The implementation of photogrammetry and automated data analysis functions at the Waihi Underground Gold Mine

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ABSTRACT

Emerging technologies are a constant challenge to integrate into production geology work flows. The large volumes of data generated, and the requirement for data to be analysed immediately becomes an impediment for the implementation of many new technological advances. This is even though decisions with significant financial implications are constantly made at an underground face where the usefulness of data acquired is measured in minutes as opposed to days.

Ore control processes at Waihi are now being positioned to leverage off new developments in the field of photogrammetry, machine learning and timely data analysis.

A structured workflow has been developed that involves three dimensional (3D) photogrammetry scans (hereafter referred to as scans) of ore drive development captured by underground mine technicians. Survey points are allocated, and the data processed and spatially registered on the day of capture in Agisoft MetaShape software. This is carried out by mine technicians in conjunction with the survey department, thus freeing up valuable time for geologists. A high resolution 3D image is available to the geologist for ore drive decisions within hours of capture. Python scripting is utilised to streamline the process. Scans are imported into CloudCompare, with geological and structural information automatically extracted. All data is imported into Leapfrog and detailed geological and structural models generated, updated with the latest data and shared for use by all personnel in the technical services department.

The immediate advantage of the implementation of this technology is higher quality and improved geological interpretations with the ability to modify those interpretations immediately after data capture. This in turn leads to better geological models, with direct positive production benefits.

The utilisation of machine learning is being investigated to further categorise veins, alteration, and lithology.

In the future it may be possible to have data processed in real time at the development face enabling the ore control geologist to make immediate decisions on ore drive direction.

Keywords: photogrammetry, machine learning, ore control optimisation

INTRODUCTION

Photogrammetry processes are now well established in the industry and have been utilised by many disciplines around the world. A common criticism of these systems has been the real-world implementation for mine sites. Key issues include establishing workflows that do not slow down current systems, as well as appropriate management and utilisation of the large amounts of data generated.

Operations must also consider at what price point they enter the technology. It can be difficult for mine geology teams to justify the cost of extra labour, new software and systems for intangible and difficult to quantify benefits, especially when traditional systems deliver a satisfactory result. The view is often ‘this is the way we have always done it’.

This paper is a case-study of implementing a photogrammetry solution at the Waihi underground gold mine demonstrating the realised benefits.

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.

History of Mining in Waihi

Gold was first discovered near Coromandel township in 1852 but economic gold was not 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, approximately 5.5 Moz Au and 38.4 Moz Ag (McAra, 1988) were extracted (174 tonnes Au and 1193 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.

Traditional Ore Control Processes

Mapping the geology associated with the ore control processes at the Waihi underground mine previously involved generating sample channels and ore face contacts in section view as well as back ore contacts in plan view (Doyle and Whaanga, 2017). Vein orientation, scale, dip and geometry can be difficult to accurately represent in the underground environment even for experienced geologists. Production time pressures and often limited physical access to structures exacerbate the problems associated with capturing accurate geological data and it is not uncommon to see contact dip variances of up to 5 degrees in a face sketch compared with reality.

Unsurveyed face positions previously relied on geological personnel measuring distances and off-sets, with the face azimuth estimated later in the office. A large portion of time was spent geo referencing face sketches and back mapping, then validating and adjusting positions. Often a best fit approach must be utilised, with ambiguous data that does not fit the model ignored. Photogrammetric 3D scans provide a solution that resolves these issues whilst generating a permanent photographic spatial record similar to a core photo library.

DATA CAPTURE

At the Waihi mine the photogrammetry data capture process is led by the underground field technician, significantly reducing reliance on the underground surveyor reaching each ore heading in a timely fashion. Each heading is washed down to at least one cut back from the face, before a numbered reflective tag is attached to a bolt on the wall corresponding to a row of rock-bolt pull collars installed into the backs and shoulders (Figure 1). These collars are picked up by survey with the cut and used to reference the scan.

Once heading direction, width and, where applicable, channel information has been painted up on the face, photos of the face, backs and walls are taken from several locations by the geology technician using a digital single lens reflex (DSLR) camera and flash. Requirements for a successful result are ensuring each photo overlaps adjacent photos by >50 per cent and, where possible, each photo is taken perpendicular to the subject. The scene must not have changed dramatically between images and photos must be in focus and sharp.

Surveyed camera locations are not required, and the system relies on the redundancy of an excess of overlapping photos.

The order of the photos is not important, extra photos from different angles will improve the resolution of the result, with the sharpest and highest quality sections of images automatically selected during the processing stage. The capture process takes a maximum of three minutes for an average drive. Photos can be taken around obstacles in the drive, including jumbo booms and airlegs, with no loss of detail in the data captured. Settings on the camera always remain the same, reducing variables needing to be selected later through the software package.

