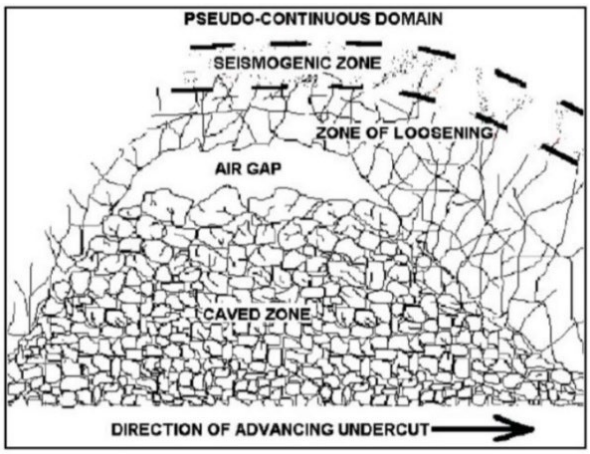
CAVE MINING 2040 CONSORTIUM FOR GLOBAL CAVE MINING RESEARCH

HORIZON 1 OUTCOMES SUMMARY

August 2022

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

mining3
TRANSFORMINGMINING

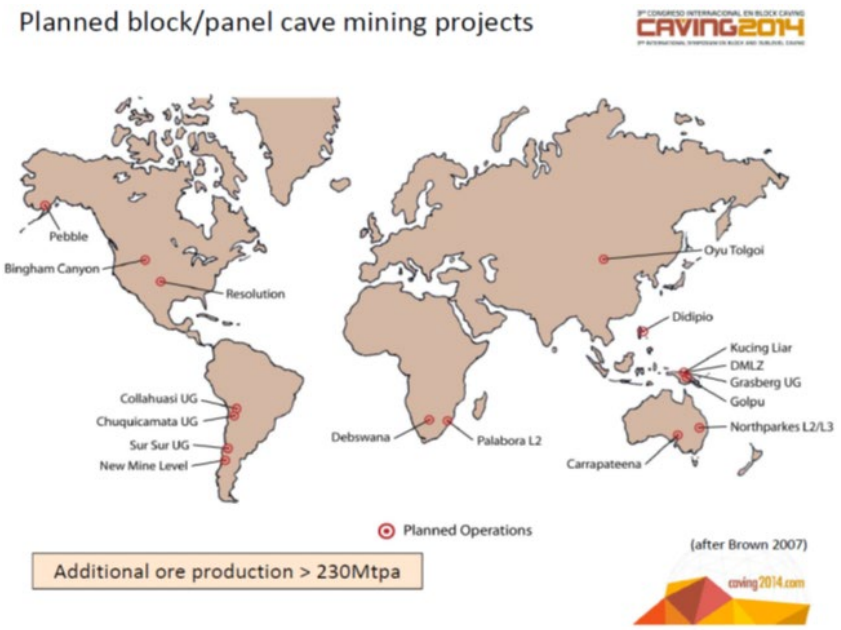


Cave Mining 2040 (CM2040) is a collaboration of Mining Industry members to develop activities to transform the cave mining industry.

Supported by Mining3, Cave Mining 2040 has been working for the past 4 years, as Horizon 1, to develop solutions that reduce lead times and capital investment by transforming cave mining as it is presently practised, to methods that improve its viability, safety, cost, production, and profitability, while improving its societal and environmental acceptance.

Mining companies with an interest in Cave Mining or mining at depth are invited to join the consortium for the next horizon of Cave Mining 2040 research.

Contact **info@mining3.com or +61 7 3365 5640**



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Sponsors (Horizon 1)

Cave Mining Research

THE ISSUES

Cave mining and deep exploration drilling are the future of the mining industry as surface orebodies become scarcer and discoveries at depth more common. Effective and efficient ways of accessing orebodies below depths of 500 m from the surface and with undercuts planned for 2000m, in the first instance, need to be a key focus for the mining industry to remain profitable into the future.

Potential high production rates and low operating costs mean that cave mining is increasingly the chosen method of extraction for progressively deeper large orebodies. Despite the long lead time required ahead of an investment decision and the high capital investment required to establish a caving mine, the current cave mining techniques of block, panel and sublevel caving are presently the only viable underground mining methods that can be used to extract large, deep, lower-grade ore deposits in harsh geological and geotechnical environments. This need changes.

