The Unseen: A Case Study of Innovative Methods for Investigating Historic Mine Workings

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Abstract. Canadian mining operations have long been key contributors to economic vitality. This has resulted in Canada standing at the forefront of implementing best practices that relate to mine closure projects. In the case of closing historic mines this can be a particularly challenging task as often the level of information available is much less than active mines preparing to close. Closing historic mines provides an opportunity to apply new, and innovative methods to collect the data required to design and execute a successful mine closure plan. The site discussed in this study is in northern Canada and used interconnecting open pit and underground mining methods while in operation but has been closed for over half a century. Historic documents indicate that the mine was closed after a failure occurred at depth and some backfill material was lost. A pond currently exists where the open pit was located. This study is Rock Mechanics focused and discusses the methods used to assess the geometry and stability of the historic mine workings. The need for innovation stemmed from the limited historic plans and documentation that existed. Empirical methods suggested that the crown pillar at the site was unstable and should have failed, which did not align with on-site observations. Therefore, an alternative method of assessing the stability was required which involved undertaking bathymetric and three-dimensional sonar surveys to gain a better spatial understanding of the open pit and underground environment. The surveys confirmed that there were no visible signs of instability in the areas where the surveys were done. Advantages and limitations exist for the methods used to complete the survey and use the survey results during this investigation. These will be discussed in this paper.

1. Introduction

For thousands of years, mining activities have been evolving over time, however the basic principals have remained constant: excavate the area of interest by means of open pit and/or underground mining, extract the material of interest and leave the waste behind. The legacy of selected methods of excavation, extraction, and waste management have long lasting impacts on the land that was mined, and communities surrounding that land.

This paper discusses a case study where investigative methods were used to gain an understanding of a legacy site. The site is located in northern Canada where an interconnecting open pit and underground mine has been closed for over half a century. The void created from the mining had filled with water and currently has the surface expression of a pond where the open pit was located. The pond is located within a populated area which resulted in concerns with respect to long term stability of the area surrounding the pond. To gain a better spatial understanding of the underground mine workings
from the pond at the open pit, a bathymetric survey and three-dimensional sonar survey were completed. The process undertaken to complete the surveys, the results of the surveys and the advantages and limitations of these survey methods are discussed in this paper.

2. Mine History
This case study is focused on a historic mine site located in a town in northern Canada. The mine operated in the first half of the 20th century where open pit and underground methods were used to extract the resource. The mine was abandoned when the shaft pillar started to collapse. figure 1 below shows a long section of the mine from near the end of its operation.

![Figure 1. Layout of historic mine workings and back filled stopes in the Case Study Mine.](image)

Figure 1 confirms that the open pit and the underground mine workings are connected. The orange shaded sections, in figure 1, show the location of the backfill in the near-surface stopes and the small red shaded area indicates where mining was active at the time. The location of the original failure and the way it progressed is not known, but failure of the shaft pillar just below the backfilled portion of the mine would have resulted in loss of some of the backfill. As water levels rose in the mine, the potential for mobilisation of backfill and failure of pillars would have increased.

This case study, is similar to many mine closure legacy projects, as it has limited available data and the quality of the existing data was poor. Previous assessment work to define the amount of backfill lost at this site had included a single point bathymetry survey and some simple horizontal distance measurements that were conducted in the 1990’s. Based on the results of these early investigations, a conservative assumption was made that all backfill and pillars were lost.

As the current underground geometry and extent of mine workings was not known in detail, a bathymetric survey and a three-dimensional sonar survey were completed. These surveys were possible with the significant advancement of survey technology [1] since the investigation completed in the 1990’s.

3. Site Investigation – Bathymetric Survey and Three-Dimensional (3D) Sonar Survey
The underground mine was accessible from the open pit pond. The purpose of the survey was to collect data to provide digital XYZ coordinate files and bathymetric plans with elevations and contours to detail the structure and notable features of the pond and underlying mining excavations.

The survey was conducted with a vessel equipped with a multi-beam echo sounder system and a remotely operated vehicle (ROV) equipped with a 3D mechanical scanning multibeam sonar. An integration of the data collected from both systems resulted in a comprehensive data set allowing the underground mine workings to be visualized.
3.1. Equipment
A selection of appropriate devices was made by the survey contractor. The devices were mounted and integrated aboard the survey vessel and ROV (figure 2) used to complete the field survey.

![Figure 2](image-url)  
*Figure 2. Survey vessel on the pond and the Remotely operated vehicle (ROV) used for the underwater survey.*

For bathymetric data collection, the Norbit Integrated Wide Band Multi-beam Sonar, high frequency (iWBMSH) MBES system was used from the survey vessel. This system consists of high mapping productivity and high-sounding accuracy as well as a dense pattern of soundings to cover the floor. This allowed for details on the bottom of the excavation, including the depth of potential backfill material to be captured.

The ROV included a neutrally buoyant, highly-visible umbilical that was 1,000 m in length. The ROV’s movements, lighting, camera position, and sonar settings were controlled from surface using a hand-held control console. The ROV was used to collect data underwater within the void (underground mine workings). The sonar and video signal were routed to the surface through the umbilical, viewed in real time, and recorded on a computer. The ROV also had a 2D multi-beam imaging sonar which provided real-time plan view information directly ahead of the device. This information was used effectively to allow the ROV to navigate, avoiding obstacles.

