Stope reconciliation

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Background

Many underground mines around the world use an open stope mining method. The profitability of open stope mining depends on the accuracy of the stope design and the execution of the mining process. The value of a stope is intrinsically linked to success of ore recovery but it is also related to the amount of unintentional dilution. Stope performance is discussed in terms of underbreak (UB), i.e. ore not extracted, and overbreak (OB), i.e. waste extracted. The maximum value obtainable for a stope will be obtained from stopes with minimum overbreak and minimum underbreak.

Open stope design approaches and tools have not evolved significantly since the 1980s and industry still extensively uses the stability graph method (Mathews et al. 1980; Potvin 1988). An exception is the concept of Equivalent Linear Overbreak Sloughing (ELOS), which was developed by Clark and Pakalnis (1997). It was initially used to assess overbreak in narrow vein mining. Capes (2009) extended the original Clark's database, applied the methodology to open stope design, and included some capability to forecast stope overbreak. For most mine sites, the robust statistical methods for forecasting overbreak are practically non-existent.

Stopes with underbreak will leave behind unrecoverable ore and this can be as detrimental to stope value and mine economics as overbreak. Existing assessments of open stope performance do not consider the evaluative, estimation, and forecasting of underbreak (Potvin et al. 2015). Potvin et al. (2016) highlight that the optimisation of overbreak and underbreak are generally conflicting and efforts that focus on reducing overbreak may increase the amount of underbreak. This emphasises the importance of having good stope reconciliation tools and procedures that can translate into future stope performance optimisation.

Techniques of underground surveying have made significant advancements when determining mined volumes, most notably with the application of the cavity monitoring system (CMS) (Miller et al. 1992). At most mines, a wealth of data is created by accurate and routine stope surveying techniques. The full potential of this data is far from being realised. This data allows for the probabilistic forecasting and comprehensive assessment of stope performance and, ultimately, the optimisation of mining economics and the utilisation of a finite resource.

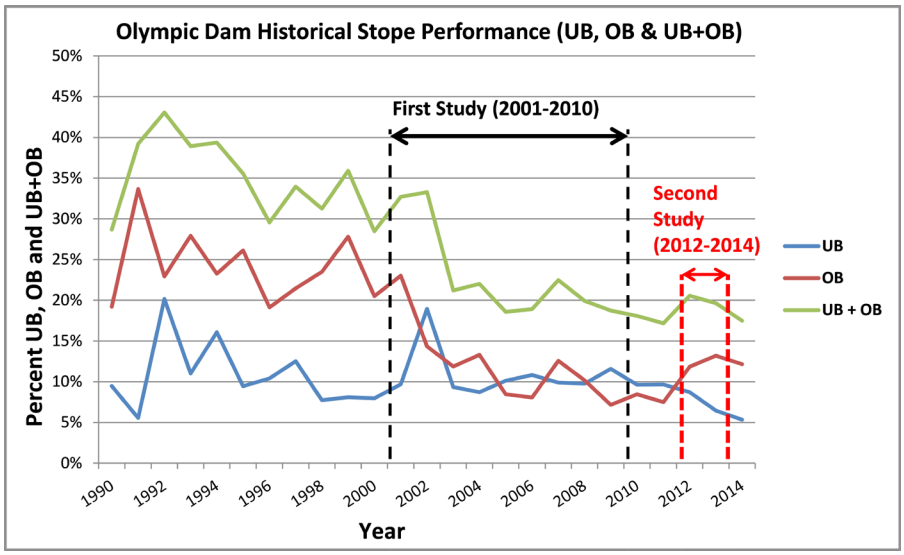

Figure 1 Historical UB and OB stope performance at Olympic Dam

A pilot case study - Olympic Dam (BHP)

Exploratory research at BHP's Olympic Dam has shown that the concept of stope reconciliation can have a significant impact on the overbreak and underbreak outcomes at the mine (Potvin et al. 2015, 2016). Figure 1 shows historical stope performance of Olympic Dam with respect to overbreak, underbreak, and a combined measure (Potvin et al. 2016).

