

ADVANCED OREBODY KNOWLEDGE FACTSHEET

Brief overview of the programme

Industry Challenge – which industry challenge does the programme seek to address?

The key mining challenges addressed by the Advanced Orebody Knowledge (AOK) program are:

- Difficulty in accurately understanding the underground orebody before and during extraction.
- Hazards due to inadequate information about geological conditions.
- Ineffective resource management and planning leading to wasted resources.
- High Operational Costs due to these uncertainties and inefficiencies.
- Limited operational life due to sub-optimal extraction methods.
- Negative effects on the environment and local communities from mining activities

MMP/SAMERDI Solution – how is the programme addressing this challenge?

The Advanced Orebody Knowledge (AOK) programme is at the forefront of transforming the mining industry through its groundbreaking technology. By creating a detailed, real-time, 3D model of the orebody, essentially a "glass rock" environment. The AOK programme allows mining professionals to visualize and understand geological conditions and ore distribution during the extraction phase. This innovative approach significantly enhances both safety and efficiency.

The AOK programme addresses the challenges by the following:

- **Improved Safety** - The real-time 3D modeling provides a clear view of underground conditions, enabling better anticipation and management of potential hazards. This proactive approach helps to minimize risks and create safer working environments for miners.
- **Increased Productivity** - Detailed knowledge of the orebody allows for more strategic planning of extraction methods. By understanding the ore's distribution and surrounding rock characteristics, mining operations can be more precisely planned to maximize resource recovery and minimize waste. Accurate orebody models allow for optimized planning and extraction processes, leading to more efficient resource utilization and increased overall productivity.
- **Cost Efficiency** - By reducing uncertainty and improving operational planning, the AOK programme helps lower operational costs. Efficient resource management and reduced downtime contribute to significant cost savings.

- **Extended Mine Life** - By providing a transparent, detailed 3D model of the orebody, the AOK programme enables mine planners, rock engineers, and geologists to visualize the underground environment as if it were glass. This reduces the uncertainty, and risks associated with traditional mining methods, which often involve working with limited or outdated information. Improved planning and management strategies supported by the AOK technology can extend the operational lifespan of mines, ensuring more prolonged resource extraction and operational sustainability.
- **Community Benefits** - Extended mine life and enhanced safety contribute to the economic stability of local communities by providing sustained employment opportunities and supporting local businesses. Additionally, better environmental practices associated with advanced technologies can reduce negative impacts on surrounding areas.

Overall, the AOK programme is committed to advancing technological solutions that not only improve mining operations but also deliver positive outcomes for both the industry and the communities it serves.

Highlights of the Programme – what are some of the programmes highlights so far? This could be milestones reached or knowledge products/solutions created etc.

- **Tunnel Seismic Tomography (TSP)** – TRL 9, Advanced geological prediction into great depths using tunnel and underground Seismics, reports available from Know More - Mandela Mining Precinct
- **Stratify Seeker (TRL7)**, a multi-camera that can create 3D models from photogrammetry, currently in development, reports available from Know More - Mandela Mining Precinct
- **ITAD (TRL 6)**, a device that can identify loose rocks during barring practices, currently in development, reports available from Know More - Mandela Mining Precinct
- **Au and PGM Resource Atlas**: available from Council for Geoscience Interactive Web Map
- **Rock Hazard Identification (tech package)**: This work package, through the Technology Scouting and the Open Innovation Challenge, identified a varied set of solutions for which further R&D and testing can be done both individually and in a complementary manner, available from Know More - Mandela Mining Precinct
- **Webinars**: Geophysics Webinar: "A recap of in-mine geophysics research and development", 06 March 2024 (youtube.com/AOKWebinar)- Michelle Pienaar (youtube.com)

- Guidelines and Training materials: Application of GPR in South African Mining/Application of ERT in South African Mining/In-Mine geophysics in Research and Development, available @ Guidelines - Mandela Mining Precinct
- Various publications within the field of Geosciences, available on request mpienaar@mandelaminingprecinct.org.za
- Actively involved in various steering committees that focus on overseeing and guiding technical aspects of projects

Statistics – Numbers give perspective. Include any interesting figures e.g. number of collaborators, number of knowledge products or solutions created/tested/adopted by industry

- Visited and conducted trials at over 30 operations
- Produced over 100 reports
- Published over 30 conference and scientific papers
- Collaborations with over 40 institutions
- Developed numerous guidelines and recommendations within the field of Geosciences
- Exposed over 20 students, interns and junior researchers within the field of Geosciences through the AOK Programme,

Remember a fact sheet provides key facts and should not be “word-heavy”. Please include pictures (in JPEG or PNG format) or suggestions of pictures that can be captured to represent the programme well.

