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Application of Online Magnetic Resonance Technology to Resolve a Mine to Mill Reconciliation Conflict

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ABSTRACT

Candelaria is an operating copper mine in the Atacama region of Chile which has operated for [30] years and produces between 150,000 and 180,000 metal tonnes per annum from approximately 78,000 tonnes of ore per day. Between 2018 and 2021, annual actual metal production showed a persistent negative reconciliation against forecast. Isolating the origin of this anomaly was complicated by the primary crushing feed configuration, where multiple sources of open pit, underground and stockpile feed report continually to a single crusher. While sophisticated real-time grade monitoring instrumentation was already installed in the floatation circuit, the intervening mixing of the crushing and comminution circuit made it impossible to allocate grades to feed sources. Candelaria personnel sought out solutions to measure copper grades on primary crushed material and at sufficiently short time intervals that individual truck-loads of ore could be identified and, through existing fleet management systems, their sources tracked. A real-time analyser for copper grade was installed on the primary crushed conveyor, the source of the anomaly was identified and the error resolved. In the first year of operation, the end-of-year copper reconciliation to forecast improved from -4,1% to -1,8% greatly improving forecast reliability, with 2023 and 2024 measured reconciliation values of -1,8% and 2,1% respectively. Real-time grade monitoring of primary crushed material using MR analyser is now a fundamental data source for the operation of the mine.

INTRODUCTION

Candelaria is an operating copper mine in the Atacama region of Chile, 29 km. south of Copiapó city. Lundin Mining owns 80% of Candelaria while the remaining 20% is owned by Sumitomo. La Candelaria is an iron ore copper gold (IOCG) type orebody with chalcopyrite being the main copper-bearing mineral.

The mining complex has operated for 30 years and produces between 150,000 and 180,000 metal tonnes per annum from approximately 78,000 tonnes of ore per day. The mine possesses several sources of ore, with one open pit mine (Candelaria) and two underground mines (Santos and Alcaparrosa), as well as 5 distinct intermediate feed stockpiles.

Between 2018 and 2021, annual tonnage-weighted grade reconciliations of modelled mining areas showed a persistent negative error, producing less metal despite achieving mined tonnage targets.

Minera Candelaria personnel sought to improve on conventional geological feedback systems and implement a system using modern instrumentation that would allow real-time and precise comparison of extracted grades against resource and grade control models. By doing so, not only could the precise location of grade anomalies be identified, but flagging of the event in real time allows for immediate action to be taken. Whereas options to resolve are all but eliminated if the event is only identified days or weeks afterwards.

The strategic decision to install a magnetic resonance analysis system at the primary crushing discharge enabled, thanks to its speed and accuracy, the determination of sources of deviations and a reduction in variance against forecast of approximately 50%, from -4,1% to -1.8%, or the equivalent of over US$30 million of copper. This document discusses the need for the installed solution, how it has been implemented, the results and its impact.

METHODOLOGY

Candelaria applies a modern adaptive modelling methodology to metal production forecasting, using real time sensing technologies to complement progressive resource model refinement through traditional reconciliation and model iteration. To generate grade forecasts, grade control models and stockpile inventory tracking are combined with production scheduling to provide weekly, monthly and annual metal production forecasts. Grade control models are generated by enriching resource and geological models with grade control drilling and bench sampling assay data. In reconciliation, grade and metal production forecasts are compared against metallurgical accounting to determine variance. Real-time XRF slurry analysers are used to enhance the quality of metallurgical accounting data by providing real-time elemental grades for both lines of flotation feed.

These systems provide a dependable methodology for comparing large-scale aggregated metal production forecasts to actuals. However, without more granular information, and given the degree of variability inherent in both geology and in mining operations, it is challenging to isolate the source of discrepancies between the two in a way that can be dependably used for geological or resource

model updating. Benndorf, et al. (2015) theorize a methodology to enable rapid updating of resource and reserve models using Smart Tags (blasthole-loaded, ruggedized trackers) to link downstream real-time processing information to mining source. This methodology has the benefit of tracking back to the drilling location, but suffers from the practical limitation of number of Smart Tags and representivity of the results.

Candelaria technical personnel sought to resolve these challenges through the use of an automated system installed at the convergence point for all material flows in the mine, immediately downstream from the single primary crusher. The team reviewed and assessed potential installation of process sample cutters, online XRF analysers, and PGNAA analysers before making a determination to install an MR analyser.

