Maximising Profits from a Challenging Ore Body: the Optimisation of Ore Control at the Waihi Underground Gold Mine

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Abstract

Ore control processes and reconciliation are critical components of mine production. Striking a balance between obtaining quality ore control data in a timely manner and implementing short-interval controls to deliver accurate reconciliations is crucial to achieve efficient and profitable extraction of economic ore. Ore control processes at Waihi have been refined to become increasingly efficient and effective at delivering economic ore that reconciles within acceptable margins, ensuring smooth mine production with minimal delays.

Development is monitored, mapped, and sampled daily. Faces are channel-sampled and entered into a customised database. Faces are mapped into COREL software on a tablet while at the face. Structural contacts, identified and marked up by the Ore Control Geologists, are surveyed and delivered as string files by the survey department. Combined with traditional paper backs-mapping of all development, the Geologists produce high-resolution digital mapping using Vulcan software. This information is updated and utilised daily to view structural orientations and relationships and inform decisions on ore drive direction. Implicit modelling in Leapfrog software utilises ore control data and oriented diamond drill core to create a detailed geological model. Tetra unfolding in Vulcan and inverse distance grade estimation are used to deal with the complex vein geometries often encountered underground. Finally, a robust mine to mill reconciliation procedure provides a measurement and improves confidence in predictions, reduces risk, and highlights areas for improvement in the design process.

This paper discusses the ore control methodologies used to optimise ore extraction while mining the structurally complex Waihi epithermal vein system.

Keywords: ore control optimisation, reconciliation, modelling, grade estimation

Introduction

Geological Setting

The Hauraki Goldfield comprises approximately fifty epithermal deposits (Braithwaite and McKay 1989) and lies within a NNE-trending Miocene to Pliocene calc-alkaline arc (the Coromandel Volcanic Zone). Gold mineralisation is localised within moderately- to steeply-dipping quartz veining, breccias and vein stock working.

Brief History of Mining in Waihi

Gold was first discovered near Coromandel township in 1852 but economic gold wasn't discovered in the Waihi area until 1878. Mining operations were transferred to the Waihi Gold Mining Co. in 1890 and mining activity continued until the close of the mine in 1952. During this time, ~5.5 Moz Au and 38.4 Moz Ag (McAra 1988) were extracted (~174 tonnes Au and 1,193 tonnes Ag). Operations recommenced in 1988 with the opening of the Martha open pit mine. Underground operations at Favona began in early 2005 and several additional ore bodies have since been identified and mined. More than 3.2 Mozs of gold have been extracted by the combined open pit and underground operations since mining recommenced in 1988.

The Ore Control Process

The ore control process is a critical part of mine production. The process outlined below has been improved through streamlining and automation to ensure that accurate and timely information is supplied to operations and a robust dataset is provided to the Project Geologist for the modelling process with minimal disruption to mining activity.

The ore systems mined at Waihi underground for the past ~11 years have become increasingly complex, with abrupt changes in textures, grade, mineralogy, width, and direction over short distances (sometimes 3-6 metres). This makes the behaviour of an ore body difficult to predict. However, precise, detailed geological mapping and Au-grade information collected on one level can provide crucial insights as to what might be encountered on the level above or below.

The backs geology for each three-metre cut is mapped by the Ore Control Geologist onto a scale paper map pre-printed with surveyed laser points. The geology is later transferred to Vulcan. Approximately every three cuts the backs are washed down and the main vein contacts are painted up. These are picked up by the Survey department and the resulting string files are imported into Vulcan using a lava script (Fig. 1). This allows accurate 3D visualisation of the geology between levels and allows immediate model comparisons.

The Ore Control Geologists sample at least one in three development advances for each ore drive, collecting samples across the width of the face. The samples are assayed for Au and Ag and either a length-weighted or area-weighted average grade is calculated for the face depending on the geology. The face map and data recorded are captured electronically on a tablet whilst at the heading to reduce double-handling of information and thus human error. The measured sample intervals are documented on the face map and assist the Geologist in accurately sketching the geology. The face is routinely photographed, however obtaining a clear photo showing detailed veining in dark and dusty conditions can be problematic. Where the face is considered unsafe to sample, only sketches of the face and backs are completed.