WEBSITE PAGE TEMPLATE

Overview of the Programme

Provide a detailed overview of the programme

The Advanced Orebody Knowledge (AOK) programme is a forward-thinking initiative designed to significantly enhance the safety, efficiency, and overall effectiveness of mining operations. Its primary goal is to establish a "Glass Rock" environment. At its core, the AOK programme aims to improve geological confidence by providing a more accurate and reliable understanding of geological conditions ahead of the mining face. This enhanced geological insight is crucial for better planning and decision-making, minimizing uncertainties and risks associated with mining operations. This will contribute to the optimal extraction and "zero harm" objectives.

A key focus of the programme is the proactive identification and management of geological risks. By using advanced technologies and methodologies, the programme seeks to detect potential geological hazards, such as faults, dykes, and gas intersections, before they impact mining activities. This proactive approach helps in mitigating risks and preventing unexpected disruptions that could compromise safety and productivity.

The AOK programme addresses several significant challenges in mining. It tackles unpredictable geological conditions, such as changes in reef topography and unexpected geological structures, which can impact mining operations. It also aims to prevent operational disruptions caused by gas outbursts, water inundations, and dangerous strata conditions. By reducing the risk of injuries and operational problems, the programme helps maintain a safe working environment and prevents productivity losses, equipment damage, and financial setbacks. As mining operations extend deeper and further, the AOK programme becomes increasingly vital as it provides the necessary geological knowledge to navigate the complexities.

The AOK Programme is based on several key components, including the use of geoscientific techniques and technologies. These techniques encompass fields such as geophysics, which involves physical measurements to investigate subsurface properties and structures; statistics, for analyzing data to detect patterns and improve ore body models; mineralogy and geochemistry, which study mineral composition and chemical properties; and geotechnical and structural geology, which assess rock stability and geological structures.

The AOK programme's implementation strategy involves the parallel pursuit of technology areas, ensuring that data acquisition, processing, and visualization technologies are developed simultaneously and integrated effectively. This approach aims to create a comprehensive "Glass Rock" system that functions cohesively.

The programme also emphasizes collaborative research and development. Industry partnerships with mining companies, technology providers, and research institutions will ensure that new technologies are practical and applicable. Continued investment in research will help maintain technological advancements and drive innovation within the programme.

The AOK programme represents a significant advancement in mining technology. By focusing on enhancing geoscientific methods and providing real-time data insights, the programme aims to create a safer, more efficient, and productive mining environment, ultimately contributing to the goals of optimal extraction and "zero harm."

The AOK programme is expected to deliver several significant benefits. Enhanced safety is a primary advantage, as improved detection and management of geological hazards will reduce the likelihood of accidents and equipment damage. Predictive capabilities will allow for early identification of potential issues, enabling timely intervention and preventive measures.

The AOK programme is in the realm of continued research and development, which will continue to focus on fostering ongoing innovation by investing in advancements in sensor technologies, data processing methods, and visualization tools. Additionally, it will continue to actively explore and incorporate emerging technologies to ensure that these capabilities remain at the forefront of the industry.

Projects

- Group projects according to years of initiation

During the inception in 2018, the AOK programme initially focused on several key areas, including refining user requirements, identifying the most promising technologies, conducting baseline assessments, and evaluating technologies to determine their potential impact. Following the initial phase, the AOK programme shifted its focus in 2020, to examining specific solutions, testing promising technologies, and conducting detailed assessments. This phase involved identifying technologies that required customization and optimization to better meet user needs and enhance overall performance.

Further research was identified (2022) into specific data collection sensors and sensor systems, such as acoustic, thermal, radar, and seismic sensors. It was realized that it was crucial to explore combinations of these sensing methods to enhance data collection by overlaying multiple datasets, which can provide more comprehensive insights. Another critical area requiring additional research is data processing methods. The mining industry needs advanced algorithms capable of utilizing current parallel-processing technologies to interpret sensor data more efficiently. The current data processing times, which can extend to hours or even days, are insufficient for real-time applications. Developing methods that achieve real-time turnaround, ideally within minutes, is essential for continuous mining operations. Finally, data display and visualization also need significant attention. Effective visualization is closely related to data processing and interpretation, as data cannot be quickly assessed unless presented in a readily reviewable form. Research should focus on enhancing data display techniques to ensure that information is accessible and actionable. Leveraging and extending ongoing work in this area can help meet the specific needs of the mining industry.