Real-time Magnetic Resonance Analyzer ('MRA') Overview

Magnetic resonance is a technology that delivers precise mineralogic concentration measurements in real time for mining applications. NextOre's MRA generates electromagnetic field pulses using an antenna tuned to the resonant frequency of a target mineral. The MRA then listens for a resonant response, and its strength indicates the quantity of mineral present. The radiofrequency signal is fully penetrative and independent of particle size range or ratio within the ore and only constrained by the conveyor size. As a consequence of highly unique, discriminating resonant frequency responses, the signal has high signal-to-noise ratio and therefore provides measurements at intervals of less than 30 seconds, and more typically 4-10 seconds, with each report corresponding to the average copper grade in the 'Pod' of ore analyzed, in the tuned mineral phase, within that time. The system does not require mechanical sampling or any sort of sample preparation. It is also absent of ionizing radiation and requires no special health or safety permissions to deploy (Bennet et al., 2007).

Figure 1 Conceptual operation of the MRA

MRA Installation

The system is installed at Lundin Candelaria at the end of 2022 is commissioned during early 2023. The selected location is the conveyor belt CV-02 located at the discharge of the primary crusher, with a nominal throughput of 6,000 TPH. There are no extensive modifications required to be done in the conveyor, as the sensor can be customised to fit the existing structure. A nearby container acts as both

a control room and housing for the electronics and power delivery system, isolating the critical elements of the solution from the harsh environment.

Given Candelaria's ore characteristics the MRA is built and tuned to resonate with chalcopyrite mineral, with an integration time of 30 seconds which translates to pods of approximately 50 tonnes each, yielding on average between four and five results per truck.

Figure 2 MRA installed con crusher discharge conveyor CV-02

The results can be monitored locally inside the control room and are also sent through site network to the DCS to allow full data integration with other sources such as Grade Control, Fleet Management System ('FMS') and XRF on-line analysis from the milling output.

To enable tracing of material source, grade and tonnage data from 4-5 consecutive MRA 'pods' is aggregated into a truck load and automatically linked to truck movement data from the FMS using timestamps. Truck dumping at the gyratory crusher is restricted to single truck dumping at a time and the methodology assumes "plug flow" of material through the gyratory crusher. [The algorithm assumes that mixing between consecutive truck loads is negligible. / The algorithm assumes some material is mixed from consecutive truck-loads, and discards the [first and last] measurements from each aggregated 'truck'.] These virtual truckloads can then be directly compared directly with grade-control modelling and with downstream slurry analyser data.

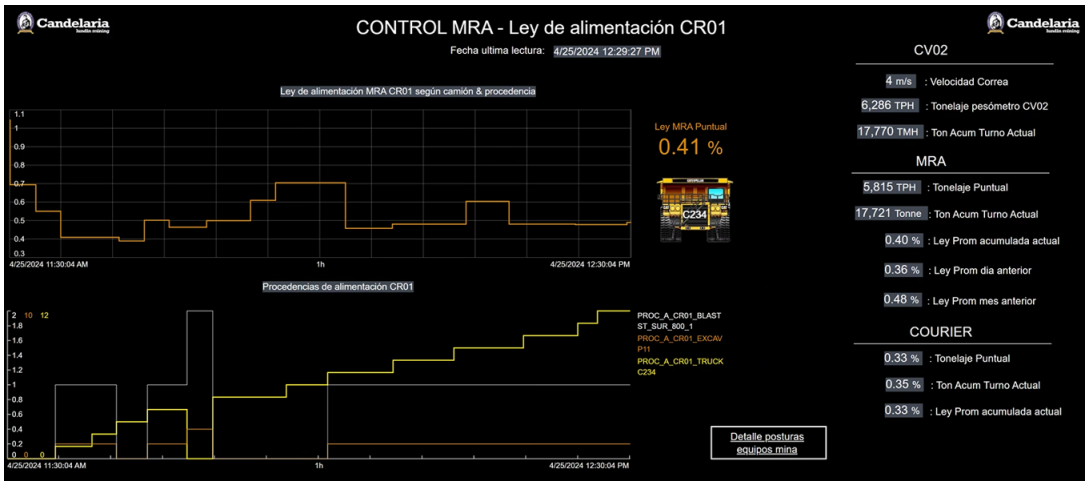

Figure 3 Integration of MRA results with Fleet Management and XRF analyzers

RESULTS AND DISCUSSION

The addition of real-time, high-resolution grade measurements from the MRA to the existing grade control data architecture of the Candelaria mine site enables real-time identification of inconsistencies between geological modelling, stockpile inventories, production schedules and metallurgical accounting. Further, it provides sufficiently granular data to trace the source of the discrepancy and enable more rapid iteration of models. By producing and linking this data in real-time, it allows technical teams to respond and adjust their production plan without waiting hours before an ore lab assay or an on-line XRF measurement from the flotation feed is available.

As an added benefit, it also provides a more accurate way to estimate the potential effects of the stockpile cone in the reconciliation process.