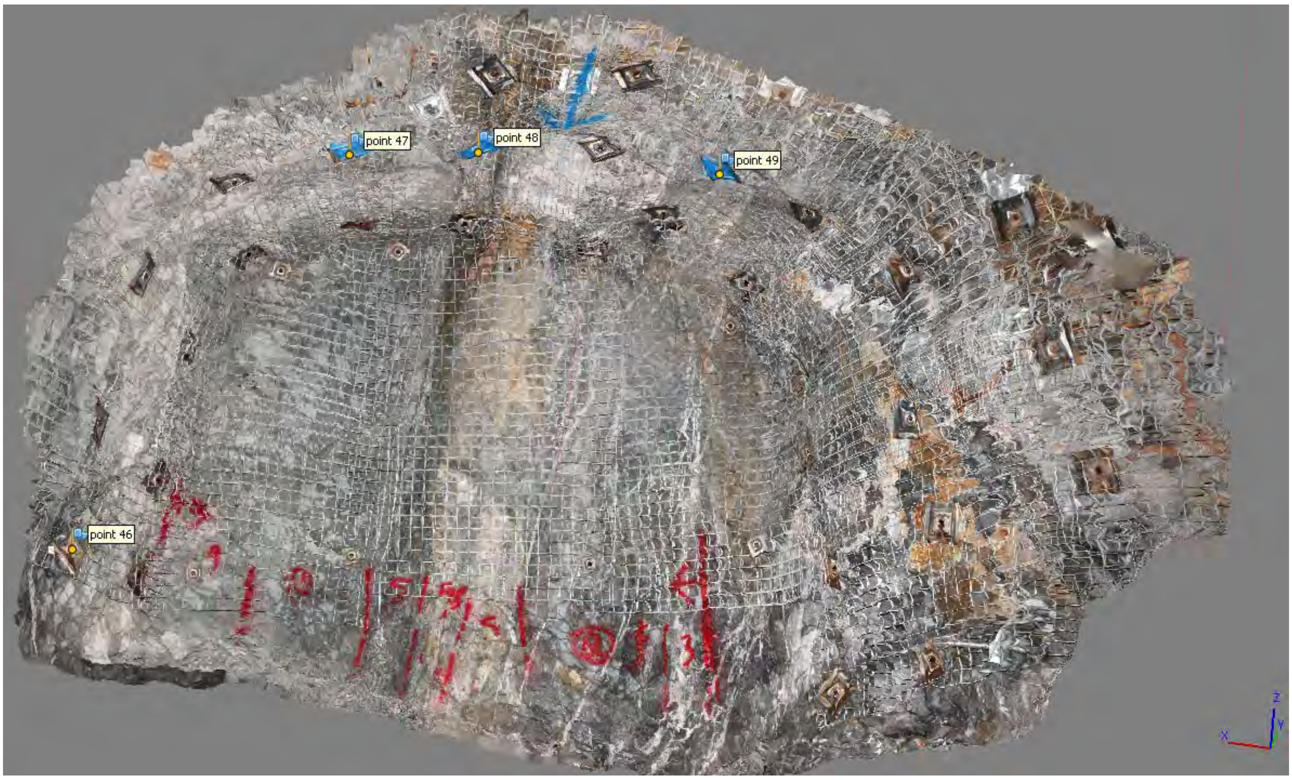


Figure 1 - Row of pull rings with the reflective tag circled.

IMAGE PROCESSING

When the technician returns to the office the photographs are split into folders corresponding to the channel ID allocated by the mine geologists and processed using the Agisoft Metashape photogrammetry software. The goal of processing images with Metashape is to build a 3D surface, orthomosaic and digital elevation models. The process has 4 main steps:

1. Metashape aligns the photos by finding common (tie) points between them. These are generally limited to 40 000 points per photo pair, to speed up processing. A sparse point cloud is generated showing camera alignment, back-calculating the camera locations.
2. The sparse point cloud data set is utilised to generate a dense cloud from the estimated camera positions and the photos themselves. This dense cloud can be adjusted considerably by sacrificing quality for speed. Even on the lowest/fastest settings the dense cloud contains several million points and a level of accuracy higher than required for mining applications. The dense cloud can be further edited and re-classified prior to moving on to the next step.
3. A 3D polygonal mesh model is generated that represents the object surface based on the dense point cloud. This step takes up the bulk of the processing time. Several options exist at this stage to smooth the mesh, remove or fill in holes that occurred due to inadequate photo overlap. The Metashape algorithms generate excessive detail so a decimation function is used to reduce the faces per mesh to 100 000 from upwards of 10 M. This dramatically reduces file size and loading times when exporting to Leapfrog.
4. Finally, the mesh is textured. Lighting, exposure and white balance are normalised between scans. The amount and quality of the textures can be specified. This step only adds small increases to overall file size but is necessary to maintain a high-quality exported image.

The use of python scripting automates the processing steps and it takes only minutes for the underground technician to set up the project, import the data and run a batch process of all the steps above with every variable controlled and pre-set. The entire process enables the geologist to generate an accurate 3D scan of a heading within an hour of returning to the office.

