAssay™ system, a 3 standard-deviation detection limit of 60-75 parts-per- billion (ppb) for gold analysis has been demonstrated experimentally. The measurement precision (one standard-deviation) varies from about 10% at 0.3 parts-per-million (ppm) to 2.5% at 3 ppm.

Design improvements are expected to improve both the detection limit and precision by approximately a factor of 2 for the PhotonAssay™ Max, Mine and Mobile units.

Total measurement accuracy is approximately 2.5% relative for samples with a gold concentration of 3 ppm. Accuracy improves to 1-2% at higher concentrations.