ENHANCING GOLD MINE EFFICIENCY AND SAFETY THROUGH THE IMPLEMENTATION OF ONSITE PHOTONASSAY™

Genzhuang Li[1]; Andrea Mclaren[1]; Joel Chuah[1]; Tim Sennett[1]

[1]Chrysos Corporation

Abstract

This presentation highlights the successful transition of Ravenswood Gold Mine from traditional analytical methods, such as fire assay, Pulverize and Leach (PAL) and aqua regia digestion, to the innovative onsite PhotonAssay™ technology. The implementation of PhotonAssay™ has significantly reduced the turnaround time for exploration and production samples while enhancing data accuracy. By deploying this technology onsite, the mine has minimized sample preparation needs, streamlined the measurement process and data QA/QC protocols, and eliminated the use of hazardous chemicals. These improvements have optimized operational performance and enhanced overall safety at the mine site.

INTRODUCTION

Ravenswood Gold Mine

Ravenswood gold mine is the largest gold mining operation in Queensland, Australia. It is privately owned by EMR Capital and Gold Energy and Resources Pte Ltd (GEAR). The mine currently mines Buck Reef West and Sarsfield open pits. The processing plant operates at an approximate throughput of 5 Mtpa, comprising of crushing, two stages of grinding, Carbon-in-pulp (CIP) leaching, electrowinning and smelting to produce the final gold doré product.

Initially, the pulverize and leach (PAL) system was used onsite for gold analysis of mine grade control samples. The PAL system simultaneously pulverizes and leaches a batch of 52 samples (~1kg each) for an hour. The PAL solution is then analyzed for gold using Atomic Absorption Spectroscopy (AAS) while selected leach residues are submitted offsite for fire assay analysis to verify gold recovery. At Ravenswood, the PAL system was capable of processing about 300 samples in a 12-hour period. Additionally, aqua regia digestion with AAS finish was used at the onsite laboratory for metallurgical samples from the process plant. Exploration samples and overflow samples were sent to an external laboratory for fire assay analysis.

One major challenge with fire assay is the slow turnaround time, which had significantly impacted the exploration and grade control drilling efficiency. The accuracy of a standard 30-50 g fire assay is often limited by sampling error for heterogenous ore present at Ravenswood which caused constant reconciliation challenges. The traditional alternatives for more accurate assay such as screen fire assay or fire assay to extinction can be even slower and significantly more expensive. The onsite PAL system was relatively fast; however, the gold results were not accurate due to incomplete gold dissolution by leaching and additional fire assay offsite on selected leaching residues were necessary to verify gold recovery.

In 2022, a PhotonAssay ™ unit was installed onsite, replacing PAL, aqua regia digestion and external fire assay. This has significantly reduced the assay turnaround time, improved data accuracy, reduced costs and improved safety. This paper examines how Ravenswood Gold Mine's implementation of PhotonAssay™ technology has optimized operational performance and marked improved safety.

PhotonAssay™ Technology

The PhotonAssay™ technology, developed by Chrysos Corporation, is an accurate, rapid, and non-destructive gold assay technique (Tickner, Ganly, & O'Dwyer, 2017; Tickner J. , 2021; Tickner, Preston, & Treasure, 2018; Tremblay, Tickner, Treasure, Oteri, & Wheeler, 2019). The technology is based on the principle of gamma activation analysis, using a high-energy X-ray source to excite the nuclei of gold atoms present in a sample, followed by the measurement of characteristic gamma emissions by these atoms. The application of the technology has also been extended for silver and copper analysis.

Figure 1 illustrates the PhotonAssay™ measurement process. The PhotonAssay™ technology does not need complex sample preparation procedures. Samples crushed to 2-3 mm and weighing approximately 500 g, are placed into jars ready for analysis. Pulverization is not required, and solutions and moisture samples can also be easily measured. The PhotonAssay™ operator scans the prepared jars, then weighs the jar and takes the fill reading before placing the jar onto the inlet feed conveyor, this process taking no more than 15 seconds. The remainder of the analysis process is completely automated, and 72 samples can be measured per hour. Assay grade, instrument error, mass, fill volume and flags are all reported to the Laboratory Information Management System (LIMS).