For the sonar survey, a survey-grade multi-beam scanning sonar was used and mounted on a frame to the ROV for the 3D sonar survey data collection of areas that were inaccessible by the boat-mounted survey system. High-resolution, 3D point cloud data of the underwater environment was provided by the mechanical scanning multi-beam sonar system. The data measured by the sonar was able to be viewed in real-time on the computer at surface and was stored for subsequent post-processing. The ROV was positioned by the pilot for each scan.
4. Results
The results from the 3D sonar survey provided high quality data. This survey resulted in the ability to create a mesh which allowed for accurate geometries of the large near-surface voids to be determined. This was particularly useful in assessing closure options for this case study (figure 3).

![Figure 3](image)

**Figure 3.** Combination of data to construct the three-dimensional image of the open pit pond and underground mine workings.

The survey mesh allowed for the identification of pillars and backfill related to the underground workings. Anecdotal evidence suggested that backfill mobilization had likely occurred at the site. The surveys also allowed for the current backfill levels to be determined. In addition, the condition and geometry of the hanging wall, foot wall, and the crown pillar was of particular interest at this site. The survey results made it possible to visualize the condition of these features and the edges of the excavations, as seen in figure 4.
The resolution of the mesh created from the survey data was high density and high-quality such that geologic structures were able to be identified, presented in figure 5, which complimented discontinuity data information collected during a drilling investigation. The stereographic projection illustrates a flat-dipping structure and near-vertical structures which coincided with the structures plotted on the three-dimensional mesh. Having two independent methods resulting in similar discontinuity orientations supported the understanding of the rock mass structures for this site where structural data was very limited.

The quality of the sonar and bathymetric survey data allowed for the data to be used as part of an assessment of the stability of the historic workings. Using the data, it had been determined that the underground void and remaining sill pillars were stable. The 3D sonar survey was able to pick out features underwater such as a beam, a satellite dish, and a boat (figure 6). This information showed that there was a lack of extensive rubble on the floor of the excavation which indicated that hanging wall
and foot wall failures were limited. The combination of these data helped inform the opinion that there was no evidence of progressive failure of the hanging wall, foot wall, or crown pillar of the historic workings.

Figure 6. High resolution scans, could detect a boat at the bottom of the underground mine workings.

These survey data were useful as a part of the site investigations for this case study. However, these surveys could also be utilized as part of stability monitoring where surveys are conducted on a set frequency and results can be compared to identify and changes in stability over time.

5. Advantage and Limitations
Following the completion of the of Bathymetric and Three-Dimensional (3D) Sonar Surveys on this case study site a list of advantages and limitations for employing the techniques discussed above at other sites was created. This list may assist the reader in determining whether the technology is appropriate to use in other projects.

Advantages:

- The three-dimensional sonar survey required the use of the ROV and the bathymetric survey required the use of a small boat. Both pieces of equipment were relatively small and easy to navigate in the open pit pond /under water.
- The ROV is easy to navigate in confined spaces underwater to collect high quality data to improve the accuracy of the understanding of the geometry of the underground void.
- The data collection using both survey tools is estimated to have taken one day. It is estimated that two days were required for mobilization and demobilization of the vessels and equipment. This is a fast way to obtain a spatial understanding of the underground workings compared to alternatives such as using historic 2D drawings to create a 3D model or drilling boreholes to determine excavation extents.
- It is possible to see the preliminary results in real time.
- These survey methods did not require human exposure in historic underground workings or above/under the crown pillar.
Limitations:

- Equipment setup time is long compared to the time it takes to collect the data using the equipment.
- The ROV requires the use of a cable which can get damaged or get caught on material in the underground void, during the collection of the survey. Damage to the cable can cause the loss of the equipment.
- Data processing can be time intensive. Turning point cloud data into 3D solids or surfaces can be difficult and time consuming. Sometimes the creation of completely enclosed solids is not possible.
- Risk tolerance for losing equipment must be considered. Acceptance of risk is dependent on the site and operator. This is unlike drones that can fly autonomously and return safely to an operator.
- In this case study, no was data collected in lateral or vertical development. Data collection was limited to the open pit pond. Experience suggests that it would be possible, but it was not tested here.

6. Conclusions
Closed mine sites often have limited and/or poor-quality data to assist in the understanding of the geometries of historic workings. This has created a need for the use of innovative methods to investigate historic excavations. Technology has been advancing rapidly and has allowed for the collection of increasingly higher quality data. In a case where a historic underground and interconnected open pit mine workings were flooded, a bathymetric survey and three-dimensional sonar survey were completed. These surveys improved the spatial understanding of the geometry of the mine workings, the quality of the rock mass, potential geologic structures exposed, the excavation conditions, and the stability of the excavation. The quality of the data allowed for the identification of joint sets and potential failure planes in the rock. Additionally, visualization of the bottom of the mine workings allowed for observations to be made that reflected the stability of the excavations. A lack of failed material suggested that minimal failures had occurred in the excavation walls and the crown pillar. This information made a positive contribution in assessing the future stability of the site.

The technology discussed in this paper may not be suitable to all geometries of mine workings. There are advantages and limitations, as discussed, to both survey methods that were conducted in the case study.

References
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