The location of each face is referenced by recording the distance of the left-hand offset (collar) on the face from a surveyed laser point. These collars are plotted in Vulcan with a bearing approximately perpendicular to the direction of the drive, creating a channel which the assays are then loaded to. The face sketches are imported into Vulcan (Fig. 2).

The Face Sampling Database captures the face data underground and contains simple reports that display the data (Fig. 3; Fig. 4). It is linked to the drill hole/assay database acQuire and the Shift Production Database, making daily trucked ore allocation straightforward.

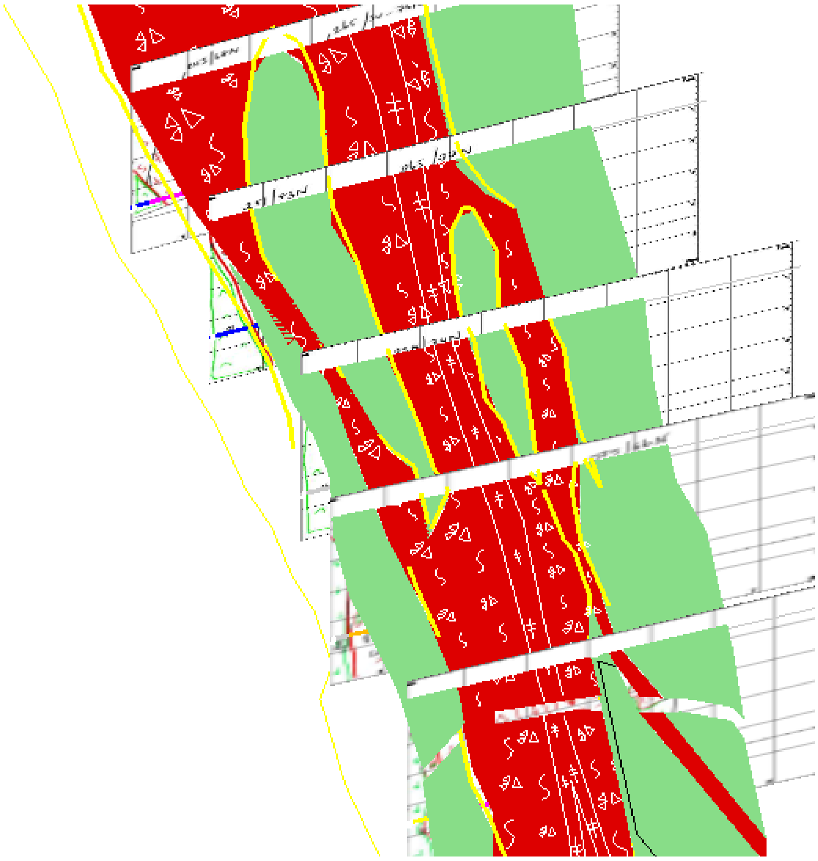


Figure 1. Slight oblique plan view of back-mapping of a level. Green is andesite country rock; red is vein material; bold yellow is a surveyed line of the vein contacts; fine yellow is the floor string of the drive.

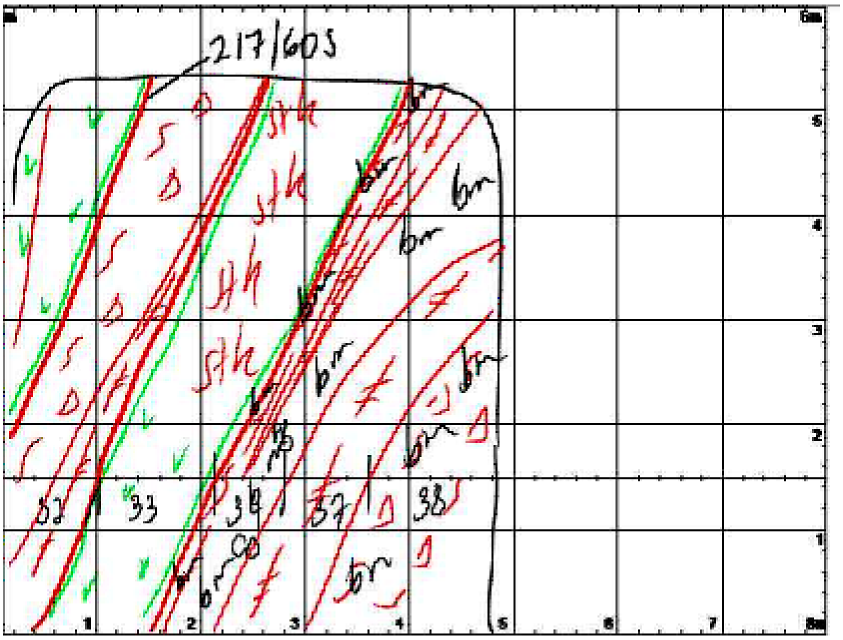
Figure 2. Spatially referenced face sketches and channels showing sample interval grade as colours.

