Mitigating the rock fall and rockburst risk in South African gold and platinum mines through advanced knowledge of the ore body

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ABSTRACT: The Mandela Mining Precinct was launched in 2018 with the goal of modernizing the South African mining industry. It comprises three major initiatives that seek to improve efficiency, health and safety in current mining operations; develop fully mechanized systems to mine narrow tabular ore bodies in hard rock; and develop non-explosive rock-breaking systems. The crosscutting Advanced Orebody Knowledge (AOK) program seeks to develop technologies to characterize the rock mass ahead of mining and identify potentially hazardous geological features. Mining methods, layouts and rock support systems will be adjusted accordingly to mitigate the risk of rock falls and bursts. Technologies include rock drilling, light detection and ranging (LiDAR), ground penetrating radar (GPR), electrical resistance tomography (ERT), and various acoustic, thermographic and seismic techniques. Machine learning methods are being implemented to improve data processing and interpretation. This paper describes the status of the research program at 31 May 2023.

Keywords: rock fall, rockburst, LiDAR, GPR, ERT, thermography, seismics.

1 INTRODUCTION

The Mandela Mining Precinct (MMP) was launched in 2018 with the goal of modernizing the South African mining industry. It is a public-private research program with similar goals to the DeepMine and FutureMine programs active from 1998 to 2003 (Durrheim 2007), but builds on the many advances in knowledge and technology since then. Labor intensive mining methods continue to be widely used in deep South African gold and platinum mines, and falls of ground and rockbursts pose significant risks. The MMP has three major objectives, *viz.* to develop technological solutions that will increase the safety and productivity, reduce the costs and ultimately extend the life of mines for the benefit of local communities and the nation; to revitalize the research, development and innovation (RDI) capability so that South Africa becomes a focal point for many mining RDI offerings; and to improve the capacity of the local mining supply chain to respond adequately and timeously to the needs of the SA mining industry, including RDI.

Three major RDI initiatives seek to improve efficiency, health and safety in current mining operations; develop fully mechanized systems to mine narrow tabular ore bodies in hard rock; and develop non-explosive rock-breaking systems. The crosscutting Advanced Orebody Knowledge (AOK) program seeks to develop and implement technologies that can characterize the rock mass ahead of mining and identify potentially hazardous geological features. A four-phase research plan was formulated:

1. Review & Assess: Gain a better understanding of the relevant in-mine environments to refine the user requirements, thereby enabling the matching of potential technology solutions to specific problems.
2. Evaluate: Establish the state of technology; comprehensive testing of promising technologies; quantification of the value that these solutions might offer.
3. Optimize, Implement & Integrate: Develop the most promising technologies to work more effectively and efficiently; integrate them with the mining production cycle.
4. Transfer Knowledge & Technology: Demonstrate solutions to industry; disseminate knowledge.

The tasks that are currently being carried out to achieve these objectives are described below, together with their status as at 31 May 2023.

2 IMAGING THE ROCK MASS IN AND AHEAD OF STOPES AND TUNNELS

2.1 Mapping the interior of the excavation with light detection and ranging (LiDAR)

Light detection and ranging (LiDAR) is a remote sensing method that uses a pulsed laser to measure reflector range and construct 3D images of objects and spaces. A LiDAR scan provides a point cloud database that can be used to identify geological structures and related hazards and provide a spatially correct geo-referenced structure map that can be consolidated with other data to provide updates of face positions for excavation measurement, reporting and control (Figure 1). LiDAR has been used for forensic investigations in South African mines (Webber-Youngman et al. 2019).

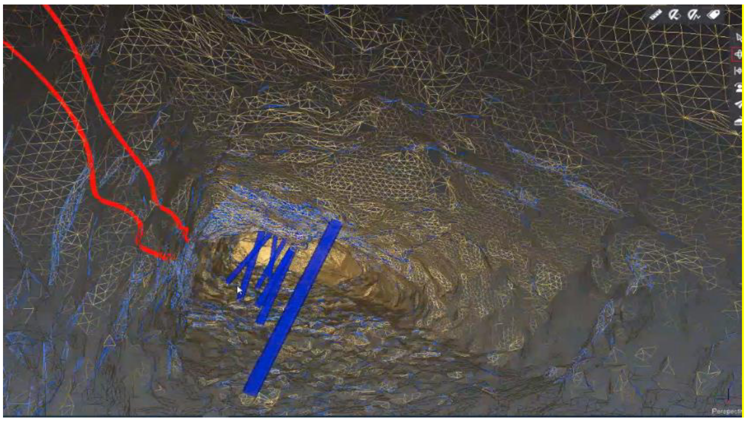

Figure 1. LiDAR image of a stope showing the reef (red lines) and mesh and prop support.