The previous work at Olympic Dam showed that the amount of overbreak was a function of traditional design parameters (hydraulic radius and the stability number), but also strongly correlated to the orientation of stope walls and the blasting pattern used. The amount of underbreak was correlated to the drilling pattern and whether blasting was against a wall of cemented fill. Other correlations were found between overbreak, underbreak and the slot opening strategies.

This research shows that, in addition to traditional measures, operational and design factors can contribute to overbreak and underbreak outcomes. This information can be used in the assessment of future stope performance and to forecast the potential for overbreak and underbreak.

Stope reconciliation project

Project overview

The current iteration of the stope reconciliation project has been supported by six sponsor sites along with the Minerals Research Institute of Western Australia (MRIWA). This project will build upon previous results at Olympic Dam to develop tools that enable a probabilistic approach to stope design. This will involve the development of improved stope performance assessment and the investigation of factors that affect overbreak and underbreak.

In practice, possible influencing factors will be assessed from a range of data including stope design (e.g. stope

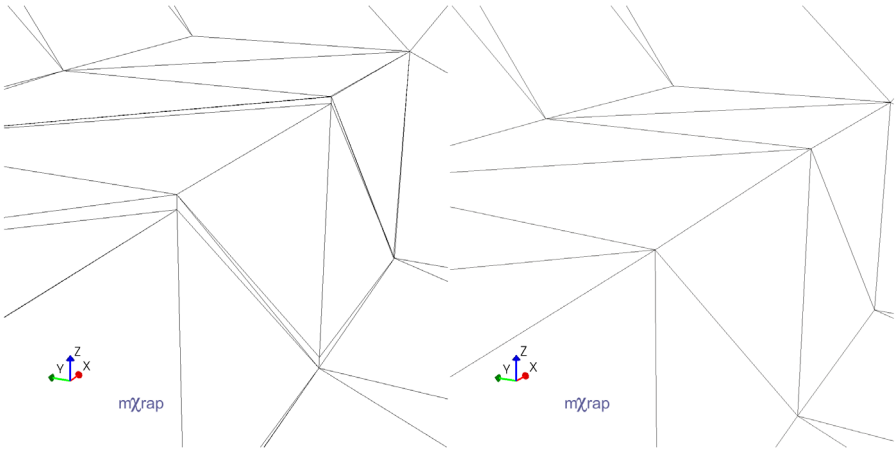

Figure 2 An erronous design wireframe (left) and an automatically corrected wireframe (right)