OCEANAGOLD

UNDERGROUND SAMPLING

DATE	19-Jul-17
FACE ID	F20170719-01

LOCATION	786ES		CUT SENT AS				
LASER O/S	3.4	DIST.	24.50	FROM	Laser		
DIMENSIONS	4.7 W x 0 H		MARKUP	0 W x 0 H		PROFILE	Square



Face Bearing 313.1

Sample No.	From	To	Width(m)	Au(g/t)	Au_Cut(g/t)	Lith	Altn	Qtz Txt
FV150432	0.00	0.90	0.90	0.22	0.22	QV		
FV150433	0.90	2.00	1.10	37.40	32.00	ANQS		
FV150434	2.00	2.70	0.70	37.00	32.00	QV		
FV150437	2.70	3.50	0.80	0.34	0.34	QV		
FV150438	3.50	4.70	1.20	2.60	2.60	QV		

Notes:

survey cont

Width(Grade):	4.7(15)
Avg(Grade_Cut):	4.7(13)

Sampled By: LDRA

Shift: D/S

Figure 3. Example of a report from the Face Sampling Database showing all the information captured when sampling a face.

OCG Underground Operations Dump Sampling

11-Jul-17 to Jul-17 4:00:45

Date	Location	Au(gpt)	Au_cut	Min	Max	Count	From	To
11-Jul-17	801CHR	1.9	1.92	0.1	5.5	6	FV150257	FV150262
	Average of Au_Cut		1.92					
11-Jul-17	905HWW	10.9	10.95	4.1	18.1	6	FV150276	FV150281
	Average of Au_Cut		10.95					
Daily Average			6.43					
12-Jul-17	801CHR					6	FV150282	FV150287
	Average of Au_Cut							
Daily Average								

Figure 4. Bulk sample report from the Face Sampling Database showing the average grade and range of grade from a number of bulk samples.

Geological Modelling

The success of the geological modelling process is largely dependent on the accuracy of information derived from the ore control process. Robust models are necessary for accurate mine planning and reconciliation. Veins, faults, and lithological boundaries at Waihi are modelled as wireframes in Leapfrog. Vulcan point-clouds form the basis of these models and are created from oriented drill core, underground backs mapping with survey pick ups of ore positions, channel data and oriented face sketches (Figs. 1-2).

Ore control and drill hole data is validated and errors are corrected prior to point cloud creation. The model intercepts are then selected. These are based on geological interpretations of vein geometries, mineralisation, grade, and structural measurements provided from drill hole data validated by the mapping carried out during the grade control process. Structural measurements from oriented drill core are visualised in Vulcan as coloured discs coded to footwall, hangingwall, or fault contacts and are used as a guide for interpretation of structural trends. Vein footwall and hangingwall points are snapped to drill hole and channel intervals, and control points are used to guide the interpretation in areas of known complexity. Fault surfaces are created from backs mapping information and used to guide vein offset interpretations. Point clouds are imported into Leapfrog and an implicit geological model is generated, honouring vein and fault timing relationships. The process is iterative, with multiple passes and point cloud adjustment required.

Drives are initially planned and designed from the geological model but the inherent complexities of epithermal ore-bodies mean that to scrupulously follow model designs would mean significant opportunity loss in the areas of maximising Au-grades and optimal drive placement for future stoping. The ability to incorporate and visualise the daily information obtained through the grade control process underpins the day-to-day decisions regarding optimal drive positions. Variations from the geological model can be identified and justified by geologists and the implications, either upside or downside, immediately understood and discussed with relevant mine personnel.

