Technological solutions to remnant mining ore control at the Martha Underground Mine

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ABSTRACT

Several new and emerging technological advances were trialled and implemented at the beginning of the Martha Underground remnant (MUG) mine project, which has been in production for 3 years. This paper presents a review of the effectiveness of these technologies in a remnant mine and an update on future work.

Three-dimensional (3D) scanning utilising photogrammetry has enabled more accurate and detailed geological mapping. This has led to more optimally positioned ore drives, with reduction of operational re-work, increased efficiency, and improved stope reconciliations. In addition, every drive that intersects the vein skin or historical void is 3D scanned, with the data points used to update the vein and historical void models to assist with stoping and defining historical depletion.

Digital mapping has given the geologist a full suite of digital data to base decisions on. The ability to accurately geo-reference and ensure the current and future face positions will be within caution buffers has increased the speed of the drive direction process whilst ensuring that safety protocols in and around historical workings are adhered to.

Continuous improvement of grade control geological modelling and estimation techniques have reduced turnaround times of wireframe and intermediate model updates, including information on historical workings such as size and spatial location. This has enabled the geotechnical and engineering departments to make financial decisions with the latest information, reducing re-work and decreasing the time from drive completion to stope design, and ultimately production.

Ore definition of remnant skins around voids is problematic, with the inability to strike drive along the vein. Foot wall drives with transverse fill and extraction drives provide a drilling platform to grade control drill short holes from a bobcat mounted LM30 mobile drill rig. Cavity Auto-Scanning Laser (C-ALS) surveys down these holes into the historical stope voids assist in determining depletion for grade control models. 3D scanning of historical voids, once broken through, allow remnant stope skin definition.

The introduction of a new generation of Light Detection and Ranging (LIDAR) scanning technologies now provide the ability to create 3D geo-referenced scans at the active heading, thus removing a further step of registration and post-capture processing on the surface. Detail captured at the drive or face allows geologists to identify and map historical workings openings and interpret stope fill from collapse and *in situ* rock and veining. These interpretations are used to refine the historical void model, allowing accurate depletion of the historically mined vein.

However, no technological revolution is perfect. Time pressures at faces have resulted in incomplete or poor quality data at times. The learning curve with new and bespoke software and the requirement for new geologists to master multiple pieces of technology to complete a task requires specific and targeted training. An over reliance on technology means that core geological skills of mapping, spatial orientation and structural measurements require constant attention to ensure they do not become diminished. However, the benefits of these new technologies outweigh the challenges.

INTRODUCTION

Mining has played an important role in the history of Waihi since Au was first discovered in 1879. Since then, the Martha deposit in the heart of the Waihi town has produced close to 6.9 Moz of Au.

Historical underground mining of the Martha veins occurred from 1882 to 1952 and an open pit mine extracted ore from the upper portions of the vein system from 1988 to April 2015. When mineralisation was discovered approximately 2 km east of the Martha deposit, the Favona underground mine was developed, and extraction of ore commenced in 2004 (McAra, 1988).

This underground mine expanded and is still in operation, having extracted ore from numerous vein systems in between the Favona and Martha ore bodies, including the Trio and Correnso ore bodies (producing approximately 1.1 Moz Au).

Mining beneath the existing Martha open pit, known as the modern Martha Underground (MUG), commenced in 2021. The MUG project consists of the remnant material left behind from historical mining and differs from the early ore bodies, which were largely virgin veins and not historically mined; stope fill, stope vein skins, and intact crowns and pillars make up the bulk of the current resource.

This paper reviews several new and emerging technologies implemented at the Waihi mine, with a discussion on how effective these technologies have been for remnant mining at the MUG project.

3D SCANNING

Currently at the MUG mine, every cut in an ore drive is 3D scanned using photogrammetry, with a geo referenced .obj file produced for importing into mining software (Whaanga, Vigor-Brown and Nowland, 2019).

With remnant mining, variability of the vein skin width can occur. Small inaccuracies in the vein position or void location has previously led to skins being created in the model where they do not exist or the absence of a skin where they should exist. To counter this, every fill/extraction drive that intersects the vein skin or historical void is 3D scanned. This gives many data points along the vein and historical void so that both models can be updated. Grade control drilling is typically done on a 12–20 m spacing depending on the ore body and location within. Adding scans of fill drives gives a 5 m x 5 m polyline of where the vein and void are spatially located. Combined with the drill hole grades for estimation, this greatly increases the accuracy of the model before stoping by helping to define the historical depletion (Figure 1).