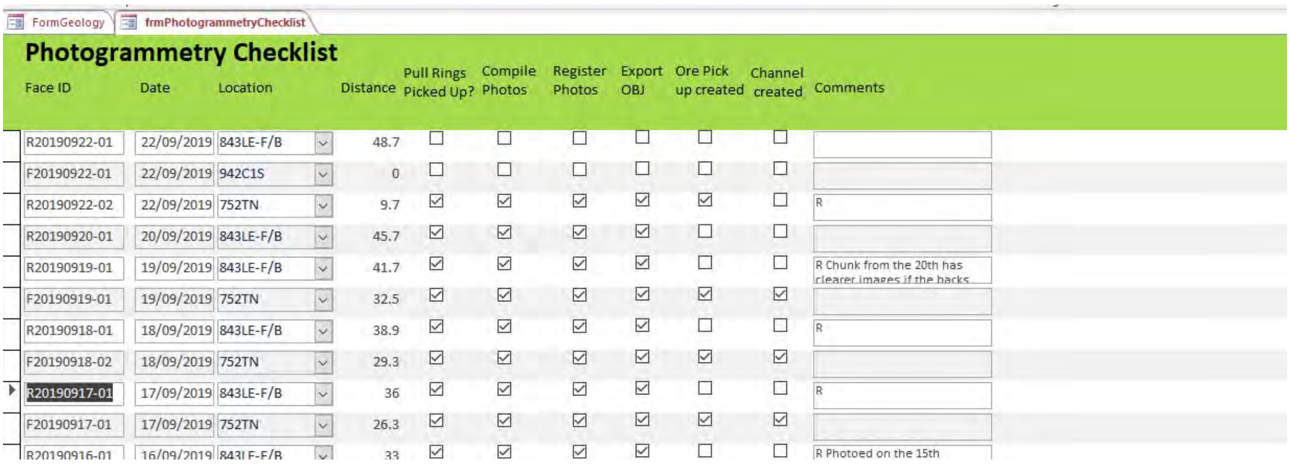
Scans are exported in wavefront .obj file format. This consists of 3 file types: the .obj file, which is the mesh or wireframe and can be imported separately; several textures (amount specified in step

4) as .TIFF or .JPG files; and an .MTL file, which defines how the textures should be referenced in relation to the mesh. Increasing the texture count is the best way of increasing the image quality of the final file.

The primary application for Metashape is to generate extremely detailed, sub-centimetre accurate 3D models. Hence for mining most of the quality settings can be reduced to a minimum, improving turnaround time and reducing output file size.

When informed by survey that the pull-collars used as references have been picked up in a drive the technician can then register and spatially locate the scans by importing the related survey .str files with x y z coordinates and labels that correspond to the bolts and pull rings. Checks on accuracy at this step ensure points picked up by survey correspond to those selected by the technician. The scan is then used in Leapfrog Geo to select hanging wall and foot wall surfaces, and to create channel positions in the drive. Wireframes can be updated for each vein as soon as these headings have been validated.

Data management is critical when dealing with this process. The amount of raw data generated is currently about 1 GB per day, with a yearly requirement to store less than half a TB of data. Storage of the raw data enables each scan to be generated from scratch again if required. The exported .obj files are spatially registered and able to be utilised by any other mine department in a variety of software packages, several of which are free (eg CloudCompare and Adobe PDF Reader). The space requirement to store these exported files is 25 MB per scan. A checklist stored in the production database is used to track each part of the process (Figure 2). Any issues with scans are detailed in a comments section with solutions to rectify.



Photogrammetry Checklist

Face ID	Date	Location	Distance	Pull Rings Picked Up?	Compile Photos	Register Photos	Export OBJ	Ore Pick up created	Channel created	Comments
R20190922-01	22/09/2019	843LE-F/B	48.7	☐	☐	☐	☐	☐	☐	
F20190922-01	22/09/2019	942C1S	0	☐	☐	☐	☐	☐	☐	
R20190922-02	22/09/2019	752TN	9.7	☑	☑	☑	☑	☑	☐	R
R20190920-01	20/09/2019	843LE-F/B	45.7	☑	☑	☑	☑	☐	☐	
R20190919-01	19/09/2019	843LE-F/B	41.7	☑	☑	☑	☑	☐	☐	R Chunk from the 20th has clearer images if the backs
F20190919-01	19/09/2019	752TN	32.5	☑	☑	☑	☑	☑	☑	
R20190918-01	18/09/2019	843LE-F/B	38.9	☑	☑	☑	☑	☐	☐	R
F20190918-02	18/09/2019	752TN	29.3	☑	☑	☑	☑	☑	☑	
R20190917-01	17/09/2019	843LE-F/B	36	☑	☑	☑	☑	☐	☐	R
F20190917-01	17/09/2019	752TN	26.3	☑	☑	☑	☑	☑	☑	
R20190916-01	16/09/2019	843LE-F/B	33	☑	☑	☑	☑	☐	☐	R Photoed on the 15th

Figure 2 – Photogrammetry checklist in the production database.

Each face is still sketched by the mine geologist and captured in the production database alongside the channel and drive information. This sketch is used in conjunction with the scan as there may be details that are not clear on the scan however wireframes are no longer snapped to points on spatially located sketches. The inclusion of photogrammetry into the ore control process has significantly increased the accuracy of the underground data captured and at the same time reduced the time taken to get data to the modelling stage.

EQUIPMENT

Studies have demonstrated that accurate results can even be obtained using basic cameras (Thoeni *et al*, 2014). Thoeni *et al* (2014) completed a 3D reconstruction of a 6 m high by 20 m long rock wall using several cameras and a laser scanner. An iPhone 4s showed a mean deviation of 16 mm with two different DSLR's producing a mean deviation of 6-7 mm. Various recommendations have improved the equipment setup although they differed on the type of software and photogrammetric analysis conducted. A DSLR mounted on a tripod with external lighting without the use of a flash was used at the Balmat zinc mine located in New York State, USA (Knight, 2017).

At the Waihi mine the aim was to gain a result that was equal to or better than standard 2D face and back sketching methods in quality and speed. A slight reduction in image quality was deemed an acceptable sacrifice for a system that involved quick capturing and processing time. External light sources and tripods were tested and compared with a hand-held camera and external flash.