The importance of the above towards optimising grade control and ultimately gold production cannot be overstated.

Grade Estimation

The Waihi epithermal vein systems contain complex folded and faulted vein geometries. Grades can be highly variable along strike and dip and are structurally controlled. Several techniques are employed to create a robust estimate including the tetra unfolding feature in Vulcan. This process uses a distorted search ellipse that follows a modelled surface so that the block model and all the samples used for estimation to stay in their true position.

Footwall and hangingwall grade distribution-trends are different and to constrain these the vein zone is divided across-strike at typically half the vein width. This limits grade-distributions to within foot wall and hanging wall trend-envelopes. This is consistent with what is observed during underground ore-control and core-logging.

Grades are typically estimated in two passes with a combined database of channel and drill holes and shorter ranges for the first pass. Longer ranges using drill hole data only are used in the second pass. The estimation method is inverse distance or ordinary kriging, depending on suitability. Variograms are difficult to interpret purely from the data, therefore the geological model is the primary driving factor in determining search ranges and directions. Field duplicate data supports the nugget values used for lodes. The Ordinary Krigged model is compared against the ID^2 model and 12-monthly reconciliation data.

Stope Reconciliation

Reconciliation is essential for measuring, identifying, managing, and mitigating variance between designed and actual results. Stope reconciliation can result in process improvements to minimise ore loss and dilution and validates grade data for modelling. This has a flow-on effect to stope design and hence drilling and firing of a stoping panel. The reconciliation process is in-effect the grade control measurement metric that identifies any grade control or modelling issues.

The process for reconciling a stope panel has been refined over the years and will continue to be improved and streamlined. The Cavity Monitoring System (CMS) surveys of stope voids are imported into Vulcan along with the CMS of the previous panel and panels below (Fig. 5), to ensure that fired material is only accounted for once. A lava script is run in Vulcan using the design shape, CMS solid, and the block model that was used for the stope design, creating a csv file which is uploaded to the Reconciliation Database. This produces a report that defines all the overbreak, underbreak, design and actual tonnes, grade and ounces and reconciled tonnes, grade and ounces (Fig. 6). An avi file is then created and presented twice-weekly to the Technical Services team for a team-based review. Any issues identified can then be promptly addressed.