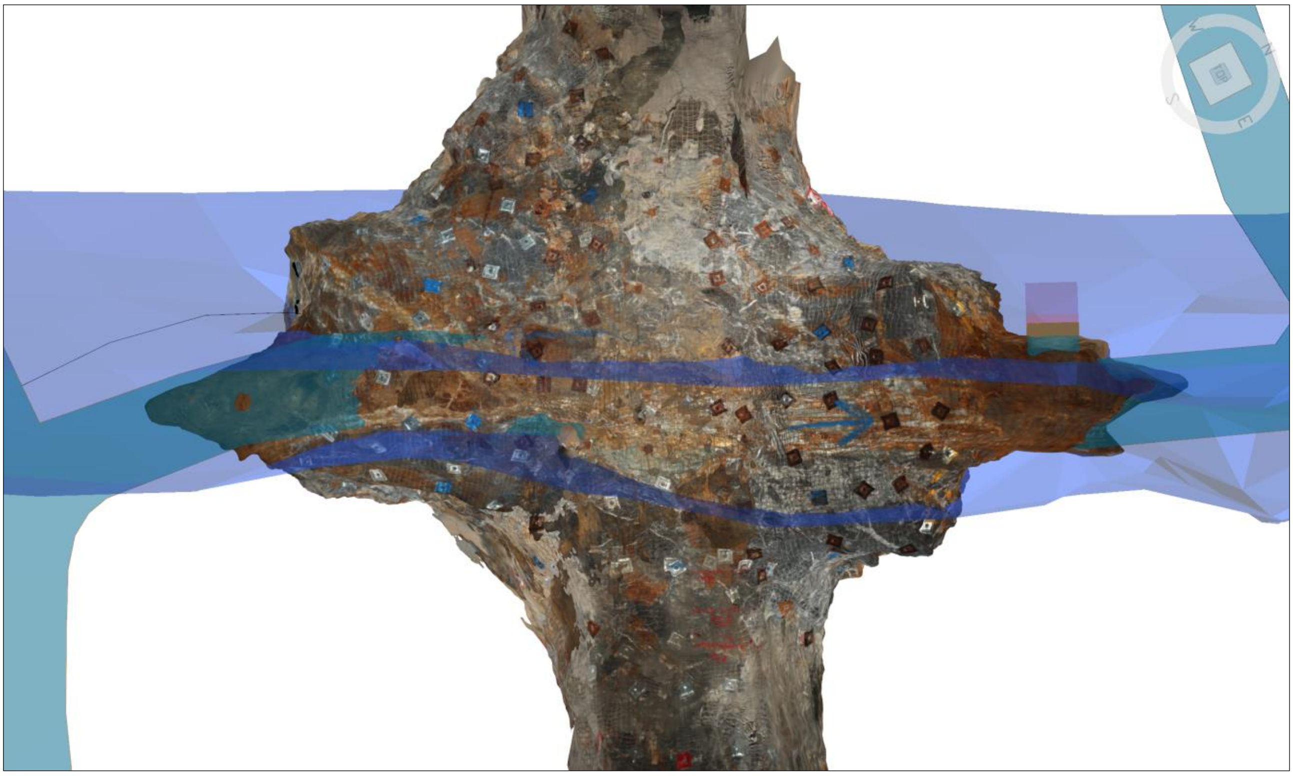


FIG 1 – Plan view 3D scan with actual historical drive position captured against void model (light blue) with modelled vein position (dark blue).

Challenges exist with accurate 3D scans of unsupported historical voids; geologists must take enough overlapping photos with sufficient light to capture the void openings and minimise shadowing.

As the process is completely digital, instances have arisen where technology has failed. To mitigate this, a backup camera is kept in the geology underground vehicle and a spare tablet on the surface. As the process requires all data to be processed underground, situations of completely failed face data are rare. There is no backup sketch taken so in these cases face channel data is not able to be spatially located or used. However, with the ability to scan the backs between these areas of data loss, the net effect on the interpretation for the area is minimal.

Stope reconciliation

Optimal drive positioning is vital to improving stoping performance alongside minimising dilution through over break and ore loss through under break. The presence of historical drives passes and stopes in current development has presented a challenge to position ore drives that create a stable economic stope shape with sufficient geotechnical pillars. 3D scanning of each ore drive has allowed the geology and geotechnical teams to review the drive position cut by cut, comparing the modelled position of both vein and historical mining to the measured positions. This has enabled drive positions to be constantly updated and modified in real time. With MUG being high graded through historical mining, modern stope grades are lower and closer to economic cut off. Optimal positioning has resulted in significantly less re-work getting drives back online, translating to lower costs and higher recoveries. Prior to the introduction of 3D scanning, drives went offline due to directional issues up to several times per month, or 10–20% of the ore drive metres mined, requiring some form of stripping or re-work to re-align. After 3D scanning technology was implemented, this was reduced to less than 5%. This is especially significant when considering the bulk of the MUG deposit consists of thinner, lower grade, more structurally complex veins that were not historically mined due to being uneconomic at the time. Compared with the earlier, previously unmined, higher-grade orebodies, Favona, Trio and Correnso, which were less structurally complex and easier to follow, mining of the MUG deposit is challenging.

DIGITAL MAPPING

Improvements to digital mapping processes using Deswik.Mapping™ have increased the level of information available to track and review the presence of historical voids.