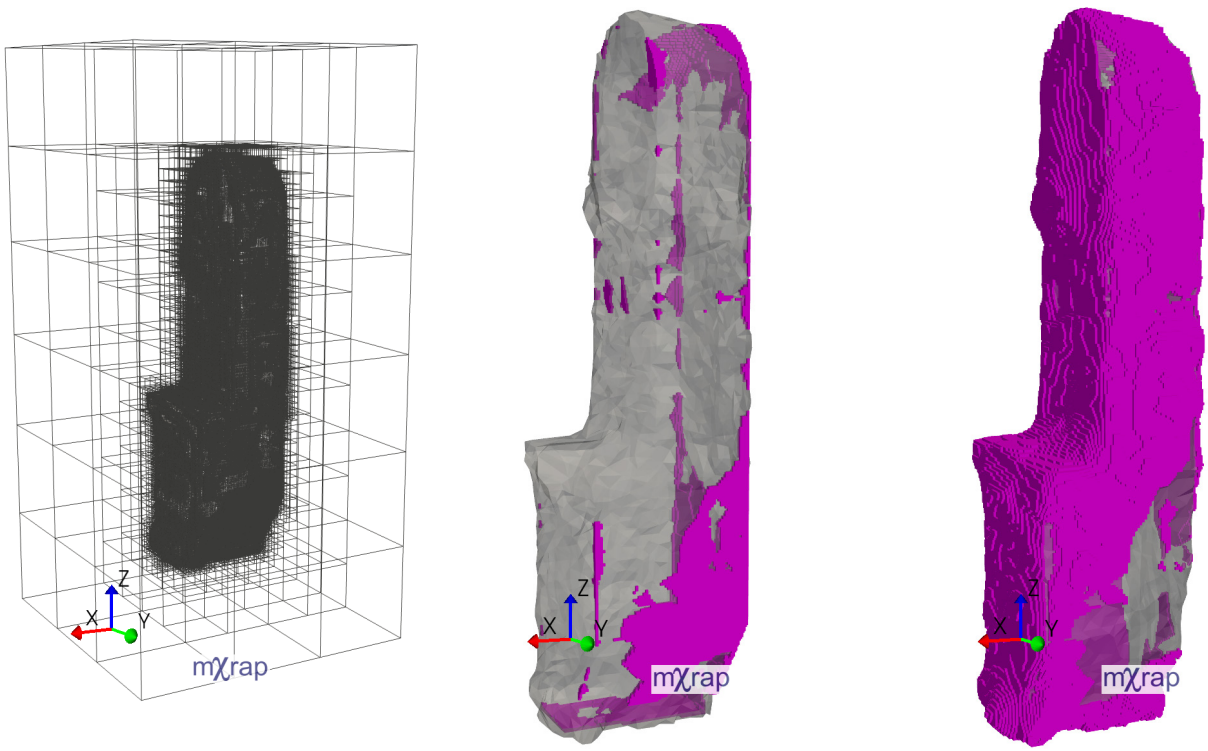

Figure 3 An octree sub-division of stope CMS and design surveys (left) and octree blocks which are volumes of underbreak (centre) and overbreak (right)

dimensions, stability number), operational information (e.g. drilling pattern, slot opening, adjacent stope fill walls), and geotechnical information. The technology transfer to site will occur via mXrap software development and will aim to minimise manual data manipulation. Conceptually, given a stope's CMS and design, the stope performance statistics will be automatically generated with an mXrap stope optimisation app. Furthermore, an additional mXrap app will provide a probabilistic forecast of overbreak and underbreak for a given stope design, historical site-specific stope performance, and factors that influence performance.

Preliminary project progress

The assessment of stope performance is underpinned by the quality of data. Initial considerations of data quality focus on the quality of surveys, specifically stope CMS and designs. Surveys can be constructed with only visualisation in mind and may contain features that influence subsequent calculations. An ideal CMS or design survey will be:

- a single surface representing an individual stope;
- consistent, i.e. no sharp edges, small ledges and other unrealistic features;
- a realistic and consistent resolution;
- free from self-intersections;
- free from internal or external volumes/surfaces; and
- a closed surface, i.e. watertight.

Survey quality is ideally considered during the CMS and design procedures to prevent automated approaches erroneously reinterpreting surveys without site-specific information. As part of preliminary work on survey quality, an mXrap app was created to explore and address some of the more basic survey quality concerns. Figure 2 gives an example of a common error (nodes not being 'snapped' together), and shows the erronous design wireframe (left), and an automatically corrected wireframe (right).

The selection of a method to find the volumes associated with 3D surfaces also must consider how additional information might be integrated in a general assessment framework. A familiar concept and format for geological/geotechnical information is a block model whereby rock properties are assigned to specific volumes. An extension of this concept is not to use blocks of a uniform size but instead to use smaller blocks where more information is available and extra detail is warranted.

A model of the volumes associated with stope CMS and designs can be achieved by the creation of an octree. Essentially, an octree is a tree data structure created from the partitioning of 3D space by recursively subdividing it into eight octants, i.e. blocks are created by dividing volumes that are intersected by surfaces until an appropriate resolution is reached. The implementation of an octree is an efficient and flexible framework for the assessment of stope performance which retains spatial information and is an essential feature to enable the assessment of factors that influence stope performance.

An example of this type of stope performance assessment is shown in Figure 3. A stope CMS and design survey is used to create the subdivision of an octree (left). These octree blocks are assessed with respect to design and CMS surfaces to determine if they are volumes of underbreak (centre) and overbreak (right).