The AOK programme identified four key themes to support the gaps as mentioned above, namely: the development and refinement of the smart drill, the integration of technologies on the mining face, the advancement of technologies ahead of the face, and the facilitation of knowledge transfer and research dissemination which incorporates the three technical themes.

1. SMART DRILL

In the 2019, possible solutions were sought to address the low drilling rates typically achieved with underground diamond drilling in the South African mining industry (SAMI). The lack of access to skilled drill operators in the SAMI was identified to negatively affect drill performance in terms of drilling rate, hole accuracy and drill bit wear, is. One solution is the development of a Smart Drill. This concept revolves around the idea that a skilled drill operator makes use of sensory inputs such as vibration, noise and visual feedback during drilling to adjust the operational parameters in real-time (such as rotational speed and rate of penetration), to yield optimal performance of the machine. In 2020, a laboratory test setup was built to establish the feasibility of this approach. It was demonstrated experimentally that drill operational parameters including torque, weight on bit and rotational speed can be used to successfully classify rock type.

During 2021 the AOK project team identified leading practices within other industries and commodities which could be adapted to improve diamond drilling practices within deep level tabular orebodies. 2022 an industrial original equipment manufacturer (OEM) partner was

identified. One of their diamond drill rigs was instrumented with sensors and a number of test holes were drilled at one of the operations in Rustenburg. The data resulting from this was analysed and compared with analysis results on core samples.

The next logical is to introduce “intelligence” in the instrumented drill rig. The development of an intelligent (AI) solution to make sense of the large amount of data resulting from the drill field trials has been planned from 2024 onwards which includes,

- Expand the core team from that of the current project phase to include AI specialists (and industry partners).
- Identify potential AI methodologies and models, narrowing these down to a smaller number all of which show potential.
- Each shortlisted method/models shall be developed into a working prototype that can be used to demonstrate the success (or not) of each using the same input data captured during the current phase field drilling trials.
- From this, a preferred method/model will be selected.

Successful completion of the above activities will confirm the utility of a truly intelligent diamond drilling rig. This will necessitate further drilling field trials to validate the utility of the selected AI method/model. A logical continuation will include the further development of the drill rig to an autonomous solution.

The step from intelligent to autonomous will improve the availability time of key geological information in almost real-time. This will further enhance the safety to drill operators and other staff in the immediate vicinity of core drilling operations. The addition of AI to the drill will have the added possibility to link the data (AI outcomes) to other equipment due to its use of digital communications technology (and with that its entry into 4IR).

2. INTEGRATION OF TECHNOLOGIES ON THE MINING FACE

Numerous technologies designed for on-face applications in mining have been identified and tested over recent years. These technologies aim to enhance the understanding of subsurface conditions and improve mining efficiency and safety. Here’s an overview of some notable on-face technologies and their applications.

Ground Penetrating Radar (GPR)

The progression of research and application of **Ground Penetrating Radar (GPR)** and associated geophysical technologies in the mining industry over recent years reveals a dynamic and evolving field. In 2018, an assessment of GPR data revealed that while current processing capabilities were promising, there was room for significant improvement. The focus was on evaluating 3D GPR trials conducted at two underground hard rock mines—one for gold and another for platinum. These trials aimed to enhance understanding of excavation stability and improve risk assessment models. The findings indicated that 3D GPR could be a valuable tool in Rock and Mining Engineering, offering potential for better risk management in mining operations.

An important part of the study involved exploring the potential integration of thermal scanning technology with GPR. Thermal scanning was considered as a complementary technology that could theoretically identify geological features closer to the hangingwall, specifically within a meter. The intent was to establish a correlation between the thermal scan and GPR data to create a comprehensive 3D model. However, the experimental study conducted at a Platinum mine in Rustenburg faced challenges. The old worked-out area, with shotcrete, mesh, and roof bolts in place, hampered the scanning process, leading to inconclusive results.

By 2020, the scope of GPR applications had broadened significantly. The research included unconventional uses of GPR, such as identifying lithological units and mapping fractures. Trials conducted at several mines provided exciting and well-received results within the industry.

GPR successfully identified different lithological units in the footwall and discontinuities, demonstrating its effectiveness in distinguishing between various geological features. This was particularly relevant for improving the understanding of the footwall's composition and structure.

Additional trials further validated GPR's capabilities. The technology was able to identify specific lithological units in the hangingwall, such as the Khaki shale, which had previously caused problematic ground conditions and led to the sterilization of significant mining areas. The ability to detect these problematic units in advance was a notable advancement. Additionally, GPR managed to map certain units in the footwall and detect blasting fractures within the mining face.