Hardware upgrades

The introduction of upgraded Panasonic Toughpad FZ-G2 notebooks from the FZ-G1 has increased the processing power, allowing for faster and more efficient use of the Deswik Geology Mapping software whilst underground. This has reduced the need for re-interpretation and “tidying up” of underground mapping data. The geologist can now use the mapping software to select a pre-determined working plane (Whaanga, 2022), interpret the lithology they see at the face, and effectively map lithologies underground, without the use of the textures function which previously acted as a stopgap due to hardware limitations. This has reduced the workload by removing the cleaning up stage of importing geological mapping, as the sections are already set to plan view and mapped to the appropriate lithologies, requiring only a simple import through Deswik process maps (Whaanga, 2022). The historical void model is large, and manipulation is data intensive. The upgraded hardware allows more information to be displayed, facilitating better decision making at the face rather than waiting until the geologist is back on the surface.

Structural measurements

Structural measurements are now being recorded electronically into the geologist’s workflow at the active work face, using Deswik Geology Mapping software and a compass. This occurs after a face section has been created, which in turn geo-references a location based on the distance from a laser station, offsets and azimuth of the face (Whaanga, 2022). This process has allowed more accurate measurement of structures in the complex underground environment, as well as allowing the validation of the wireframe and vein orientation between drill holes while at the face. Reconciling the historical working positions with new drilling and vein interpretations is often difficult. Structural measurements at the face combined with the void model assist in determining which vein was historically mined and how to integrate new data to place drives in optimal positions.

Template updates

Remnant mining has increased the complexity and frequency of development and production interactions with historical voids and material types. Jumbo probe data, design stops, caution buffers, vein and void model wireframe updates, C-ALS surveys and grade control drill information are all considered at the design signoff stage. Once approved, attributed information is incorporated into master design projects with critical safety information available on digital survey memoranda for operations personnel and digital templates for technical services personnel. The geology team has incorporated this information into the latest Deswik templates, which are automatically refreshed overnight with completed and approved data from the previous day (Whaanga, 2022). Once spatially located, geologists can interpret the historical void/material type at the active face within the context of the design template notes. If a drive has broken through into an interpreted filled stope that contains a void, geologists contact the geotechnical and survey teams requesting respective surveys/inspections. A review of logged data from on level grade control drilling can offer insight into the accuracy of modelled void positions. Due to the unpredictable nature of remnant mining it would not be possible to print out a series maps covering every area of the mine and every eventuality that may be encountered at active headings. Updated digital data in a 3D mapping suite is an efficient and powerful way of organising a wealth of information, enabling fast, safe and confident decisions at the face (Doyle and Whaanga, 2017).

Mapping training

Since the introduction of a complete digital mapping workflow in 2019 at Waihi, several new geologists have been trained and moved through the department. Younger geologists are receptive to digital technology and the time taken to become competent with the Waihi workflows is notably fast. Mapping in 2D, both plan and section, are not required to the same extent, and with implicit modelling is no longer required at the wireframe construction phase. The quality of these skills has noticeably and predictably declined. However, this does not appear to be a problem with the increase in the ability to work, think and communicate in 3D. Good quality mapping training must continue, including taking structural measurements, identifying kinematic indicators, mineralogical features, and timing relationships.

HISTORICAL VOIDS

A historical void model for the MUG mine was created from historical map digitisation and reserve drilling of the ore bodies. These wireframes are then updated and adjusted as new information becomes available (Muir, 2023).

Cavity auto scanning laser (C-ALS)

With a diameter of 50 mm, the C-ALS cavity monitoring system is easily deployed downhole or uphole through boreholes to survey inaccessible spaces. A system of hinged, lightweight 1 m rods provides a fixed azimuth capability and enables C-ALS deployment down boreholes typically up to 50 m in length. A nosecone camera gives full visibility of the borehole during deployment, so operators can see any obstructions and judge when C-ALS has entered the void. The C-ALS probe has sensors to ensure it can be tracked down the borehole and that the scan is automatically georeferenced to fit into existing 3D mine data. Once in the void, the laser-scanning head rotates on two axes, measuring the three-dimensional shape of the void with full 360° coverage, and with a range up to 150 m. A load-bearing cable attached to the probe transmits all the measured data back to the surface unit.

Grade control drilling

A bobcat mounted LM30 and more recently a mobile drill rig (MDR) have been utilised to drill short holes from foot wall drives, ideally less than 30 m in length. Holes are designed to bridge open stopes if possible and continue on the opposite side of void, with the void and depth noted for poly insertion at completion of the drill hole. Designing holes in this way gives the option of obtaining a C-ALS of an open void if intersected, while still collecting core and samples of remnant vein skin around the void.

If an open void is intersected, the drill hole is lined with poly when the hole is completed, and a C-ALS scan taken. Using the C-ALS scan and lithological logging of vein skin gives a much more accurate model for remnant vein material along with size and location of the void (Figure 2). A common issue with the scanning of voids is the collapse of drill holes. Due to the fragmented broken nature of the ground around these historical voids, the drill holes often collapse before poly can be inserted to the void depth. An improvement to this process would be to scan through the drill string itself before pulling the rod string out.

Due to the variable vein skin width, a denser spacing of drill holes is required around historical stopes. Without high precision of both the hanging wall/foot wall and the historical void position, economic material may be overestimated or depleted.