THE RESEARCH EVOLUTION

The Proposal for the Cave Mining 2040 Horizon 1 Study Areas evolved from the May 6, 2016, *Cave Mining Industry Workshop* held during the week of the MassMin 2016 International conference, focusing on the future of mass underground mining variants, specifically caving mining methods at depths approaching 2000m in the first instance.

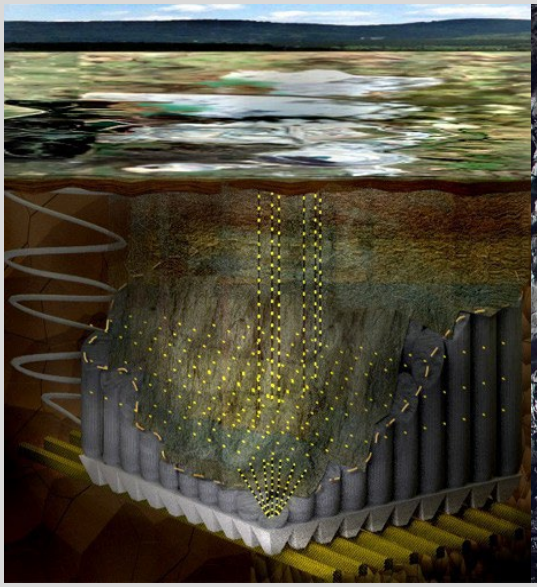
The purpose of the May 2016 workshop was for the active participants to identify critical challenges that they or the cave mining industry is now facing (*known - unknowns*) and more significantly those expected to be faced in the immediate and long-term future.

The developed consortium aims to develop solutions that reduce lead times and capital investment by transforming cave mining as it is presently practiced, to methods that improve its viability, safety, cost, production, and profitability, while improving its societal and environmental acceptance.

Mining3 (formerly CRC Mining) is a pre-eminent, industry-driven centre for global mining research and innovation. With a track record of collaborating and partnering with leading mining companies, original equipment manufacturers (OEMs) and universities, Mining3 delivers transformational research and innovations that maximize mining productivity and enhance resource utilization, safety, and sustainability.

CM2040 Horizon 1 Contributions to Knowledge

BACKED BY CASE STUDIES



Contribution to knowledge

Detailed reports

Study areas to be completed 2022

All six study areas for the Cave Mining 2040 Horizon 1 will be completed during 2022 and each is believed to have come up with at least a **'Contribution to knowledge'** to one of the known unknowns in that study.

Detailed reports were submitted to the 30-31st March 2022 Cave Mining 2040 executive steering committee meeting and are summarised as follows:

CM2040 Horizon 1 Study Areas (2018 – 2022)

An exhaustive list of natural geological, geothermal challenges spanning deposit depth, size, shape and more, as well as man-made challenges including ore-body access, productivity costs, safety, and longevity and sustainability of business. These generic priority areas were collectively referred to as *'The Cave Mining 2040 Horizon 1 Study Areas'* in accordance with a roadmap which evolved from a May 2016 workshop attended by participants from the caving mining industry.

The Cave Mining 2040 'Horizon 1 Project' comprised of six study areas (*each briefly outlined below*) likely to have short to mid-term impacts on cave mining methods during the next 10 years and ultimately contribute to the overall transformation of cave mining variants, which are conventional, macro, sublevel caving and inclined caving. As the research work progressed, the names of some of the study areas were changed to suit.

1. Total deposit knowledge

An adequate level of orebody knowledge—including the 'total' deposit knowledge (TDK) i.e., geological, geotechnical, and hydrogeological characteristics—is the foundation upon which cave mining will be transformed in the future. The ultimate objective of TDK research is the ability to produce a 3D mining 'uncertainty' model of an ore deposit (that is, quantifying the key characteristics of the ore body not fully measured).

2. Rapid Cave Establishment

Reducing the high capital investment required to establish a caving mine requires a paradigm shift in how future deep ore deposits are accessed and caves are established. The cave establishment study area is focused on safety, speed, efficiency and reducing the up-front capital requirement.

3. Mine design for new and emerging technologies

By redesigning the extraction level arrangement to maximise ore recovery, we also enable the cost-effective use of emerging technologies and reduce the amount of required horizontal and vertical mining development, as well as ensure the effective and cost-effective implementation of automated production systems. Because the extraction level must remain in place for an extended production period, overall layout design, ground support and roadway conditions are critical factors. By initially investing in high-performing, large-scale, lasting infrastructure, the day-to-day operational costs can be lowered throughout the life of the cave.