Despite advice that an external flash does not work well in dusty underground environments, excellent quality images were obtained by testing camera/flash settings and camera locations. A Canon 80D DSLR, 10-18 mm EFS wide angle lens with Canon 600EX ii RT flash allows an average of 50 photos per 3x5x5.5 m round (with 3 m overlap) to be captured in approximately 3 minutes. Not using external lights or a tripod significantly speeds up the image capture process. Images are high resolution JPG with EXIF metadata tagged to allow Metashape to utilise exposure, shutter speed and focal length settings to optimise lighting and image alignment. Images are downloaded to an HP Z4 G4 4 core(s) workstation with a NVIDIA GTX 1070TI graphics card. Processing time averages 30 minutes per round and varies with drive complexity. The equipment cost was NZD $5000 for the camera and accessories, $5000 for the processing computer and $5000 for Agisoft Metashape. Agisoft now offer a cloud computing service with access to fast processing times at the cost of a monthly subscription.

ORE DRIVE DIRECTION

Previously, mine surveyors picked up development drives after a maximum of three cuts. Hanging wall and foot wall surfaces painted on the face were only picked up every third cut, whereas the contacts in the backs were picked up continuously.

With the implementation of 3D registered scans, detailed contacts are being registered for every cut with only 5 per cent of faces being unavailable. Scans are generated and registered from survey points 1-2 cuts back from the current face, and with less than half a day turn around the generation of contacts and vein positions are often one cut ahead of the survey as-built.

Ore direction arrows are marked up in the backs with a left or right wall on the face along with a desired drive width. Ore drive turnouts on veins are often problematic with the need to balance optimising the mineralised vein position and operational requirements to manoeuvre heavy plant. The geologist can now channel sample the walls of the turnout, mark up the desired turn out position and have this photographed and registered. This is imported in 3D with other supporting data such as modelled vein positions, mapping and drill holes, and reviewed the same day with the senior geologist, operations and engineers. As the position is reviewed in 3D the mark up position can be altered and avoids stripping to adjust the position with associated ground support, bogging, trucking, ore loss and dilution.

Review of the arrows painted in the backs also provides a valuable learning tool, clearly showing whether the operator accurately followed the direction. Reviewing geological drive direction mark ups has been particularly useful when ore structure orientation changes abruptly. Geologists are often faced with making on-the-spot decisions using structural orientation in face and backs. In situations when the planned ore drive direction does not honour the orebody direction due to an unexpected change in orientation, the geologist’s mark-up decision can be justified. An example of this is illustrated in Figures 3 and 4.

GEOLOGICAL GRADE CONTROL MODELLING

With the introduction of photogrammetry at the Waihi underground mine, the fundamental principles of ore control and the data collection processes remain largely unchanged. The geological modelling process still relies heavily on the accurate data collected during the ore control process. However, the use of scans of the underground ore drives and faces adds a new dimension to the modelling process, resulting in geological grade control models produced with a higher accuracy, better data honouring and a faster turnaround between ore drive development, model generation and stope design. The scans make it easier to adjust the model as the ore drive progresses.

Previously the grade control modelling process at the Waihi mine began with ore control and validation of the drill hole data, with errors corrected prior to point cloud creation. The model intercepts were then selected. These are based on geological interpretations of vein geometries, mineralisation, grade, and structural measurements provided from drill hole data, and validated by underground mapping. Structural measurements from oriented drill core were visualised in Vulcan as coloured discs coded as foot wall, hanging wall or fault contacts and used as a guide for interpretation of structural trends. Vein foot wall and hanging wall points were snapped to drill hole and channel intervals, and control points used to guide the interpretation in areas of known complexity. Fault surfaces were created from backs mapping information and used to guide vein offset interpretations. Point clouds were imported into Leapfrog and an implicit geological model was generated, honouring vein and fault timing relationships. The process is iterative, with multiple passes and point cloud adjustment required (Doyle and Whaanga, 2017).

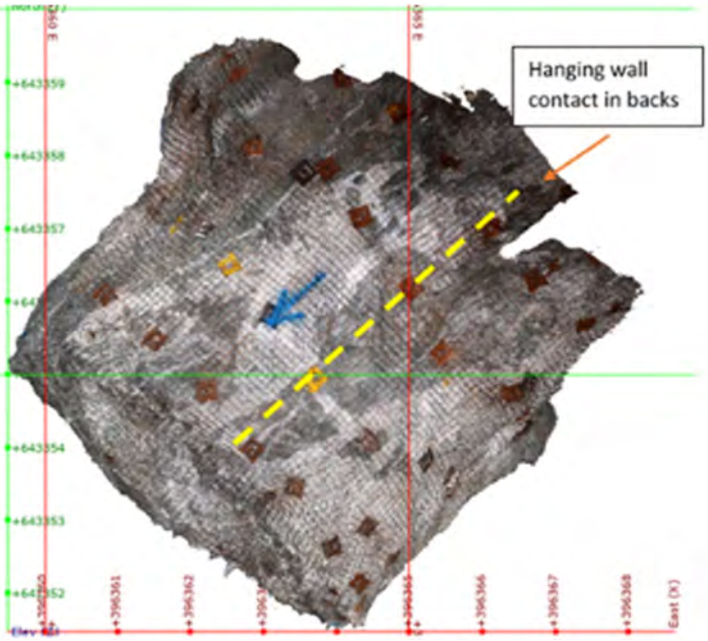


Figure 3 – Geology direction mark up (blue arrow) on ore drive backs. The orebody appears to trend in a straight direction relative to the face and backs of the ore drive.