If the drill hole intersects pillar, crown, collapse or fill material, digitised shapes can be manually adjusted to match the drilling. In areas with filled stopes, drill holes are designed to ensure at least one hole drills through a pillar or crown and near the edge of the historical stope, to best confirm its location.

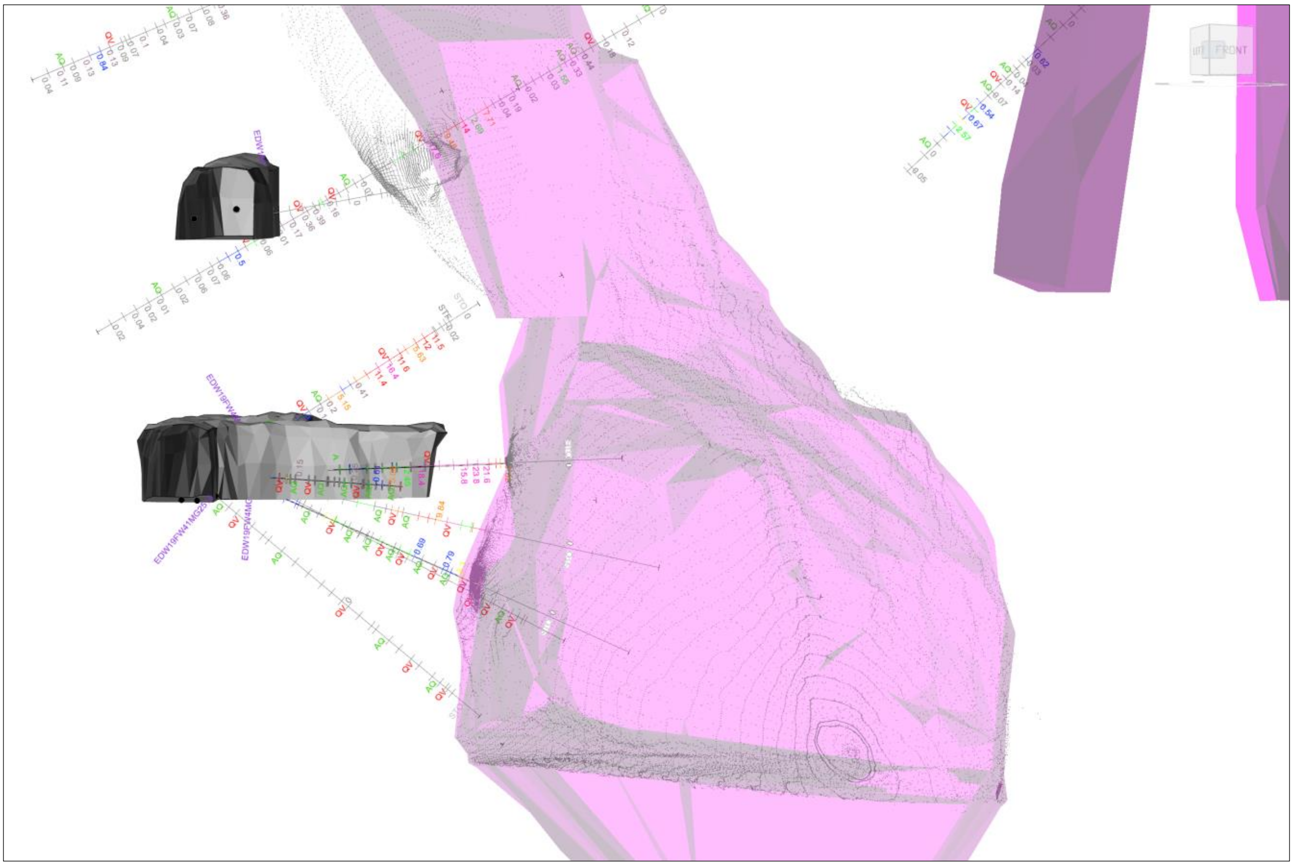


FIG 2 – Short grade control drill holes from foot wall development targeting skins and pillars, with point cloud C-ALS scan (grey) and adjusted historical void shape (pink).

GRADE CONTROL MODELLING AND ESTIMATION

Importing data

The inputs required for geological model wireframes and grade control model estimations are diamond drill hole data and underground ore control channel data. Previously, data was exported from the two acQuire databases and combined in an Access database, which is then connected to Leapfrog Geo via an ODBC link (Vigor-Brown and Whaanga, 2022*)*. Software updates to Leapfrog Geo have made this work around redundant. Multiple databases can now be imported, with data compiled into a combined table and combined merge table to be used for modelling and estimation.

Interval selection

Grade control modelling is done solely in Leapfrog Geo using face channels, drill hole data and polylines, generated from registered 3D scans (Whaanga, Vigor-Brown and Nowland, 2019). Interval selection is more complicated with the presence of open stopes and historical voids. Void information must be carefully selected as the original vein no longer exists in many areas. The relationship of the vein position as it exits the open stope has a large influence on vein skins.