The AOK project, led by Prof Hendrik Grobler of the University of Johannesburg, aims to support the routine application of LiDAR to record the rock type, the geotechnical properties of the rock mass and the actual installation and performance of support elements. The identification of geological features can facilitate more accurate and detailed mapping of the orebody and provide additional information regarding geological structures and potential geological hazards. Several trials have been conducted. The contact between the reef and the host rock was identified and mapped in absolute co-ordinates, and the dip and strike of the reef computed using the three-point solution. It was demonstrated that geology can be mapped effectively under specific circumstances and can add value to the inspection and supervision of working underground faces in a narrow tabular mineral deposit.

2.2 *Scanning stope and tunnel walls with ground penetrating radar (GPR), infrared thermography and acoustic sounding*

Ground penetrating radar (GPR) is a technique that uses transmitted and reflected high-frequency electromagnetic waves to map the structures and discontinuities within a rock mass. GPR is widely used to identify geological features in the immediate hangingwall, assess the fall-of-ground hazard, and guide actions to mitigate the risk such as the barring down of loose rock slabs or the installation of props or rockbolts (Kgarume et al. 2019).

A research project, led by Thabang Kgarume of the CSIR's Future Production Mining Cluster, seeks to improve the efficiency of GPR surveys and improve the interpretability of radargrams. GPR surveys (Figure 2a) were conducted in different mines with the aim of testing the applicability of GPR in identifying different lithological units and the tracking of the reef. GPR was successful in both cases, but had limitations when the survey was acquired in an excavation reinforced with wire mesh, as the mesh attenuated and reverberated the GPR signal, making it difficult to interpret the radargrams. Several geological and geophysical applications of GPR were tested at various mines, including some unconventional applications such as fracture mapping. GPR scans have proved to be an effective method in investigating the stability of excavations, particularly the hangingwall, to mitigate the risks posed by the falls of ground.

The Integrated Thermal and Acoustic Device (ITAD) assists miners to detect loose rock using a non-contact thermal camera method to detect suspected loose rock and display its location to the user. ITAD has the potential to speed up the process of visually assessing loose rock. Thereafter, the assessment can be verified by tapping the rock with a pinch bar and analyzing the acoustic response. This process is known as 'sounding' the rock. These methods will make current rock hazard identification methods more reliable, consistent, and objective. Three prototypes were produced and tested by the CSIR team led by Dean Pretorius from the CSIR's Emerging Digital Technologies for the Fourth Industrial Revolution Research Centre at the Industry Test Mine (Figure 2b). Entry examination was simulated by tapping the hangingwall with a pinch bar to sense if a rock is solid or loose. Acoustic data was collected for further processing and analysis. Tests were also carried out with the thermography camera and produced encouraging results.

Figure 2. Trials of (a) Ground penetrating radar (GPR), (b) Integrated thermal and acoustic device (ITAD).

2.3 *Imaging the rock mass ahead of mining with electrical resistance tomography (ERT)*

Electrical resistance tomography (ERT) is an established geophysical method for mapping the rock mass in mines (Van Schoor 2005; Van Schoor and Binley 2010). A typical in-mine ERT survey took about 8 hours, the most time consuming steps being the drilling of electrode holes (for galvanic coupling) and data acquisition.

A project, led by Dr Michael van Schoor of CSIR's Future Production Mining Cluster, seeks to optimize ERT for routine application of disruptive geological structures in to-be-mined blocks. Trials were conducted at two different sites to evaluate efforts to optimize ERT to make it a viable in-mine mapping tool. Surveys were conducted using modern ERT equipment, electrode configurations and measurement schemes. The survey time was halved, largely due to faster drilling of the electrode holes using a better drilling system, and faster acquisition using a fully automatic, pre-programmable system. The correlation between known geology and the output images was reasonably good. Furthermore, efforts were made to integrate ERT and LiDAR data seamlessly to enable easy geo-referencing.

2.4 Imaging the rock mass ahead of mining with seismic methods

Reflection seismics was first implemented in the 1980s for brown- and greenfields exploration for gold and platinum ore bodies (Malehmir et al. 2012, 2014). Since then there have been dramatic advances in seismic technology, providing valuable information regarding the disposition of the ore body and the presence of potentially hazardous features such as faults and dykes (Manzi et al. 2014). In platinum mines, particular problems are posed by iron-rich ultramafic pegmatites that may be seismogenic, and 'potholes' that might reduce the mineable ore and contribute to poor ground conditions (Manzi et al. 2019, 2020).

A project, led by Professor Musa Manzi of the University of the Witwatersrand, seeks to develop and implement 'in mine' seismic methods to gather structural and geological information around and ahead of tunnels. Seismic experiments were conducted underground (Figure 3) and on surface at the Industry Test Mine. In these experiments, active and passive seismic data were recorded using surface nodal arrays and an in-mine seismic land streamer. The tunnel seismic profiling (TSP) survey consisted of seven 2D profiles above and below a known platinum ore body. Careful data processing enhanced high-quality reflections and suppressed infrastructure-generated noise. Borehole data and geologic models were used to constrain the interpretation. Despite challenges presented by the noisy in-mine environment, the platinum ore body was successfully imaged.