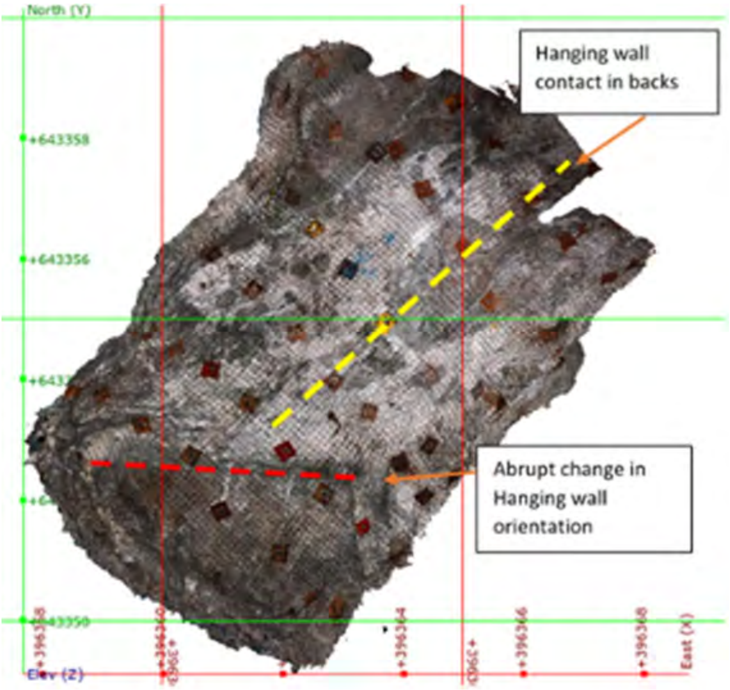


Figure 4 – 3D scan from Figure 3 with the addition of the next 3 m cut. An abrupt right hand turn in the orebody can be seen approximately 0.5 m from where the previous face had been marked up as straight.

A shift has now been made where grade control modelling is done solely in Leapfrog geological software using face channels, drill hole data and polylines. Correctly registering the 3D .obj files is paramount to this process working correctly as the scans become one of the focal points in which decisions influencing the model are made. The scans essentially replace the face sketches (although sketches are still used for face grade calculations and comparison with scans) and ore survey pickups. Now the foot wall and hanging wall contacts are digitised directly into Leapfrog on the face, backs and wall of the scan, giving a highly accurate polyline defining the geological contacts used in creating and updating the wireframes combined with the channel data (Figure 5). Using the interval selection tool, channel data can easily be selected using Au values or lithology (or any other field) to assign that portion of the channel into the correct domain (Figure 6). Validation of data can be done quickly when viewing scans, selected intervals, foot wall and hanging wall polylines with survey drive pickups on screen, as illustrated in Figure 5 below.

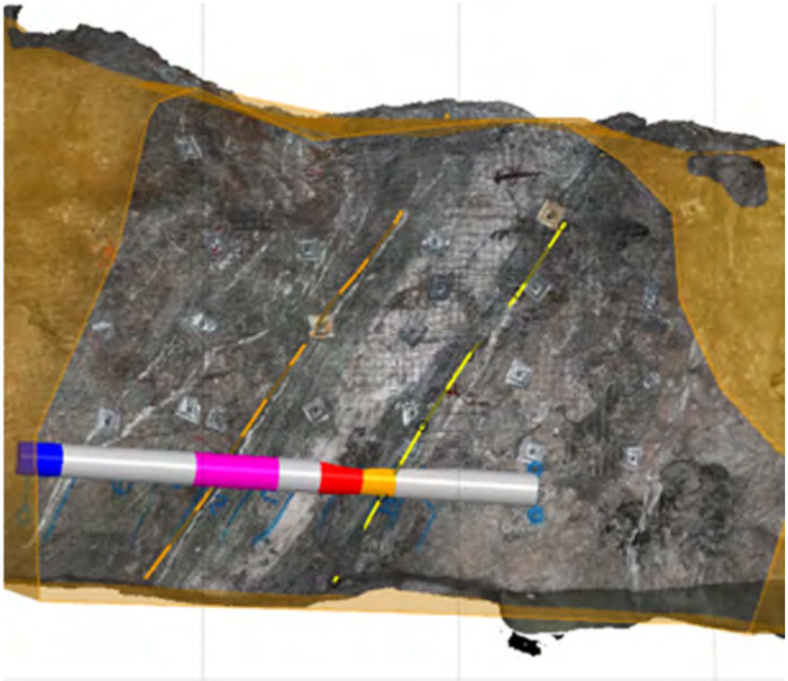


Figure 5 – Image showing a channel, 3D scan, and hanging wall and foot wall polylines on a vein structure with the level asbuilt matched to the scan.