Model relationships

The MUG mine can be grouped into several principal areas, each with distinct geological characteristics. Previously, grade control models were created for these mine areas and dynamic links established to the master geological model (Vigor-Brown and Whaanga, 2022). A single master geological model is no longer used. Each mine area now has its own geological and grade control model. This approach has significantly reduced processing time for geological models, as geologists can work on different mine areas concurrently. Dynamic links between the geological and grade control models within single projects make better use of Leapfrog's functionality; for example, the use of wireframes for variable orientation as opposed to the export and import of reference surfaces.

Seequent model branching functionality is still used to branch off alternative interpretations. Kriging Neighbourhood Analysis (KNA) models and estimates are manipulated for purposes outside drill and blast design; for example, life of mine and reserve models with modified variables for minable shape optimisation processing.

Grade estimation in Leapfrog Edge

Leapfrog Edge has a similar workflow structure to Leapfrog Geo. Each step in the estimation process is dynamically linked, from initial composite data built from assays within a wireframe domain, through to block model calculations that create combinations of first and second passes and resource classifications (Vigor-Brown and Whaanga, 2022).

Three years of MUG remnant mining with the current dynamic grade control systems has embedded a workflow with the engineering department that allows the use of best available data to make timely decisions, whilst also allowing for accurate and timely grade estimation validation and final release to ensure the model quality is acceptable. Intermediate working grade models are released with correct geological models and outstanding assay data, for use by drill and blast engineers to begin stope designs. Final validated models are released and stope authority documentation updated to reflect any changes (Vigor-Brown and Whaanga, 2022). This has proven to be a fast and efficient method to reduce the delay from ore drive or drilling completion to stope design and mining. Occasionally, more major changes are made to the geological model and estimation with the addition of grade information, which creates re-work for the drill and blast engineers; however, production delays are still minimised.

Intermediate models with incomplete drilling information are also released to the long-term planning engineers. Mine Stope Optimiser (MSO) is used to generate stope shapes and determine the initial economics of an area and allow a head start to long term designs. As discussed, final validated and released models are evaluated against the designs completed and minor changes made where required. In situations where stopes are generated in unexpected areas or there is an absence of shapes in expected grading material, there is a focus on review and validation of geology and estimation prior to the final model release.

This iterative approach to model updating and engineering design has greatly assisted with the dynamic nature of mining remnant material, where every historical void interaction can change the short-term mining plan, requiring flexibility from all departments.

Modelling and estimation of historical voids and remnant ore

Extensive historical underground workings in the MUG mine area pose a unique challenge with geological modelling and estimation. Historical drives, passes, open, filled and collapsed stopes need to be modelled to a high spatial accuracy, added to the grade control estimate and each dealt with uniquely. The historical void model is used to deplete and code material in grade control estimates.

In remnant areas, stope skins, crowns and pillars are targeted for extraction and often contain economic Au grades. Accurately representing these in a block model estimate is challenging (Figure 3). Areas where the wireframes and void model overlap indicate the mined ore to be depleted, and what remains is modelled and estimated. Where the relationship between the two is inaccurate there is a high risk of modelling and estimating skins, crowns and pillars that do not exist or depleting ones that do (Figure 4).

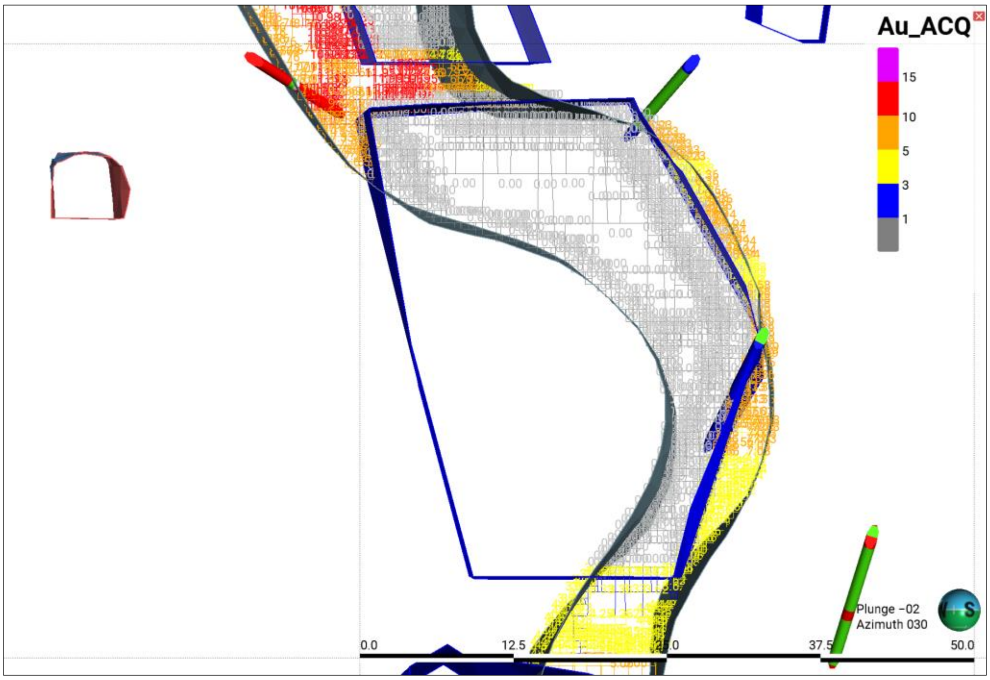


FIG 3 – A cross-section of a modelled historical open stope with no data to inform skins on the left had side of the void, and incorrect depletion and skins forming on the right-hand side. The historical void is not informed by C-ALS.