4. Macro-block design and sequencing optimisation

The development of mining strategies for caving ore deposits with large footprints using the concept of macro-blocks has the potential to provide significant benefits. By considering in situ and induced rock-mass conditions and geological structures, while maintaining extraction level stability, macro blocks will potentially delay ingress of waste, as well as reduce up-front capital expenditure.

5. Cave Front /Cave Back Tracking Using Active and Passive Microseismic Data
Knowledge of where the cave is at any time is important for miner safety (to limit risk of catastrophic air blast as a consequence of cave back sudden failures) and for production (to know in advance if the cave is moving towards waste rock). One of the most useful techniques currently used for cave front tracking is passive Microseismic monitoring.

In high stress environments, the cave front is preceded by a cloud of Microseismic events as the intact rock above the cave begins to fail (Seismogenic zone). As this cloud of micro seismicity leads the cave by a distance called the aseismic gap, a likely cave surface can be fitted somewhere below the cloud.

This simple approach (currently state-of-the-art) is limited in its use, as it only informs on the region where micro seismicity is occurring, therefore "imaging" a relatively small volume. This may be useful in small and simple caves, but in larger caves, would fall short drastically, as it ignores several factors such as lateral cave growth, location uncertainty and varying system sensitivity.

6. Sublevel Caving Benchmark
Sublevel caving is a method often evaluated in parallel with block and/or panel caving options. It requires multiple levels of development and ongoing ring blasting for production. Sublevel caving allows for a more selective extraction but typically achieves lower production rates than block and panel caving methods.

By assessing and quantifying the interrelationship between blasting, fragmentation and gravity or disturbed flow that is available from purpose-conducted, full-scale studies can determine methods for improving (primary) ore recovery. The research would extend or build upon ongoing work carried out at Glencore's Ernest Henry sublevel caving mine in northwestern Queensland, and the Ridgeway sublevel caving operation, outside Orange, NSW, both in Australia.

Total Deposit Knowledge (*TDK*)

MAIN AUTHOR: ANDRE VAN AS (FOR VAN AS GEOTECHNICAL PTY LTD AND ASSOCIATES)

The primary objective of the TDK Project was to develop best practice guidelines for the collection, analysis, and interpretation of geoscientific data (geological, geotechnical, hydrogeological) required to construct a robust geotechnical model from which thorough cave mining analyses can be conducted for cave design and planning, cave performance. To this end, several subject matter experts (SMEs) in their field were engaged to provide a concise overview on their area of expertise. These contributions have been compiled into various chapters comprising the overall guideline document.

In addition to data collection and data processing, the issues surrounding data variability and uncertainty in geo-model development were proposed through the application of a novel geostatistical framework. Geostatistical methods of quantifying geo-model reliability and sufficiency for different phases of study were also suggested. Finally, a novel framework for describing the state-of-the-art methods/tools for identifying, quantifying, and reporting geohazards was proposed and its application demonstrated through a current case study.