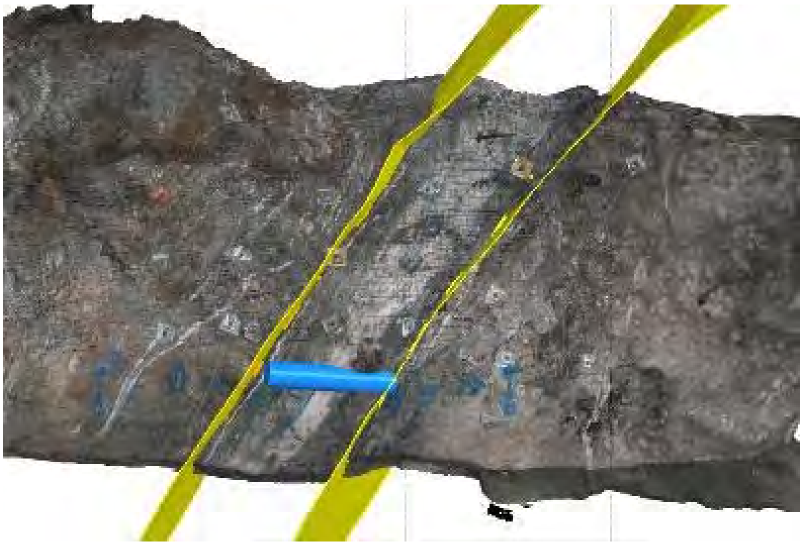


Figure 6 – Same image as Figure 5 after interval selection has assigned interval of channel to the correct domain. The wireframe has been refined using interval selection along channel and foot wall and hanging wall polylines.

Digitising using the scans is not limited to the main orebody. Any structure within the ore drive, such as fault structures interacting with the orebody, may be accurately digitised to the same precision as the orebody itself. Structures can also be modelled to the same precision and accurately linked to existing drives or extrapolated to designed development (Figure 7). 3D scans helped to identify the foot wall structure, track it between drives and identify the point at which the structure pinched out.

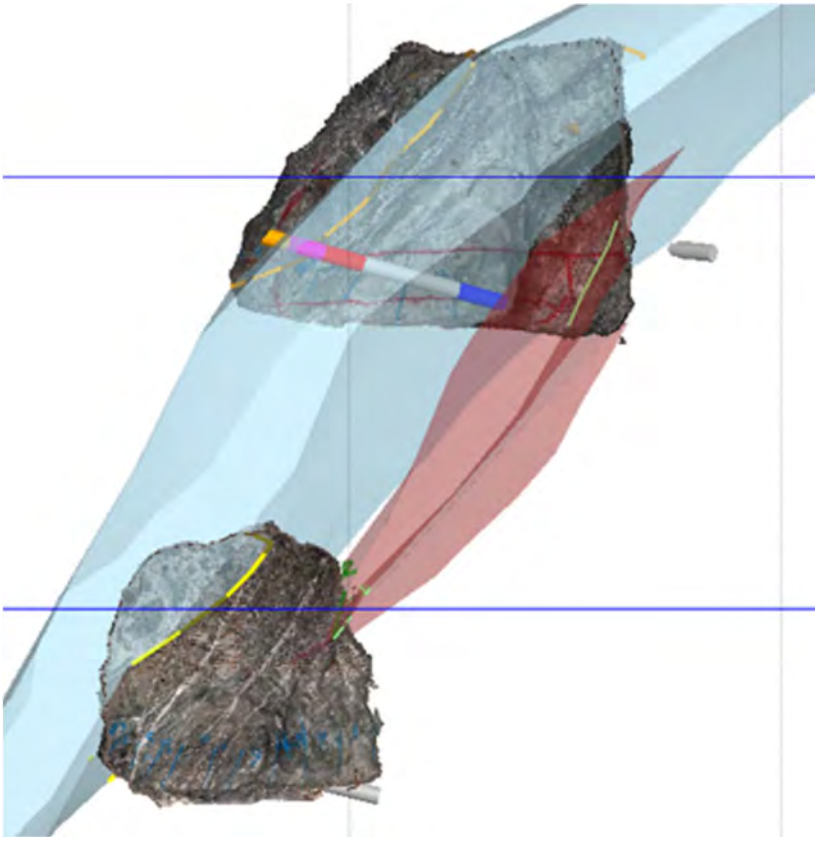


Figure 7 – A small high-grade splay (green poly line, red triangulation) in the foot wall of main structure (blue triangulation).

Previously, backs mapping was done to achieve the same accuracy. The mine geologist painted multiple continuous lines representing the orebody and fault structures on the backs and walls, which then required a survey pick up. With the use of photogrammetry, digitising all the structures in a particular scan only requires 3 individual points of the drive to be picked up by survey (Figure 8).

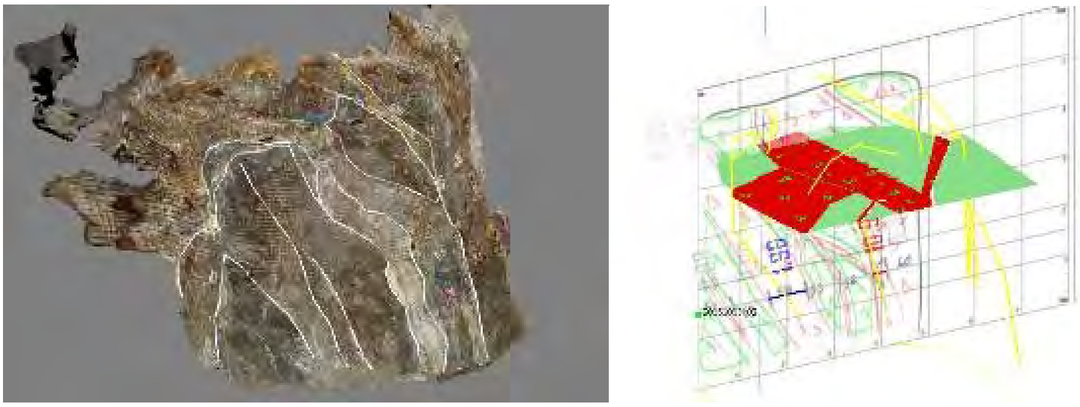


Figure 8 – 2D plan back map and section face sketch showing interpreted vein positions compared to actual vein position generated from scan.