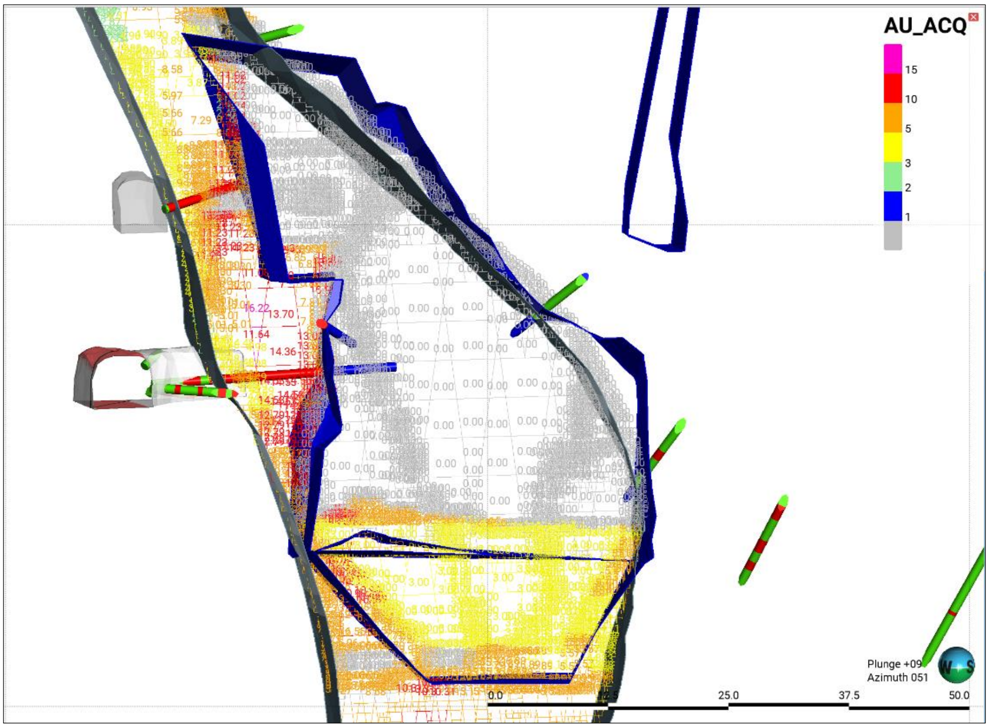


FIG 4 – Section view with foot wall drive drilling to target skins and historical void. The historical void model is adjusted based on drilling and C-ALS. Updated wireframe interpretation and excluding portions of selected segments and midpoints then re-estimated giving better representation of reality.

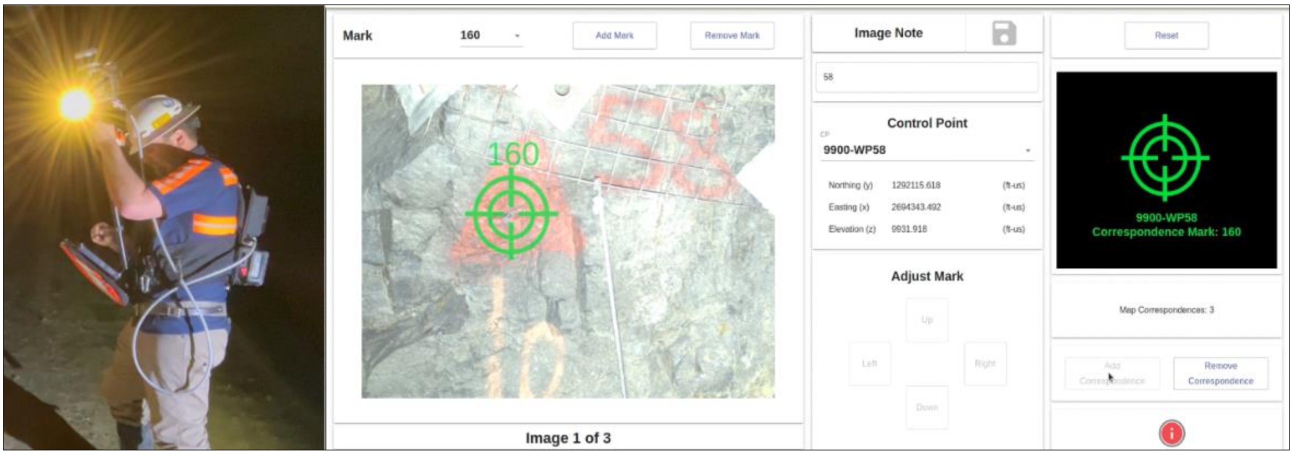
The ability to update grade estimates quickly based on new data, including information on historical workings such as size and spatial location, supports the need to model remnant material as accurately and timely as possible. Development breaking into historical workings for filling and extraction provides additional data and resolution of the location of skins and voids. These breakthrough cuts can be scanned, the wireframe and voids updated, re-estimated and provided to engineers for finalising drill and blast design on remnant ore.