Some of the trials conducted were focused on testing the depth and range capabilities of GPR within the footwall. These trials produced accurate models that were successfully integrated into geological models, demonstrating GPR's potential for extensive application in geological mapping.

and risk assessment. This success led to an invitation to apply these learnings to other Platinum operations, indicating the growing confidence in GPR's utility within the field of Geoscience.

In 2021, the focus shifted towards integrating GPR outputs into a 3D visualization environment. This integration involved incorporating GPR data with mining information such as mine plans to create comprehensive visual models. The research evaluated various seismic attributes in real GPR data to determine their effectiveness in enhancing subtle structural features.

The findings suggested that some of these attributes could significantly improve the detection and interpretation of structural features in GPR data. However, further research was recommended to compare the processing approaches involving these attributes with traditional methods. This comparison aimed to assess whether the use of attributes provided a significant advantage or if similar results could be achieved using existing GPR software options.

Additionally, the integration of GPR with LiDAR technology was explored. This combined approach promised to advance the development of a unified tool that leverages multiple geophysical technologies, enhancing the overall effectiveness of subsurface mapping and modeling.

Substantial research funding was invested in developing in-mine applications for the GPR technology. These efforts led to significant advancements in survey logistics, user-friendliness, data output, and visualization. In 2022 the project was closed out with a close-out report and GPR guidelines were made available, which aimed to improve the implementation and effectiveness of these technologies in mining operations. The guidelines and knowledge transfer efforts were intended to empower mining operations to leverage these technologies more effectively.

In 2023, the AOK research dissemination workpackage included a webinar that highlighted the benefits of GPR in optimizing extraction and improving safety in mining. The addition of 3D Lidar mapping to geophysical data analysis was also discussed, based on the insights gained from use-case studies.

The webinar suggested several future research directions, including the need for training programmes for mines, logistical improvements, and the integration of data analytics and artificial intelligence. The importance of staying updated with technological advancements was emphasized, alongside addressing both technical and human factors in the implementation of geophysical technologies. This ongoing focus on innovation and practical application underscores

the commitment to enhancing safety and efficiency in the mining industry through advanced geophysical methods.

GPR has proved to be a technology which can identify geological discontinuities within the hangingwall (1-3m) of a mining excavation. In 2020, **Thermal scanning** was identified as a potential technology that could hypothetically be used in conjunction to that of GPR to identify geological features in proximity (<1m) of the hangingwall. The intent was to establish if any correlation could be obtained between the information obtained from the thermal scan to that of the GPR survey, ultimately being able to create a 3D model. An experimental study was then conducted at a Platinum mine in Rustenburg, to determine if any correlation existed between the results of that of the thermal scan versus the GPR survey that was conducted. The study was conducted in an old worked out area where shotcrete, mesh and roof bolts were in place which hampered the scanning. The scanning results were inconclusive.

LiDAR

In 2020, **LiDAR** has been identified as one of the exciting technologies that could be applied for geological mapping. Its use and application have been limited to the survey departments due to the size of the equipment and the high cost. Furthermore, processing of the point cloud data is tedious and time consuming, where scans contain big data sets that might not necessary be required. Various work was done on this through the AOK programme to identify if it would be an alternative mapping tool and assist with georeferencing, however the cost associated with this technology has remained a stumbling block. LiDAR underground trials showed the benefit and detail of data captured and could be a feasible alternative to conventional geological mapping. LiDAR results were also used with the integration of ERT, TSP and GPR tests. This will ultimately lead to a usable 3D model for mine use.

In-mine geophysics has struggled with efficiently and accurately georeferencing data due to the lack of GPS in underground environments. LiDAR technology has provided a solution by offering portable, handheld devices that can provide accurate maps of excavations and infrastructure. Terrestrial, tripod-based LiDAR systems have been used in the past, but they are time-consuming and logistically difficult.

In 2023, portable LiDAR technology, such as the Geoslam were tested, which allows for easy data acquisition with high-resolution point clouds in a short amount of time. The acquired point cloud data can be georeferenced and converted to a standard file format for further processing and visualization.

Integrated Thermal Acoustic Device (ITAD)

The **Integrated Thermal Acoustic Device (ITAD)** is a technology designed to enhance safety in underground mining by identifying potentially hazardous loose rocks through a combination of thermal imaging and acoustic analysis. Developed by the CSIR, this device aims to improve rock stability assessments and mitigate rock-related incidents in mining environments.

In 2022, three ITAD prototypes were produced and tested at the Industry Test Mine. The primary objectives were to identify loose rock using thermal imaging, gather large-scale acoustic data, and evaluate the ITAD's efficacy in assessing the acoustic response of rock. The trials successfully achieved these goals. A total of 1,806 acoustic data samples were collected, which were sufficient to train a machine learning model with an accuracy of 77.9%. This indicated that the dataset was of an adequate scale to support meaningful analysis.