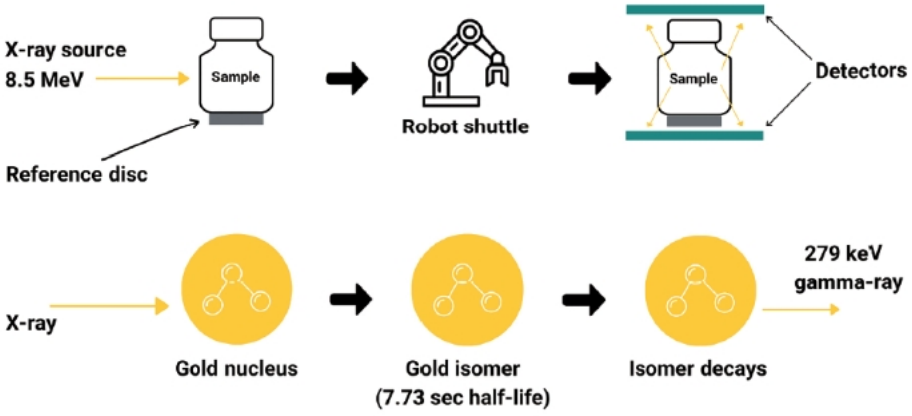

Figure 1. Illustration of PhotonAssay™ Process

The gold measurement performance with PhotonAssay™ is summarized in Table 1, based on extensive testwork with Certified Reference Materials (CRMs) (Chrysos, 2024). Unlike traditional methods such as fire assay and leaching, which are sensitive to different matrix and mineralogy, PhotonAssay™ is agnostic to matrix, mineralogy and particle size. This is due to the very high energy X-rays that activate all gold atoms in the entire sample volume and the subsequent high energy gold gamma rays that are emitted. Compared to standard 30-50 g fire assay, PhotonAssay™ is more accurate for nuggety or coarse gold ores because of smaller sampling error by using larger sample mass (Dominy & Esbensen, 2024).

PhotonAssay™ eliminates the need for dangerous chemical reagents such as cyanide and lead, fluxes, high temperature ovens and lead disposal in destructive processes such as fire assay and PAL. Samples can be stored for future re-assay if required or reused for metallurgical test work.

Table 1. Performance Parameters of PhotonAssay™

Gold Assay Performance	PhotonAssay™*
Lower Detection Limit (2-sigma, 95% confidence)	0.01 g/t (blanks)**
Upper Detection Limit	350 g/t (PAAU02***) 3,500 g/t (PAAU02H***) 10,000 g/t (PAAU02HH***)
Repeatability at 0.35 g/t Au	7%
Repeatability at 1.0 g/t Au	4%
Repeatability at >10g/t Au	< 2%

** For a standard 2-cycle measurement.*
*** Detection limit on clean material & blanks with no presence of U, Th and Ba.*
**** Multiple service options depending on the upper limit of samples' grades.*

RESULTS

Feasibility Studies

In 2021, two feasibility studies with PhotonAssay™ were conducted on Ravenswood samples to evaluate the performance of PhotonAssay™. The first study was managed by Chrysos whereby 30 leach feed and tailings samples were assayed with PhotonAssay™, and the results were compared to an original single fire assay of 50g. The second study was independently managed by Ravenswood, whereby 280 samples, including grade control samples, drill core samples, metallurgical process

samples and blind CRMs, were submitted to MinAnalytical Laboratory (now ALS) in Perth, W.A. and assayed with PhotonAssay™ and duplicate fire assay from the same PhotonAssay™ jars.

For the low-grade tailings samples, a 10-cycle measurement process was adopted for enhanced measurement precision. The comparison of the PhotonAssay™ (PA) and fire assay (FA) results is shown in Figure 2. A R^2 value of 0.922 was observed for PA-FA comparison and no statistically significant bias at a 95% confidence level is observed, with the log-weighted mean ratio of the PhotonAssay™ measurements to fire assay results equal to 1.04 ± 0.05. These results were limited by sampling error, comparing against a single 50g fire assay taken from a split sample and not directly from the PhotonAssay™ jar.