LIDAR

OceanaGold is currently trialling Mine Vision Systems (MVS) FaceCapture™. This features a 90° x 360° field of view LIDAR with a 20 000 lumen light, combined onto a sensor head with integrated vest, and containing fast GPU processing, standard batteries and a 4 TB hard drive. It is connected to a wireless tough tablet (Figure 5).

FIG 5 – FaceCapture™ system with sensor head, integrated vest, and tough tablet.

Georeferencing is achieved by the operator using imported survey control. A photo is taken of the survey markers and correlated with the existing survey database (Figure 6).



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Control Point

CP 9900-WP58

Northing (y) 1292115.618 (ft-us)
Easting (x) 2694343.492 (ft-us)
Elevation (z) 9931.918 (ft-us)

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Image 1 of 3

FIG 6 – Photograph of survey control marker.

Subsequent scans are aligned with the existing location base map and georeferencing is passed to the localised scan, removing the requirement for survey control in every scan. Painting the LIDAR at the face/exposure of interest achieves higher resolution through over-sampling and allows a 3D registered mesh to be created live (Figure 7). The LIDAR has a working range of 50 m, allowing point clouds of historical drives and voids to be generated. 3D meshing has a range of 1–20 m, exceeding the current working range of photogrammetry of ~10 m. Drift accuracy of the system is 1%, giving centimetre rather than millimetre accuracy. From a mining perspective the accuracy is on par or greater than Waihi's existing system and prioritises speed of use and processing, with file sizes in the megabytes rather than gigabytes. Other LIDAR systems require post processing and down scaling of the point cloud data sets generated to be immediately useable for a higher level of accuracy and detail not required for mining applications.

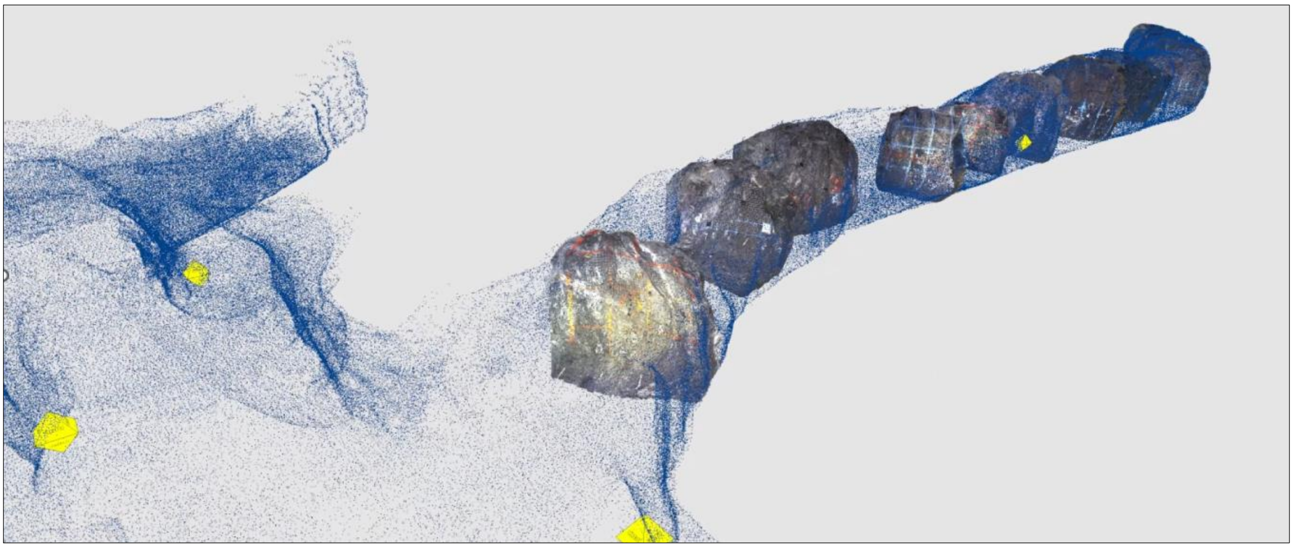

FIG 7 – Drive point cloud (blue) with 3D geo-referenced face meshes and survey control (yellow).

FaceCapture™ and Deswik Mapping are operated on the same tablet. The 3D georeferenced meshes are imported directly into Deswik Mapping, via the import .obj feature; point clouds can also be imported. Geologists map directly onto the meshes as per the existing photogrammetry process; however, geo-referencing or conversion of mapped features from Metashape to Deswik Mapping and post-processing is no longer required. Data captured underground only needs to be synchronised with the master mapping layers on surface. Detail captured at the drive or face allows geologists to identify and map historical workings openings and interpret stope fill from collapse and *in situ* rock and veining (Figure 8).