The acoustic subsystem of the ITAD demonstrated its capability to distinguish between safe and unsafe rock based on frequency response. However, the thermal imaging component faced challenges, particularly with the accurate identification of loose rock areas due to its limited angle of view and difficulties in interpreting the thermal images.

In the 2023, the ITAD was used to validate its effectiveness in various mining environments without modifying the initial prototype. The validation revealed that the ITAD performed better in Platinum and Chrome mining environments compared to Gold environments, showing a high correlation with miners' opinions. However, issues such as "wrongful safes" and variability in performance based on rock types and excavation conditions were noted. Additionally, the performance of the ITAD was influenced by the type and length of the pinch bar used during acoustic testing.

The thermal imaging component continued to face challenges in detecting loose rock areas accurately. These issues highlighted the need for further development in both the thermal imaging capabilities and the overall functionality of the ITAD.

For the 2024, the focus will be on improving the ITAD's algorithm. This includes validating and testing new algorithms to enhance performance and comparing results obtained with different or combined algorithms. Additionally, efforts will be made to develop a remote tapping method to eliminate the need for direct human interaction, possibly using a mechanical device to apply a constant impact force to the rock.

The project will also explore strategies for reducing noise in acoustic measurements, aiming to filter out extraneous sounds and improve the clarity of the rock's acoustic signature. Enhancements to the thermal imaging capabilities will be pursued to better detect loose rocks, and integration with communication technologies will be investigated to enable real-time data visualization and analysis.

To address the identified issues and improve the ITAD, several recommendations have been made. These include refining the algorithms for better accuracy, optimizing barring practices and tools, implementing noise reduction strategies, and enhancing the thermal imaging system. Continued field data collection and industry collaboration are also crucial for advancing the ITAD's development and ensuring its effectiveness in real-world mining conditions.

The ITAD technology holds significant potential for improving safety and efficiency in underground mining operations. Ongoing development, validation, and refinement are essential to achieving this potential, with a vision of advancing the ITAD towards commercialization and broader adoption in the mining industry.

Stratafy Seeker

Stratafy, a finalist in the 2022 Fall of Ground (FOG) Challenge, focused on hazardous rock identification using a comprehensive three-pronged approach. This approach integrated specialized hardware, human-executed techniques, and both local and cloud-based processing capabilities. The aim was to combine these elements into a practical and cost-effective solution for identifying and visualizing geological and rock hazards.

The project centers on three major components: the "Digital Pinch-Bar," Stratafy's Photogrammetric processing platform, and the integration of these elements to enhance hazard identification. The "Digital Pinch-Bar" comprises two key parts: the Scanning Head (Syntopic Camera Array) and the Processing Pod, which delivers a real-time 3D model to the user's handheld device.

Initiated in 2023, Part 1 focused on developing a scanning head prototype to generate accurate 3D point clouds. The development included miniaturizing the scanner hardware and integrating essential components such as the power source, LED lights, and trigger mechanism. Testing was conducted in real-world environments at different mines. The results were positive, and the prototype of the scanning head was successfully completed.

For Part 2, the focus shifted to developing the Processing Pod, which provides real-time feedback in the form of a 3D model display. This component is crucial for verifying the quality of scans and ensuring effective processing and analysis. Key steps included custom building and testing the Processing Pod and remote screen for 3D visualizations, scaling up to process 3D point clouds from the syntopic camera, and verifying the hardware's performance in real-world conditions. Adjustments will be made as needed during this phase.

The final part involved integrating the **Stratafy Seeker** with the existing Stratafy Photogrammetric processing platform. This step leverages the platform's open architecture to quickly incorporate the new capabilities without extensive redevelopment. Key tasks included modifying the Stratafy platform to handle Fall-of-Ground Plug-ins, updating it to manage complex 3D models, and enhancing API capabilities for delivering overlays and hazardous zone information to end-users.

The development of Prototype V1 included building a 3D model scanned at DigiMine and testing it further at Bakubung. The camera and lighting systems were thoroughly tested for performance, including ensuring optimal LED brightness, color tone, and zero shadow. Subsequent improvements from V1 to V1.5 focused on simplifying the design, reducing the weight, optimizing battery life, and enhancing processing speed. The V1.5 prototype also improved user ergonomics for easier maneuverability in underground settings.