The octree format lends itself to less conventional methods of assessing stope performance. Figure 4 illustrates preliminary work that explores spatial characteristics of stope design and performance. Shown in this figure (right) is the result of an algorithm which automatically detects the 'unique' straight, angled, and domed faces of a stope design. Shown left is a projection map for a 'unique' face. This plot shows the distance between CMS and design surfaces in a direction normal to the design survey. This plot highlights the areas and severity of overbreak (positive distances) and underbreak (negative distances).

Areas plotted as blue are underbreak, red are overbreak, and green are mined to design.

Concluding remarks

Stope design and performance assessment has not significantly progressed despite the economics of mining being intrinsically linked to ore recovery and dilution. Stope surveying data allows improvements to be made when assessing stope performance, particularly when assessing the amount of underbreak and the development of probabilistic methods of stope design that optimise value.

Previous research assessed stope performance at BHP Olympic Dam and showed that by considering operational and design factors, in addition to

traditional measures, overbreak and underbreak outcomes can be improved. The current stope reconciliation project will further develop tools to assess the influence of factors on stope performance and probabilistic stope design. Initial work has focused on survey quality, developing a general assessment framework, and developing exploratory tools that characterise stope design and performance.

Details about the ACG Stope Reconciliation and Optimisation Project are available at www.acg.uwa.edu.au/acg-research.