These interpretations are used to refine the working void model, allowing accurate depletion of the historically mined vein.

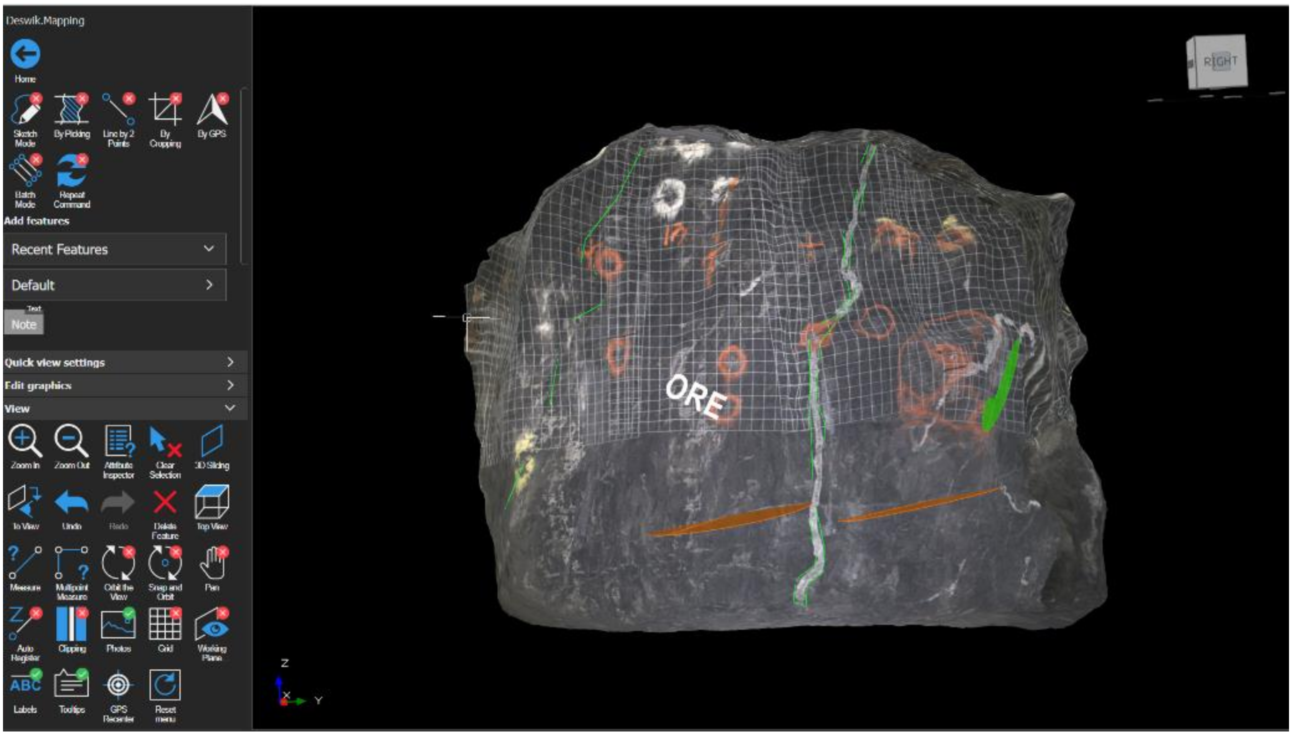

FIG 8 – Face sketching directly onto geo-referenced meshes in Deswik Mapping.

Integration with Deswik.OPS™ allows calculation of advance, grade line, as built, volumetrics for overbreak/underbreak and volume mined from the generated point clouds. The end of month pickup process can be streamlined with actual face positions and scans, assisting survey, and increasing the accuracy of the mine reconciliation.

CONCLUSION

The objectives of this review were to look at the real-world application of several technological innovations and grade control workflow improvements developed over the last 7 years at the Waihi underground mine, share learnings on the successes and highlight areas with room for improvement.

The challenge presented by the MUG remnant mining project has meant that the authors have had 3 years of implementing and rigorous testing of the work flows and technologies developed. Every aspect of ore control in a remnant mine is more difficult and challenging: 3D scanning of unsupported historical voids; managing diamond drilling programs through existing voids and categorising the different aspects of historical fill, collapse and vein skin; ore drive direction with the complexity of reconciling historical void positions with vein interpretations and optimal placement to achieve both economic and stable stope shapes; accurately representing depleted historical void shapes to generate grade control models; and managing large datasets on portable hardware devices to ensure timely decisions can be made underground rather than on the surface.

The technology advancements described have been utilised to overcome the challenges presented by the MUG remnant project and have directly contributed to improvements in ore drive development and stope placement, in turn lowering costs and improving profit margins.

Recent improvements to current scanning techniques with the introduction of LIDAR and real time geo-referencing will allow more work to be completed at the underground face. This will further improve information turnaround time, allowing the underground geologist to make correct, timely decisions with accurate data.

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