For 2024/25, the planned work includes:

- Building the Scanner-Specific Processing Pod, which will serve as both an output display and processing unit for the images gathered by the Stratafy Seeker Head.
- Creating a plug-in for the Stratafy Platform to enhance its functionality, facilitating seamless data integration from the Seeker for in-depth analysis and near-real-time feedback.

The Stratafy Seeker project has seen the development and testing of multiple prototypes (V1, V1.5, and V2), validating the use of photogrammetry and multi-camera lens overlap to create effective 3D models for hazardous areas. The prototypes have undergone rigorous testing in real-world underground settings, consistently yielding positive results and confirming the viability of the innovative approach. Further development aims to refine these prototypes, enhance processing capabilities, and integrate with existing platforms to improve geological hazard identification and visualization.

Laser-Induced Breakdown Spectroscopy (LIBS) Technology

As part of the SAMERDI AOK programme's research efforts in 2018, a comprehensive study was conducted to evaluate various 'non-conventional' technologies for advanced orebody knowledge. This study culminated in the report titled "Review of Non-Conventional Tools for Advanced Orebody Knowledge" (Vogt, 2018). The report provided status reviews of technologies such as hyperspectral imagery, X-ray fluorescence (XRF), X-ray diffraction (XRD), and laser-induced breakdown spectroscopy (LIBS). Furthermore, PGE and Gold samples were obtained whereby it was analysed using Laser-Induced Breakdown Spectroscopy (LIBS) and Mineral Liberation Analysis (MLA) scanning technologies. This was compared with mineralogical/assay grades. Tests conducted indicated that LIBS would not be a sufficient technology to replace gold chip sampling, however there is a potential for PGM's grade testing.

In light of advancements since 2018, including ongoing background work and sensor technology developments, it was proposed to revisit LIBS technology. For 2024, the aim is to evaluate its current applicability and performance, particularly in local platinum and gold mining environments. The study recommended further investigation into LIBS through laboratory testing and numerical modeling, followed by in situ geological studies for quantitative assessment. Given the progression in LIBS technology, it is timely to test a commercially available LIBS scanner through controlled experiments.

Revisiting LIBS technology through this proposed experimental approach aims to provide updated insights into its practical applications and performance in local mining environments. By conducting controlled experiments and validating results through traditional assays, this study will offer valuable data on the effectiveness of LIBS for advanced orebody knowledge.

Rock Hazard Identification Technologies (RHID) and Showcase Event

In the beginning of 2022, the AOK programme with the Minerals Council FOGAP team, in collaboration with mine partners Sibanye-Stillwater and Impala Platinum, embarked on a project aimed at identifying and developing novel solutions for rock hazard identification and safe rock removal. The primary focus was to enhance safety by reducing falls of ground (FOG) and improving worker safety through advanced technological solutions.

The **RHID** project included global landscape research and technology scouting, contacting 52 experts from various international locations such as Sweden, Germany, and Japan. This extensive research helped identify cutting-edge technologies and innovations in rock hazard identification.

A call for proposals in the Rock Hazard Identification category invited submissions featuring a range of innovative technologies. These technologies were proposed to provide real-time rock mass quality inspection and improved hazard detection.

In November 2022, a panel consisting of representatives from the Mandela Mining Precinct, Minerals Council South Africa, Sibanye-Stillwater, and Impala Platinum shortlisted the top seven submissions. A final judging round took place in December 2022 at a virtual "pitching den" event. Reutech Mining emerged as the winner of the challenge.

Within the mining industry, data is gathered from a wide spectrum of data sources such as diamond drilling, sampling and mapping. This data comes in from multiple sources and at different scales which makes it difficult to model the underground environment using conventional tools, neither can geological structures be predicted with the use of classical statistics or machine learning as they are not capable of predicting linear features as required. Due to the success during 2022 of the Rock Hazard Identification challenge, it was decided to follow a similar approach and conduct a **showcase event** in 2024.

The proposed methodology aims to investigate, report on and then host an event showcasing the existing technologies used to create "glass-rock" environments. Providing such a showcasing opportunity to service providers will ultimately assist in adopting and developing plug-and-play software for geological data and analysis that can be effectively utilised in mine design and planning.

3. INTEGRATED TECHNOLOGIES THAT WILL BE USED TO OBTAIN INFORMATION AHEAD OF THE FACE

In the early stages of the AOK programme, TSP and ERT/RIM were identified as potential technologies to be further investigated. Tunnel-to-Tunnel tomographic technologies such as TSP, ERT and RIM has shown promise which could enable one to obtain readily available information between two raise lines and potentially larger areas ahead of the mining front. More comprehensive datasets can be obtained to give a more accurate and detailed geological model.