3D scans are instrumental for the modelling geologist in gaining an understanding of the orebody being modelled and refined. Combining the scans in geological software and stepping though them is essentially like walking down the ore drive. This is a useful way for geologists and other personnel to understand structural orientation and complexity, and to identify and re-interpret subsidiary structures, eg foot wall splays that were not in the original model prior to the commencement of mining (Figures 9 and 10). Geotechnical personnel in particular have found the ability to visualise structural relationships extremely useful. This is possible from face sketches and backs mapping but is much clearer in scans.

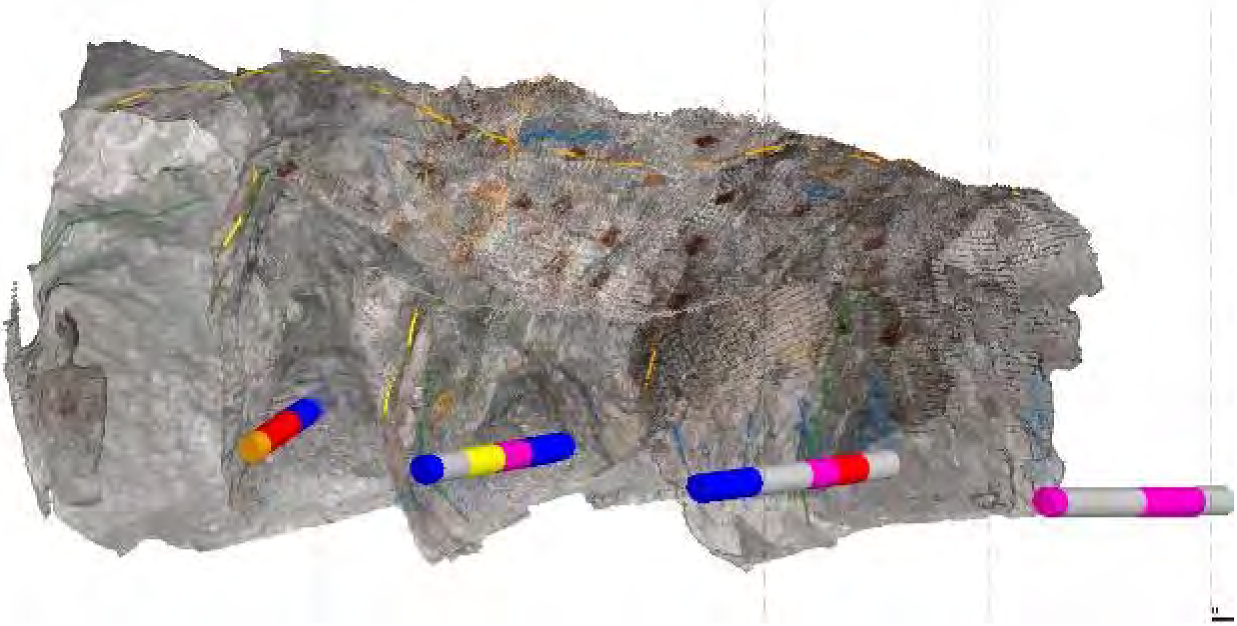


Figure 9 – Oblique long section showing several scans merging together resolving complex vein geometry.