Figure 3. Seismic surveys being conducted in tunnels.

2.5 Prediction of geological structures ahead of mining using artificial intelligence (AI)

Artificial Intelligence (AI) is a concept that encompasses many fields, including statistics and geostatistics, pattern recognition, data science, big data analytics and machine learning. Machine learning algorithms have recently been applied in South African mines to quantify gold resources (Nwaila et al. 2020) and to scan through reflection seismic cubes and detect 'potholes' found in the Bushveld Complex (Zhang et al. 2021). A project, led by Professor Glen Nwaila of the University of the Witwatersrand, seeks to improve these methods to map or predict the likelihood of geologic structures that affect resource estimation, mine planning and safety. The first application of testing the predictability of 'potholes' in Bushveld Complex platinum ore bodies showed promising results. The focus for the next phase will be the detection of geological structures such as dykes and faults within the gold mining environment.

2.6 Probing the rock mass ahead of mining with diamond drilling

Diamond drilling is the surest way of determining the position of the orebody, mapping structures such as faults and dykes, and detecting the presence of hazards such as high pressure water and flammable gas. Current drilling performance, measured in terms of drilling rate and accuracy and drill bit wear, was deemed to be poor.

A project, led by Dr Abrie Oberholster of the University of Pretoria, seeks to develop a 'Smart Drill' that is equipped with sensors that record factors such as penetration rate, vibration and noise; makes use of machine learning to interpret the data; and then adjusts the operational parameters such as rotational speed, bit force and water supply to achieve optimal performance. Such machines have been developed for open pit mines, but not for the conditions encountered in gold and platinum deep level mines in South Africa. The project team built a laboratory rig equipped with suitable sensors, intelligence and controls (Figure 4). An instrumented rod measures torque, weight on bit and rotation speed and rotational vibration; an accelerometer measures rotation unit thrust bearing axial vibration; and a microphone measures the noise emitted by drilling. Tests were carried out on different rock samples. Artificial neural network (ANN) implementation demonstrated that the captured data contain sufficient information to classify rock type and rock hardness with relatively high accuracies. Further testing is planned at an underground mine.

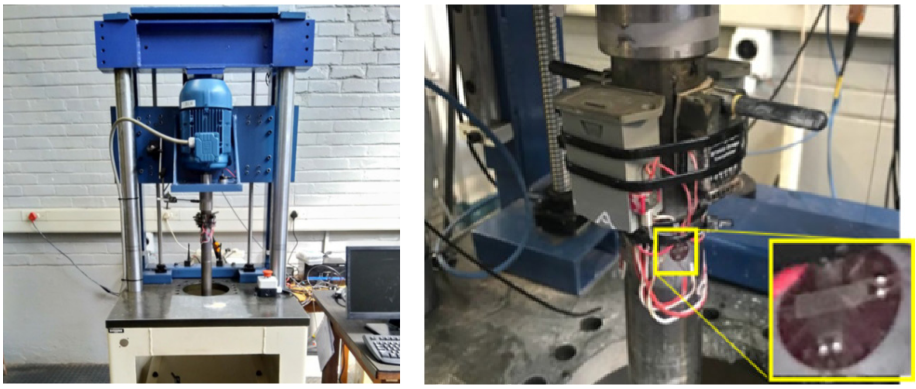

Figure 4. Laboratory rig used to develop drilling control system.

3 CONCLUSIONS

The Mandela Mining Precinct's Advanced Orebody Knowledge program aims to develop technology to create a 'glass rock' environment in which the ore body is 'visible' so that it can be efficiently mined, and where geological hazards (e.g. rock falls and bursts, inrushes of water and flammable gas) can be reliably detected and measures taken to mitigate the risks. In summary, mining can be made safer and more efficient if there is accurate and up-to-date information describing:

1. The topography and rock type of the walls and roof of the excavation, and the type and performance of rock support elements and systems installed inside the excavations. The most suitable technology is deemed to be LiDAR.
2. The condition of the jointed and fractured rock mass that surrounds the excavation and poses a rock fall or rockburst hazard. This zone is typically several meters thick. Ground penetrating radar (GPR), thermography, acoustic sounding and seismic surface waves were deemed to have the best ability to do this.
3. The location and grade of the orebody and the condition of the rock mass that will be exposed in the coming weeks and months. This zone typically extends tens of meters ahead of the excavation. Diamond drilling, electrical resistance tomography (ERT) and tunnel seismic profiling (TSP) were deemed to have the best ability to do this.

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