Tunnel Seismic Profiling

In 2018, a numerical modeling study was carried out to evaluate the suitability of Tunnel Seismic Profiling (TSP) or similar technologies for deep-level gold and platinum mining. This study compared TSP with passive seismic monitoring in terms of resolution and range. The positive outcomes from this comparison led to the inclusion of TSP in the AOK project plans.

From 2020 to 2022, active-source and passive seismic surveys were conducted at a Platinum mine, introducing several innovative approaches. These included the integration of surface and tunnel seismic profiles and the use of various seismic instruments. These innovations proved essential for effective seismic data acquisition, paving the way for more cost-effective and environmentally friendly seismic surveys in tunnels and mines both in South Africa and globally.

The in-mine underground tunnel seismic experiments included underground GPR surveys along the seismic profiles. The experiment aimed to reduce drilling costs, lower exploration costs, maximise mine safety, increase the possibility of finding new prospects, and increase the life of a mine. The Tunnel Seismic Tomography trials which are the first in Africa had such positive results, further testing was extending to one of our older deep gold mines to test at more extensive depths. This project was conducted parallel to the European Funded project called "Future Mine".

In 2023, surface experiments and tunnel surveys conducted yielded valuable insights into the subsurface geology, including one of the major structures intersecting the mine's architecture and the distribution of the orebody. The use of broadband nodal sensors, cabled systems, and fiber optic cables enabled high-resolution imaging and enhanced geological structure detection.

The integration of surface and tunnel data improved the understanding of the geology, contributing to more accurate resource estimation and optimization of mining operations. The successful application of different sensing technologies and data synchronization through GPS time tagging demonstrated the effectiveness of these methodologies. Overall, these advancements in seismic imaging techniques have significantly enhanced the ability to gather geological information ahead of the mine face, supporting mineral exploration and mining activities.

Electric Resistance Tomography (ERT)

The development and application of Electric Resistance Tomography (ERT) for detecting reef disruptions in mining tunnels evolved significantly from 2018 to 2023. In 2018, initial simulations comparing ERT with Resistivity Imaging (RIM) highlighted ERT as the more promising technology for detecting disruptions like potholes. By 2019, a plan-review visit was conducted where the ERT proposal was presented to the Geoscience team. This led to the identification of an underground site for testing, and the necessary site requirements were outlined and reviewed during an onsite visit.

In 2020, the project was divided into two trial surveys. The first, a small-scale survey, used basic computer simulations to aid in planning. It successfully detected and resolved the intended

geological targets, with significant improvements in logistical aspects such as site preparation and data acquisition, making one-shift surveys feasible. The second, larger-scale survey, presented more challenging in-mine conditions, revealing obstacles that needed further research before ERT could be routinely used in mines.

The year 2021 saw the completion of a set of guidelines for in-mine ERT surveys, including a step-by-step procedure and a standardized measurement scheme tool. This tool was enhanced to automate the determination of measurement schemes and to convert data into compatible formats. The team successfully demonstrated that ERT could potentially become a routine reconnaissance tool, with improvements in survey logistics and data handling, including successful data export and georeferencing.

By 2022, significant research funding was invested in developing ERT. Advances in survey logistics, user-friendliness, and data visualization were achieved. A close-out report for the ERT projects focused on transferring skills and knowledge to mining operations, aiding them in implementing these technologies in-house or through service-level agreements.

By 2023, a webinar was held as part of the AOK research dissemination workpackage. This webinar emphasized the benefits of ERT and GPR in optimizing mining operations and introduced 3D Lidar mapping as a valuable addition to geophysical data analysis. It suggested future research directions, including improved training, logistical enhancements, and the integration of data analytics and artificial intelligence. The webinar underscored the importance of staying updated with technological advancements and addressing both technical and human factors in the implementation of geophysical technologies in the mining industry.

Statistical analysis and machine learning

In the mining industry, geoscientists work with data from various sources and at different scales. Data is collected from diamond drilling, sampling and mapping. This wide spectrum of data sources makes it difficult to model using conventional tools. Most of the geological structures in mining operations are identified during underground geological mapping and a select group of major geological structures are identified using both 2D and 3D seismic data. These structures cannot be predicted with the use of classical statistics or machine learning as they are not capable of predicting linear features as required.

Data collection from one of the PGM Mining houses was initiated during the first phase of the project in 2020. In 2021, data processing and geodomaining from data collected was conducted.