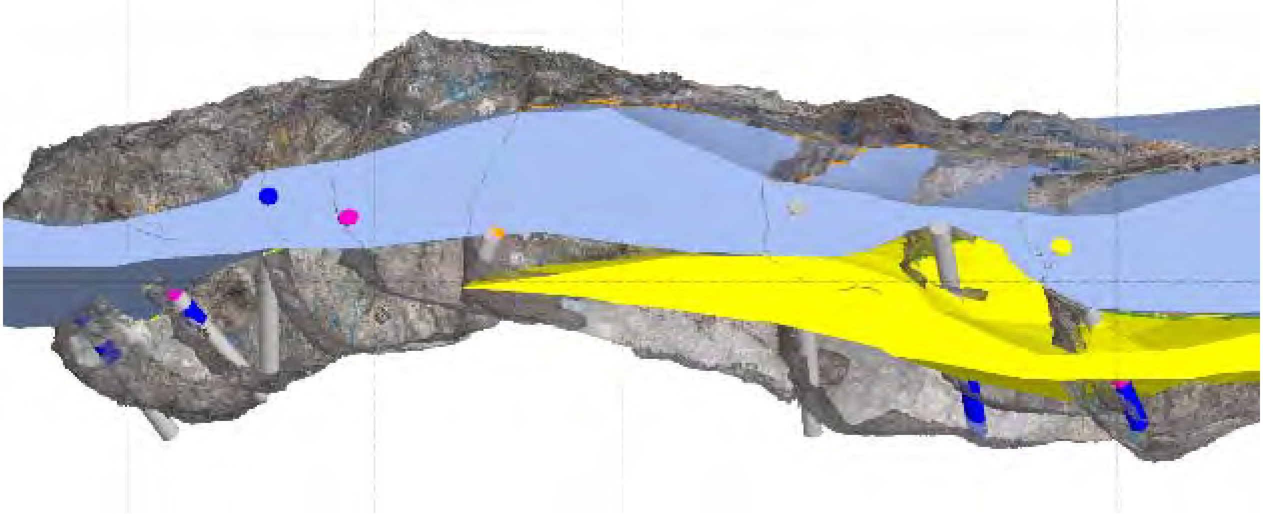


Figure 10 – Simplified vein wireframes.

Geological grade control modelling that honours data sets and geological domains is vital in underground mining and is a key contributor influencing future ore development drives, stope design and maximising Au grades. Photogrammetry currently plays an important role in the current grade and ore control modelling process and is actively contributing to a better understanding of orebody complexity and accurate grade control modelling at the Waihi underground mining operation.

APPLICATIONS FOR FURTHER USE

CloudCompare is a free, open source program that was originally created to quickly detect changes in high density point clouds acquired with laser scanners for industrial solutions (Girardeau-Montaut *et al*, 2005). It has now evolved into more general and advanced 3D processing software.

Structural information

The gathering of structural information underground for geological and geotechnical purposes involves taking as many measurements of features deemed to be significant as time permits. This means the data collected is selected in the field and later has to be spatially referenced with maps or point data. Often surfaces and structures are not exposed at floor level or are inaccessible, and ground support and machinery affect compass bearings.

CloudCompare uses a plugin called Facets that extracts planar features from point cloud data sets, calculating dip and dip direction and visualising the features with interactive stereograms (Dewez *et al*, 2016). Data can be filtered and segmented to remove most planes that are associated with a development profile (Figure 11).

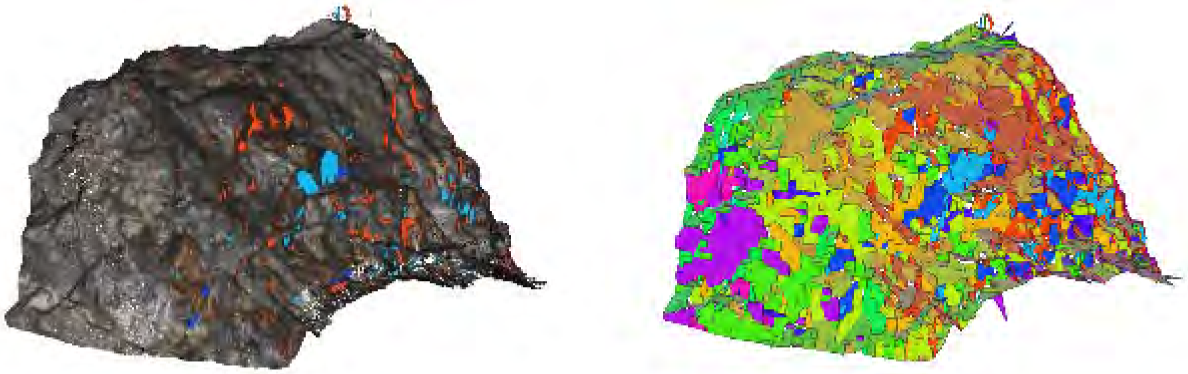


Figure 11 – RGB point cloud with joint planes of interest filtered in blue and red.

Planes can then be categorised and added incrementally to a 3D structural model. As every plane can be accessed, outliers can be easily identified and removed. Quantitative assessments can also be made about the frequency of structures rather than relying on the selection of a single measurement.

Compass is another more conventional tool within CloudCompare and allows single measurements to be made, similar to a geologist with a compass in the field. Geological features can be measured, and the data stored in a variety of formats for further analysis in CloudCompare before being exported to drawing programs to create conventional two dimensional (2D) maps.

Machine learning

Machine learning has been applied successfully in exploration geology to generate predictive maps of basement rocks under cover (Hood *et al*, 2019). It has also been utilized for automated identification of sulphides from drill core imagery (Cracknell *et al*, 2019), identifying veins and their orientations as well as mineralogy, producing large amounts of quantitative data. Future work involves exploring the use of this technology to create a first pass categorisation of geological information from scans, thereby generating 3D polygons that can quickly and simply be edited into existing grade control model workflows.

CONCLUSIONS

3D modelling techniques have been hailed as the solution to time consuming 2D sectional single interpretation models. However, the data used for these models is often still captured in 2D. Comparisons of this 2D data with 3D photogrammetry scans have revealed that estimated face positions were up to 2 m out along strike, with widely varying bearings. At the Waihi gold mine, using scans, lithology, mineralogy and structural observations from face to face and between different geologists are repeatable, with the same contacts being interpreted. Interpreting and resolving geometrical issues has almost completely been eliminated. Registered scans are either correct or not and contacts line up perfectly in all dimensions continuously from scan to scan, reducing any re-work to nil. Geologists are free to spend their limited time at the face recording accurate relationships between lithology, structure and mineralogy, safe in the knowledge that the spatial relationships will be faithfully reconstructed with no interpretation bias.

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