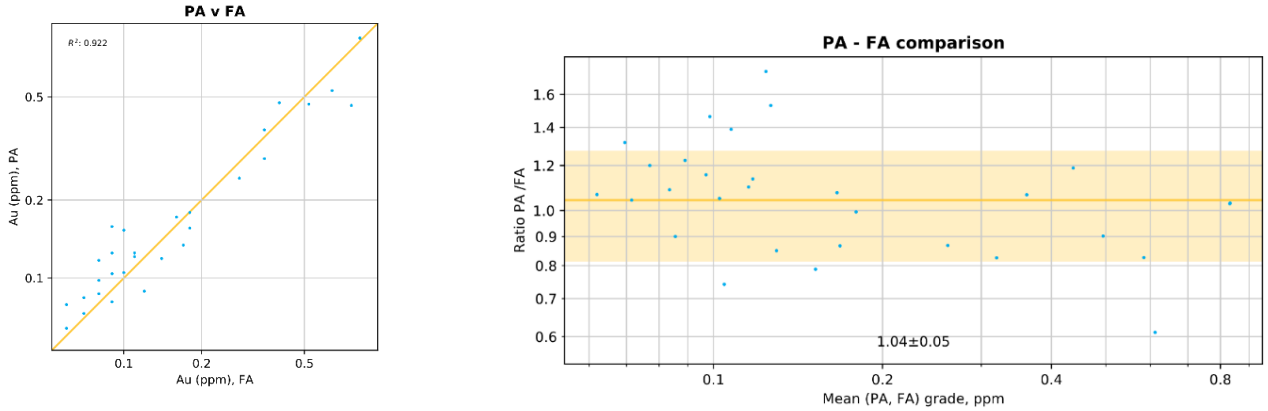

Figure 2. PhotonAssay™ and Fire Assay Comparison for Tailings and Leach Feed Samples

On the 10-cycle service, PhotonAssay™ achieved a 10% precision at 0.1 g/t and 2.8% at 0.5 g/t. In comparison, laboratory fire assay results on the tailings and leach feed samples achieved a precision of 25% (based on historical duplicate fire assay results of such samples by Ravenswood). Precision by 2-cycle PhotonAssay™ measurements was estimated at 20% at 0.1 g/t, still indicating better precision performance over the fire assay.

For the 280 samples of the independent test program, standard 2-cycle PhotonAssay™ measurements were compared to the average of duplicate fire assays, as shown in Figure 3. Over a broad grade range of <0.1 g/t to >10 g/t, a R^2 value of 0.997 was observed for PA-FA comparison. The Tukey ratio plot shows that the log-weighted ratio of the PhotonAssay™ to fire assay grades is 1.02 ± 0.02, indicating no statistically significant bias between the two results.

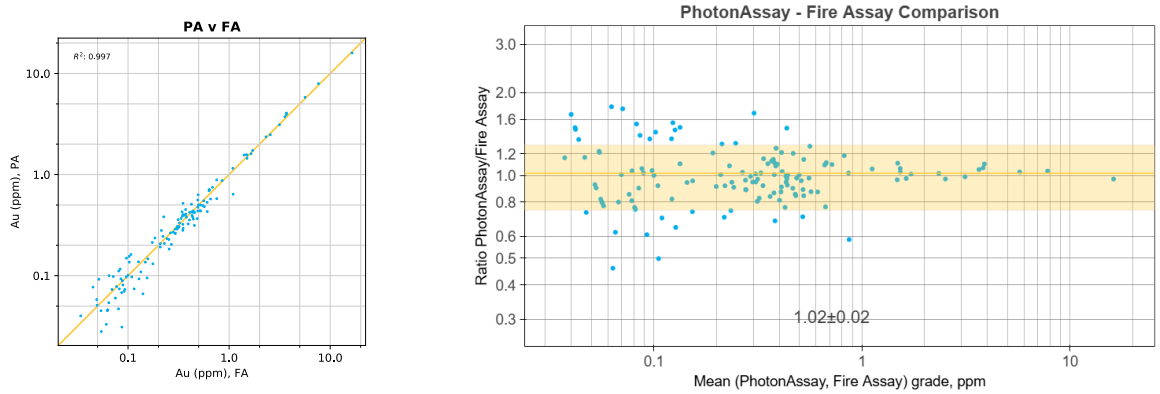

Figure 3. PhotonAssay™ and Fire Assay Comparison for Tested 280 Samples

Table 2 summarizes the comparative precision performance of PhotonAssay™ and fire assay methods across various gold grade ranges. For sample with grades between 0.1 – 1 g/t, PhotonAssay™ achieved a precision of 21.3% while fire assay achieved a precision of 35.7%. Samples above grades of 1.0 g/t, PhotonAssay™ achieved a precision of 4.5% while fire assay achieved a precision of 10.2%. For very

low grades samples (below 0.1 g/t), the precision can be further improved with PhotonAssay™ using the high-precision service, as demonstrated in the first study on tailings samples.