Numerical block modelling and computer simulations took place to gain deep learning for the prediction of potholes. Statistical analysis and machine learning was applied to data provided, to identify if there is a way to conduct pothole prediction ahead of the face. A software programme was created, and two models were produced and given back to the mining house. Prediction accuracies (hit rate on known potholes) of 90 to 95 % were achieved using interpolation methods that rely on seismic attributes. This was obtained up to 600 meters ahead of the face. However, some challenges were experienced with the extrapolation model which is in the 600 meter and above range.

In 2022 The aim of this research was to use statistical analysis and machine learning for the prediction of geological variables such as ore grade and geological structures (e.g., faults) ahead of the mining face. An improved workflow that builds on data tools used to predict potholes in the Bushveld Igneous Complex and its modification to incorporate spatial weights was used to predict in-situ Au grades and geological structures in the Witwatersrand Basin.

The project Phase 1 which included data collection & data cleaning, and feature engineering & model training was successfully completed at South Deep (Goldfields). Phase 2 which includes Field acquisition of 3D seismic data, stacking and migration, Creation of a 3D synthetic seismic volume and training of CNN and Prediction of faults and cross validation was completed under phase two in 2023 and incorporated into the Tunnel Seismic Tomography project's results.

Au and PGM Resource Atlas

In 2018, cataloging and quantifying the platinum group metal (PGM) resources and reserves within the Bushveld Complex and gold resources was conducted. The scope extended nationwide, resulting in the compilation of data from 186 defunct and 47 operating gold mines, totaling 233, as well as 88 gold projects. For platinum, data was collected from 34 mines and 76 projects. Detailed physical characteristics of ore bodies, such as reef thickness, geological structure, orebody geometry, geotechnical features, and mineability were defined and recorded.

The project also included determining the "upside potential" or Exploration Target, which involved assessing the additional mineral resources available beyond the current and defunct mines and identifying areas where mineralization was known or expected. A conservative geostatistical approach was used for this quantification. To foster collaboration and innovation, a workshop was conducted, which encouraged ideation and solution development. Part of the project focused on

capacity building, including software training, collaborative work, and technical handover. A fit-for-purpose information system was successfully implemented, which featured best fit analysis, a platform approach, modularity, and scalability. This system included crucial elements such as data security, modeling, processing, validation, and curation.

By 2020, the Au and PGM resource atlases were made publicly available for researchers, students, and industry professionals. CIMERA's work indicated that these resource atlas could help identify areas with untapped potential for gold and PGM extraction. The results highlighted potential unmined “white” areas in the Witwatersrand Goldfields and Bushveld Complex. It was also noted that advanced mining technologies were required in certain areas, particularly in the Central Rand and Evander Goldfields, where deep and thin reefs presented extraction challenges. The PGM and Au atlases were tested and released, with all servers configured and ArcGIS software installed. A custom-designed web-based GIS platform was created, including a new homepage for the National Resource Atlas. All relevant third-party and reference data were integrated and made accessible online through the platform.

The project reached a significant milestone in 2022 with the decision to migrate the Au and PGM Resource Atlas to the Council for Geosciences (CGS). This move was intended to ensure the system's sustainability and further growth. The CGS, with its existing operational capacity, was well-positioned to support the Atlas from technological, data, and personnel perspectives. Strategically, the CGS was also well-placed to integrate the Atlas with other geoscience data, enhancing its utility for the wider mining community and supporting the expanded vision of the Atlas.

4. KNOWLEDGE TRANSFER AND RESEARCH DISSEMINATION

As part of one of the AOK programme's focus areas, the emphasis will be on the ongoing transfer of knowledge, skills, and learnings. This involves maintaining a structured approach to facilitate the effective sharing and application of expertise throughout.

The programme will continue to prioritize holding and attending various events such as workshops, training sessions, and conferences. These activities are essential for the dynamic exchange of knowledge and for fostering professional development. Workshops and training sessions will be designed to address specific needs and challenges, offering targeted learning opportunities for participants. These sessions will not only disseminate the latest research findings and advancements but also encourage practical skill development and knowledge application.

Webinars and seminars will be integral components of the programme's strategy. Webinars offer a flexible and accessible way to share knowledge, allowing participants from various locations to engage with content and experts in realtime. These online sessions can be particularly useful for reaching a wider audience, providing updates on recent developments, and facilitating interactive discussions on specific topics. Webinars enable the dissemination of information in a convenient format, accommodating busy schedules and diverse time zones.

Attending conferences will be another key element of the strategy. Conferences provide a platform for engaging with the broader community, staying updated on the latest trends, and networking with experts from diverse fields. By participating in these events, the programme can gain insights into emerging issues and incorporate new knowledge into its activities.

Overall, this approach ensures that the programme remains at the forefront of its field, continuously integrating new information and practices while fostering an environment of collaborative learning and professional growth.