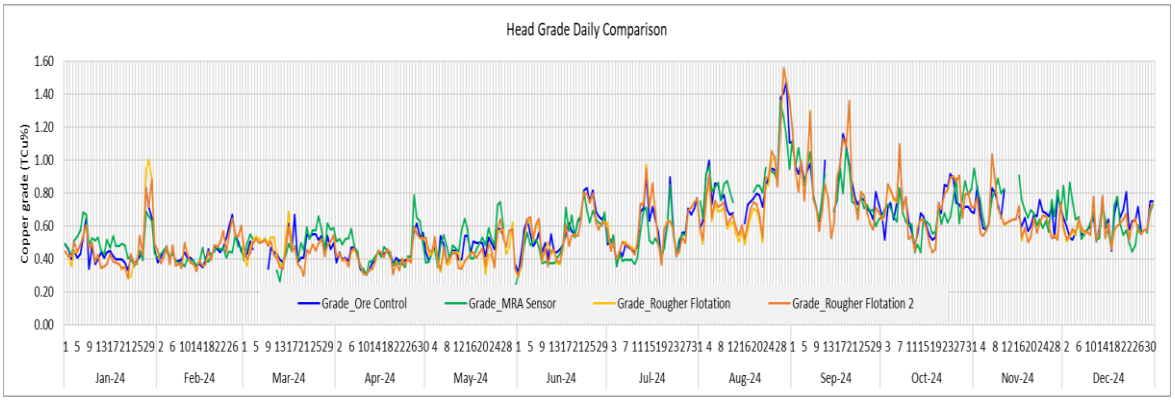

Figure 4 Grade comparison (MRA/Grade Control/Flotation XRF)

The availability of high-quality, integrated and timely data ultimately allowed the Candelaria technical team to reduce the reconciliation and discrepancy error by nearly fifty percent since its adoption.

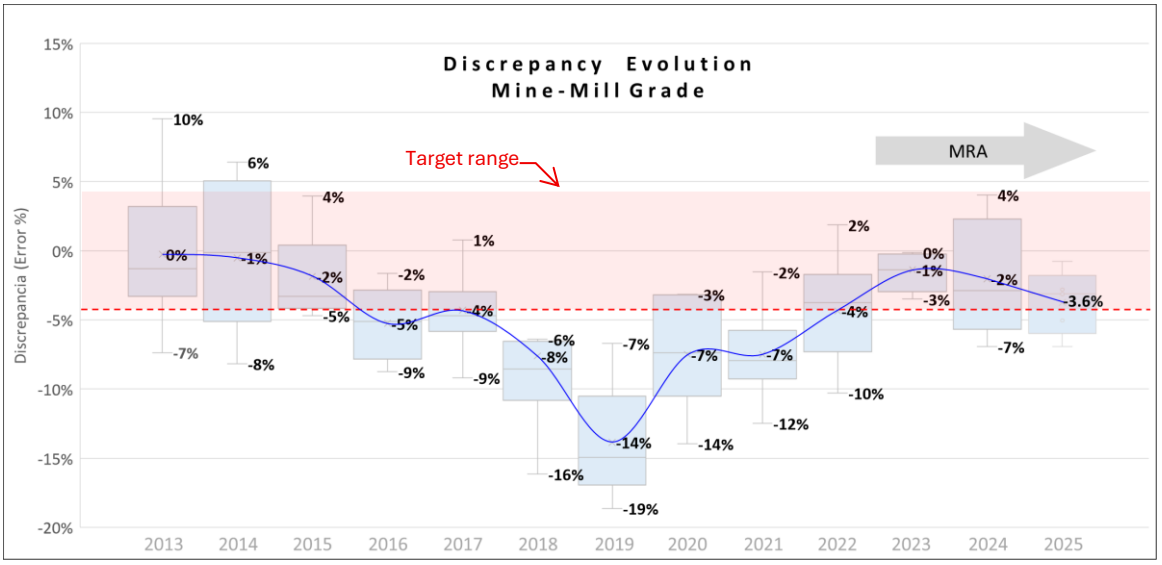

Figure 5. Discrepancy evolution 2013-2025 (actual)

CONCLUSION

The strategic decision to invest in a magnetic resonance analyzer has yielded exceptional benefits to the mining operation at Lundin Candelaria. The data generated from the system has been proven to provide actionable insight to the geological, mining and metallurgical technical teams.

Next steps

Based on successful validation of the NextOre MRA and its reliable use in improving reconciliation performance, as well as observed heterogeneity in feed material, the next logical implementation for the MR technology in Candelaria is to invest in a mobile ore sorting solution for preconcentration, or to recover ore from existing stockpiles.

NOMENCLATURE

DCS	Distributed Control System
MRA	Magnetic Resonance Analyzer
Pod	Arbitrary subdivision of the ore stream for which a grade is reported by the MRA
TPH	Tonnes Per Hour
FMS	Fleet management system
XRF	X-ray fluorescence
PGNAA	Prompt gamma neutron activation analysis

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