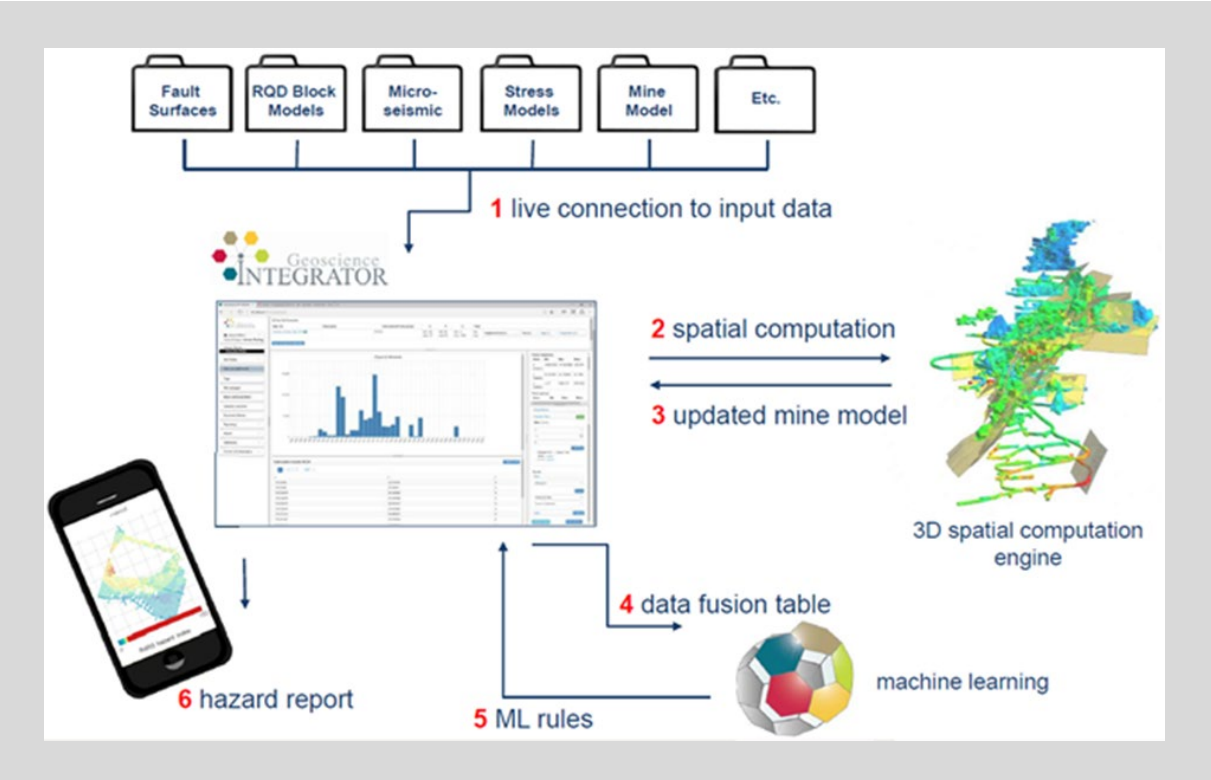


Figure 1. Geohazard framework from data source to reporting (after Mira Geoscience).

Note: Author asked and permitted to publish and use the framework for actual case histories.

‘Rapid’ Block Cave Establishment Scheduling and Optimisation

AUTHOR: STEVEN DONALDSON (FOR POLYMATHIAN)

This project has developed the first strategic decision support tool capable of solving the block cave establishment problem using mathematical optimization. The tool is a data driven hosted web application that integrates generically with industry standard mine planning packages such as Deswik, Spry, and DataMine. It has been iteratively configured alongside sponsor data through case studies.

This project has shown that it is possible to optimise the block cave establishment problem using a fundamentally different approach to what is currently industry standard. This approach uses mathematical optimisation driven by a global objective function instead of the typical engineer driven priorities. This allows for improvement and/or validation of mine schedules. There have been several key learnings from this work:

Mine design set up is key: Existing scheduling approaches influence how engineers create mine designs. Exports from existing models for use in the tool (as occurred for the case studies) can have missing dependencies, artificial planning constraints and/or heavy reliance on priorities, which can all introduce complexities.

Expression of task relationships is fundamental: As an optimisation tool, tasks which don’t provide direct value or don’t lead to value in other tasks will not be scheduled. This means task relationships must be clear and support the value driven optimisation.

Calibration of the objective function is key to finding good results: The objective function describes what is a good plan. With fully connected task relationships, this can be as simple as ‘finish establishment as early as possible’. Alternatives like ‘value all work as soon as possible’, and ‘value milestones’ may be required to account for relationships not expressed in the design.

CASE STUDIES

Polymathian have iteratively collaborated with the sponsors and their data to guide the project. This has resulted in:

- Wide ranging exploration of objective function outcomes, with over 2000 hours of computation across the project.
- Added functionality for variable task rate decisions allowing the optimisation to evaluate when work is completed and at what rate.

Highlight case study:

- OZ Minerals Carrapateena Block Cave Expansion.
- Objective function configuration: >20 different objective configurations trialled to explore impact on this data set.
- Result: 1-month faster schedule over the existing plan.

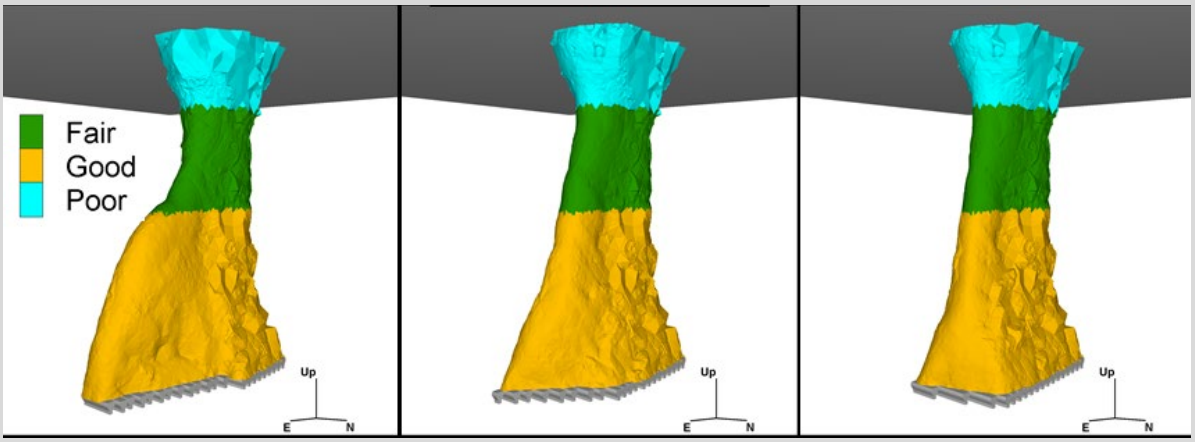
Designing Block Caves for High Recovery (Macro blocks)