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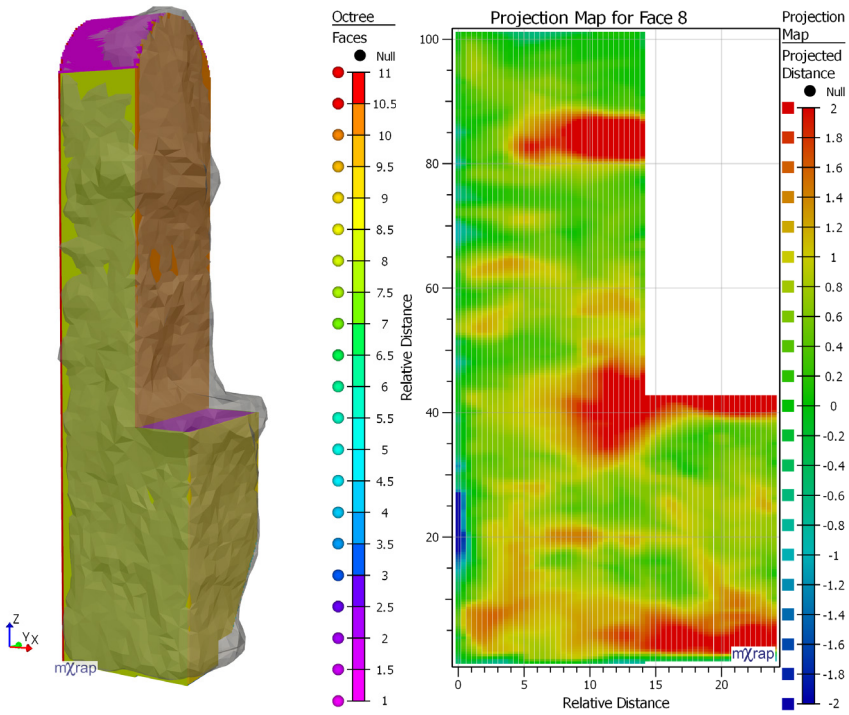
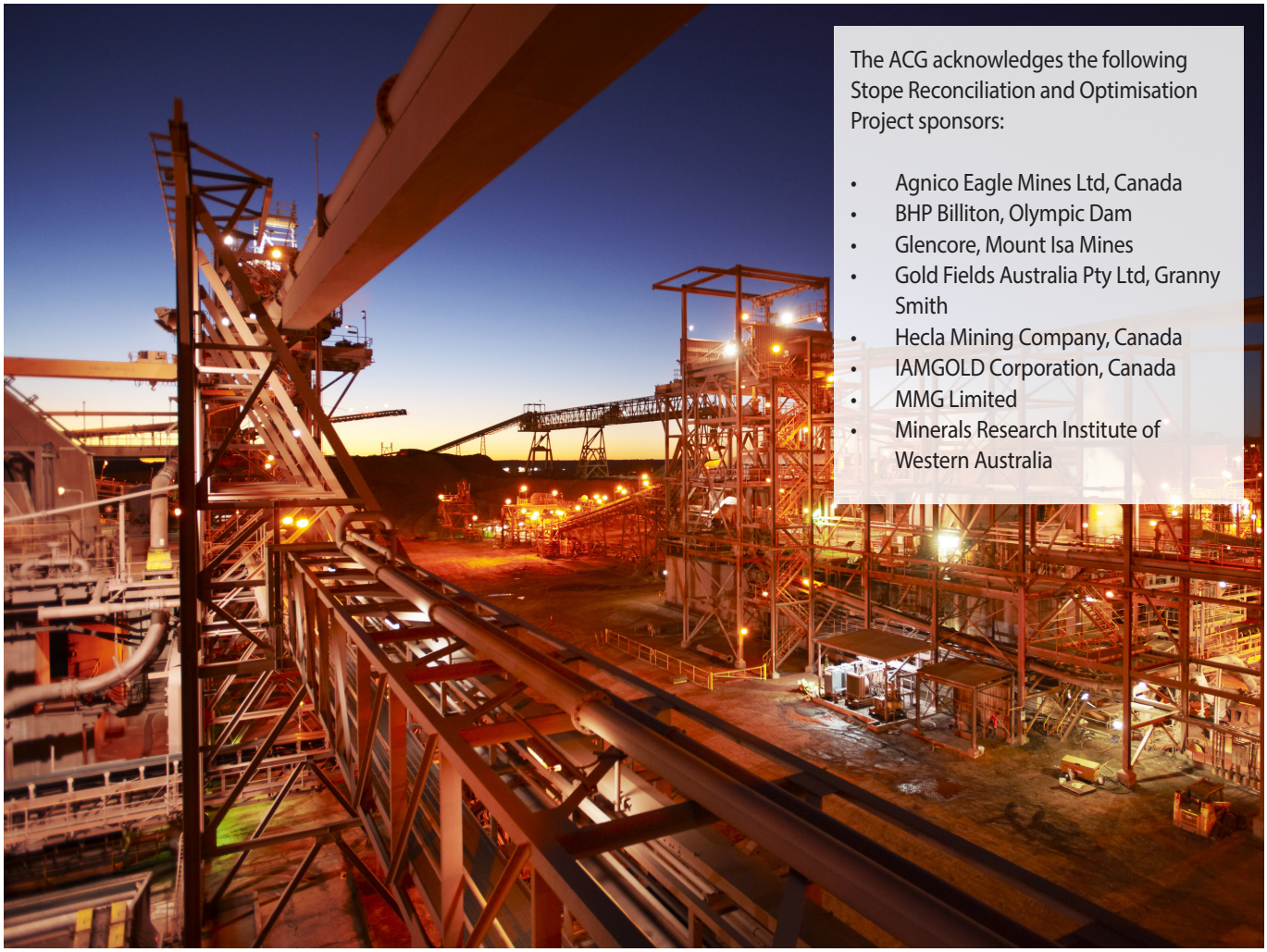


Figure 4 Right - Results of an algorithm which automatically detects the 'unique' straight, angled and domed faces of a stope design. Left - A projection plot shows the distance between CMS and design surfaces in a direction normal to the design survey



The ACG acknowledges the following Stope Reconciliation and Optimisation Project sponsors:

- Agnico Eagle Mines Ltd, Canada
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- Glencore, Mount Isa Mines
- Gold Fields Australia Pty Ltd, Granny Smith
- Hecla Mining Company, Canada
- IAMGOLD Corporation, Canada
- MMG Limited
- Minerals Research Institute of Western Australia

The ACG's Stope Reconciliation and Optimisation research project will build upon the previous results at Olympic Dam to develop tools that enable a probabilistic approach to stope design