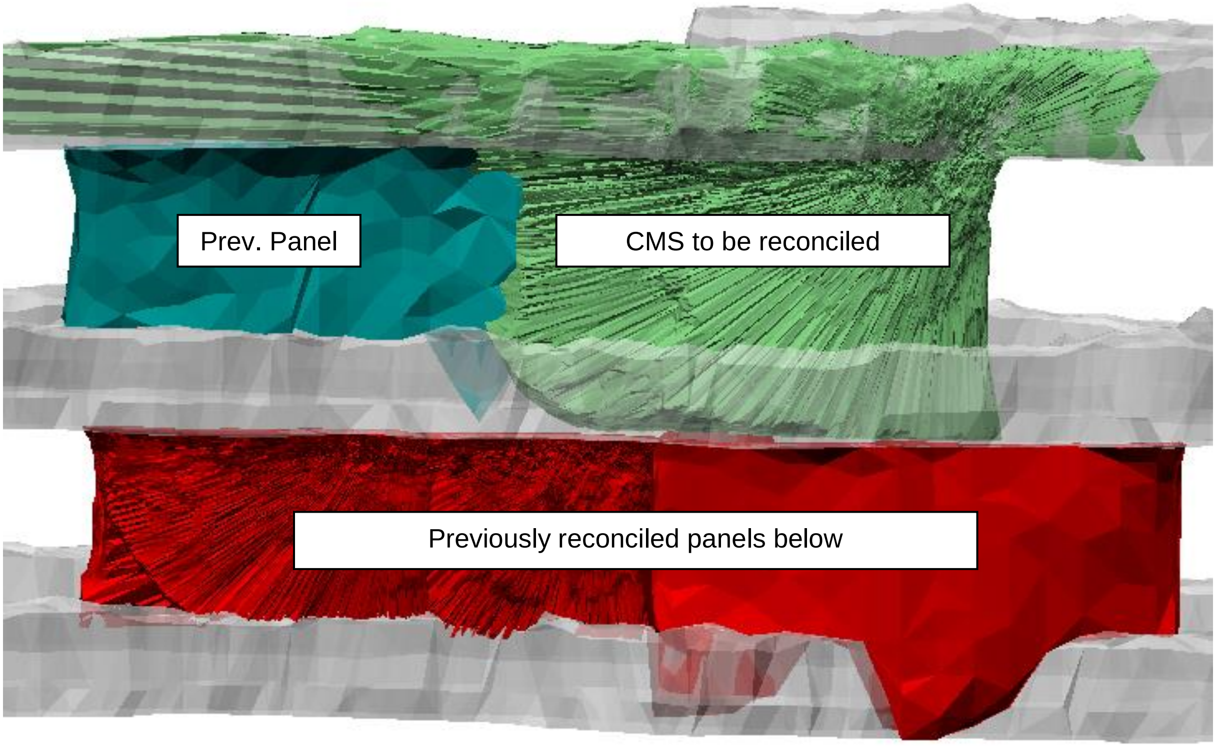


Figure 5. Long section view in Vulcan of a current CMS panel showing the panels below and previous panel.

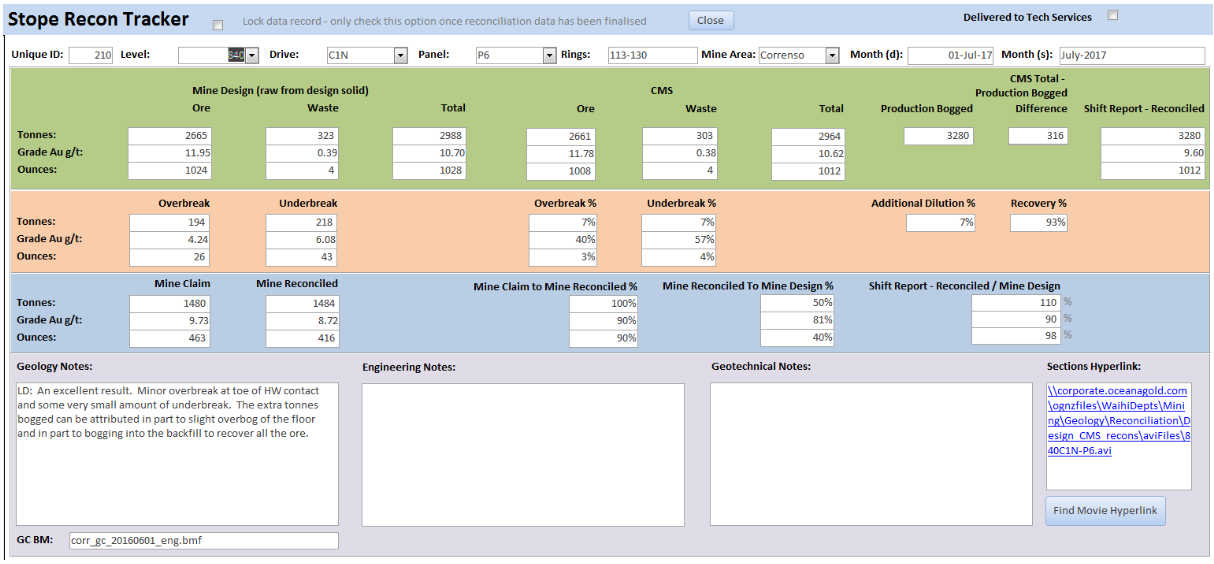


Figure 6. Stope reconciliation report for a panel from the Reconciliation Database