Table 2. Precision Comparison of PhotonAssay™ and Fire Assay for Tested 280 samples

Au grade (g/t)	PhotonAssay™	Fire Assay
0.1-1.0	21.3%	35.7%
>1.0	4.5%	10.2%
Full range	24.6%	34.8%

Deployment and Installation

The Ravenswood team's decision to adopt PhotonAssay™ technology was supported by compelling results from feasibility studies, and the technology's numerous demonstrated benefits. In 2022, a PhotonAssay™ unit was deployed at the Ravenswood laboratory in a separate building next to the sample preparation area (Figure 4). The unit is leased for a 5-year term, with the option to extend the lease. Deployment of the PhotonAssay™ unit was performed by the Chrysos team. Once a unit is installed, Chrysos provides ongoing support with on-site maintenance and 24/7 remote operational assistance.

Figure 4. Lab Location (Left) and The PhotonAssay™ Unit (Right)

The transition was seamless without disrupting the site operations. The PhotonAssay™ unit assays samples for the exploration, resource, grade control and processing operations of the Ravenswood gold mine. With a throughput of about 800 samples per day, it has replaced both the onsite PAL system and the external fire assay lab for routine analysis.

The adoption of PhotonAssay™ technology has significantly enhanced Ravenswood's operations, yielding multiple benefits: the insourcing of the site laboratory, improved quality assurance and control (QA/QC) processes, enhanced data quality, increased operational efficiency throughout the mining value chain, and significantly improved safety which has led to improved Environmental, Social, and Governance (ESG) performance.

Insourcing of Site Laboratory

By replacing PAL and Aqua Regia digestion procedures, Ravenswood improved workflow efficiency. The automation of PhotonAssay™ eliminates steps where human error can occur. Results are transferred directly into a spreadsheet, making the process more streamlined and efficient. The onsite PhotonAssay™ unit also reduces dependency on external service providers, making the lab more responsive to the sites' needs. The insourcing of site laboratory has also been more cost effective, significantly reducing or eliminating logistics expenses and assay fees.

Improved QA/QC Processes

The fire assay process involves numerous sample handling stages, each of which introduces potential points for human error. Consequently, rigorous quality control measures are required including the use of duplicate, blanks and CRMs. PAL, while simpler than fire assay, still requires pulverizing and leaching of the sample, leading to potential contamination and other human errors.

In contrast, PhotonAssay™ requires simplified sample preparation and operates through a non-destructive and highly automated process, eliminating human error and contamination. Crushed geological and grade control samples are split into jars and the process samples are filtered and dried before being loaded into jars for analysis. CRMs are inserted into sample batches systematically, one for every 20 samples and the measurements are monitored automatically in real time; CRM results outside of expected performance are flagged and immediately relayed to the 24/7 Chrysos Physics Support team to investigate. This streamlined QA/QC approach ensures consistent data quality at Ravenswood.

Overall, the geology and metallurgy teams are now confident in the quality of the assay results coming from the laboratory and now direct their efforts to the effective utilization of the assay data.

Enhanced Data Quality

Ravenswood gold ore samples exhibit a nuggety effect, and a key limitation of both fire assay and PAL was the sampling bias and sampling error. Fire assay analyzes only 30-50g sample, which can lead to inaccuracies in assays of nuggety ores. PAL typically assays a 1 kg sample and is effective for cyanide extractable gold but may fail to recover all the gold especially those encapsulated and resistant to dissolution. In contrast, PhotonAssay™ analyzes approximately 500 grams of samples and is matrix-agnostic, ensuring more representative results for nuggety and coarse gold ore samples.

To further reduce sampling errors and enhance representativity for metallurgical accounting process plant samples, the Ravenswood team has increased the sample mass measuring up to 4 jars (i.e. 2 kg) which has decreased the sampling error by a factor of two. With the improved data quality from PhotonAssay™, reconciliation at Ravenswood achieved a variance within +/-5%, marking a significant improvement over results based on PAL and fire assay results.

Improved Drilling Efficiency

Ravenswood Gold Mine has two drilling rigs running 24/7 for near-mine exploration and mine grade control. Before the implementation of PhotonAssay™, the grade control samples were submitted to the onsite PAL assay lab while the exploration samples were contracted out to an external fire assay lab located in Townsville, approximately 130km from the mine site.

For grade control samples, due to the large sample volume and long turnaround time of the PAL assay procedure, a substantial backlog of samples was accumulated in the lab, which significantly affected production timelines. Grade control practices were compromised to keep up with production. To facilitate the assay turnaround, the team had to send segments instead of the entire drill hole to the lab or skip certain holes. The selective sampling led to data loss and inefficiencies in the process, as well as increased double handling efforts.