Mine to Mill Reconciliation

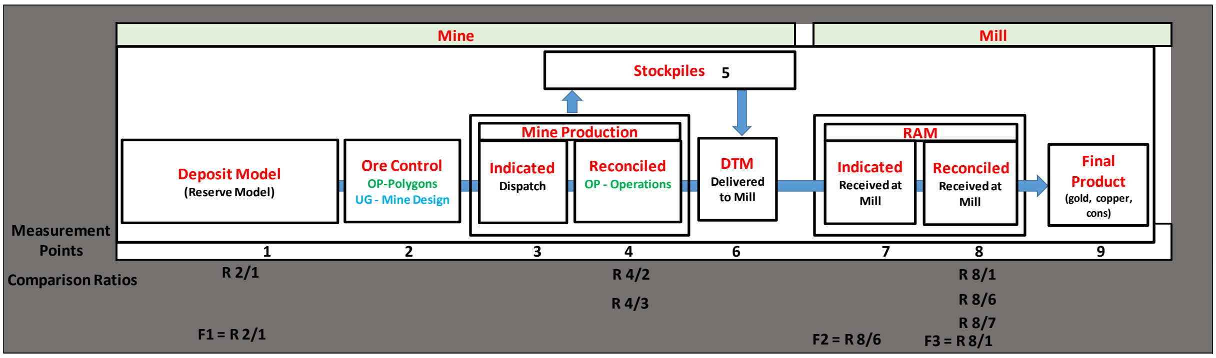
The purpose of reconciliation is to provide reliable information to:

- Maximise return from the mine by helping to reduce planned and unplanned dilution and maximise gold recovery;
- Improve confidence in prediction;
- Reduce risk;
- Highlight areas for improvement in the design process.

The following factors are measured, compared, and reported each month by stope or development location (Fig. 7).

- Comparison of the reserve model to the ore control estimate;
- Comparison of the performance of the processing facility to the mine production;
- Comparison of the process facility production to the reserve model estimates.

Measurement intervals are monthly, 3 monthly and 12 monthly rolling averages. For mine reconciliation, three monthly increments will generally be the minimum period over which meaningful trends can be determined.



Key Measuring Points;		
Reserve Model	1	Reserve Model tonnes and Grade
Ore control	2	Tonnes and Grade from Design and updated Grade control models
Mine Production - Indicated	3	Claimed production based on truck despatch and design grade
Mine Production - Reconciled	4	Reconciled production based on mill tonnes adjusted for stockpile movemnets
Change in Stockpiles	5	Change in Stockpiles, from dispatch material movement, reconciled for change in survey volumes.
Delivered to Mill (DTM)	6	Claimed tonnes adjusted for stockpile movements
Received at Mill (RAM) - Indicated	7	Process Feed based on indicated dry Tonnage (Dry) and indicated Process/Mill Feed Grade
Received at Mill (RAM) - Reconcile	8	Process Feed Tonnage (Dry) and Reconciled Process/Mill Feed Grade. Dry Mill Feed tonnage represents the amount of dry ore entering the primary SAG or Ball Mill(s).
Final product	9	The metal content of the doré bullion or filtered flotation concentrate(s) produced within a defined production period.

Figure 7. Mine to mill reconciliation.

End of month hoist data is exported from the production database, modified for reconciled stope data and a mine claim calculated. Grade control design and reserve data is calculated for all locations mined during the month. Finalised monthly production data, including closing stocks and mill reconciled figures are imported into the reconciliation database. This ensures data is validated, simple to upload and a suite of data analysis tools are available to quickly identify and correct issues or variance.

Reconciliation processes have been established for many years at Waihi, with variation well understood. Monthly meetings occur between mining, metallurgy, and geology to review reconciliation data and create actions to address any issues as and when they occur.

Conclusions

The Waihi gold operation currently has a robust ore-control process in place to optimise ore extraction in a complex and challenging ore body. Daily information collected by the underground geology team becomes quickly available for further analysis. Using tools such as digital data capture and display in databases and Vulcan, and survey pickups improves the accuracy and knowledge of the ore bodies. This quality information and understanding feeds immediately into the geological modelling and grade estimation process to create robust models for mine planning and production. The models are reviewed using virtually real-time data and used in the mine to mill reconciliation process to maximise ore recovery and highlight areas for improvement. In addition, the stope reconciliation process provides information that can be used to mitigate ore loss and dilution in future stopes.

The input of grade control and underground mapping data means continually improving accuracy of the modelling with on-going validation and enables decisions to be made with as much up-to-date information as possible. This gives confidence to the processes and decisions that underpin the entire mining cycle.

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