With the implementation of PhotonAssay™, the turnaround time for grade control samples has been significantly reduced to less than 24 hours. This quick response has allowed the Ravenswood team to adapt their grade control practices dynamically, such as reducing sampling density in well-understood areas and reducing the risk of misclassifying mineralized ores to waste dumps.

For near-mine exploration drilling, the Ravenswood team uses PhotonAssay™ to receive drill results within 24 hours. The rapid turnaround allows the Ravenswood team to evaluate results before a drill hole is completed, enabling real-time adjustments and optimization, such as whether to proceed with the next hole or skip it. This approach enhances drilling efficiency, exploration effectiveness and has resulted in cost savings.

Overall, the reduced turnaround time provided by PhotonAssay™ enables more flexible and informed decisions in grade control and exploration.

Enhanced Metallurgical Process Control

Before implementing PhotonAssay™, Ravenswood Gold Mine relied on the destructive aqua regia digestion method for analysis of process samples. The slow aqua regia digestion procedures delayed decision-making in responding to ore quality changes, impacting the plant's ability to adjust its processing operations effectively.

With the implementation of PhotonAssay™, Ravenswood has gained a rapid, non-destructive and advanced assay method that allows the laboratory team the ability to measure all sample types on site including comminution samples, leach solutions, loaded carbon, leach tailings, etc. The original sample remains intact for verification or additional testing. For loaded carbon samples, PhotonAssay™ offers the added advantage of eliminating the ashing pretreatment step, and thereby significantly streamlining the assay process and accelerating turnaround times. For the low-grade tailings samples, Ravenswood uses the 4-cycle Au service for higher accuracy.

Samples from the process plant are prioritized at the onsite lab, providing assay results in less than 4 hours. This enables the Ravenswood team to make critical decisions based on near real-time information.

PhotonAssay™ will be used in the future to monitor the content of deleterious copper in the leach circuit so that cyanide usage can be optimized to maintain optimal gold recovery.

Enhanced Safety and ESG

The implementation of PhotonAssay™ has significantly improved the safety and ESG performance of the Ravenswood operation. Its ability to measure crushed samples has enabled Ravenswood to streamline their sample preparation process by eliminating the need for pulverizing. This has significantly reduced dust generation associated with the pulverization process.

PhotonAssay™ has removed the need for heavy grinding media used in the PAL process significantly reducing the manual handling requirements for laboratory operators.

Finally, PhotonAssay™ has lowered health risks for lab technicians by eliminating exposure to hazardous chemicals previously necessary for PAL, and the process generates no hazardous waste.

CONCLUSIONS

This paper presents the successful transition of Ravenswood gold mine from traditional analytical methods, such as fire assay, Pulverize and Leach (PAL) and aqua regia digestion, to the innovative onsite PhotonAssay™ technology. Through an accurate, rapid, non-destructive process, significant benefits have been demonstrated across the Ravenswood operation, including insourcing of site laboratory, enhanced QA/QC and improved data quality, improved operational efficiency through mining value chain, and enhanced safety and ESG performance.

REFERENCES

Chrysos. (2024). *Technical Note 001 - PhotonAssay Measurement Performance for Gold on Certified Reference Materials.*

Dominy, S., & Esbensen, K. H. (2024). Application of PhotonAssayTM to Coarse-Gold Mineralisation - The Importance of Rig to Assay Optimisation. *TOS Forum*, 1-30.

Tickner, J. (2021). Commercial Analysis of Gold Ores Via Photonuclear Activation. *IRPS Bulletin*, (pp. 6-12).

Tickner, J., Ganly, B., & O'Dwyer, J. (2017). Improving the Sensitivity and Accuracy of Gamma Activation

Analysis for the Rapid Determination of Gold in Mineral Ores. *Applied Radiation and Isotopes*, 28-36.

Tickner, J., Preston, R., & Treasure, D. (2018). Development and Operation of PhotonAssay System for Rapid Analysis of Gold in Mineral Ore. *ALTA Conference*, (p. 11).

Tremblay, C., Tickner, J., Treasure, D., Oteri, A., & Wheeler, G. (2019). PhotonAssay - Efficient and Bulk Gold Analysis in the Modern World. *International Mining Geology Conference* (pp. 88-98). Perth, Australia: Australian Institute of Mining and Metallurgy.