AUTHOR: GLENN SHARROCK (FOR ITASCA AUSTRALIA)

The key industry questions this project addressed was **"***how should footprint layouts and draw schedules in block caves be designed to achieve high recovery during cave interactions***".**

The broad goal was to use experience and analysis to understand how block cave interactions are best managed during cave transition. The primary objective was to improve understanding of Cave Interactions between neighboring mines (i.e., blocks, panels, SLC & open pit) for selected vertical and lateral interaction scenarios. The focus of the research project was to undertake a series of parametric analyses on key geotechnical and mining parameters identified to influence interacting block caves. Over 750 models were run across three interrelated topics: (1) Caveability & Draw (2) Gravity Flow (3) Excavation Stability & Rock Bursting.

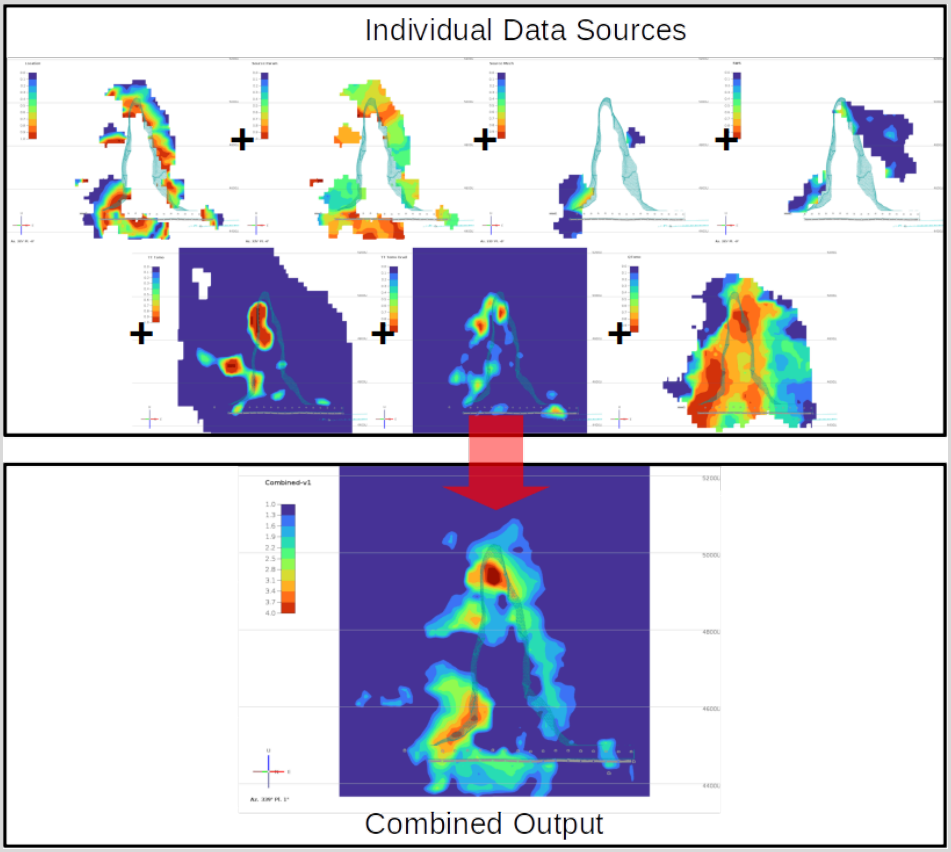
The seminar outcome of the project was development of over 200 guidelines, formulated for feasibility studies. However, it is noteworthy that specific study has design complexities that are not typically reducible to simplistic guidelines. Even so, guidelines form an invaluable starting point in deciding what geotechnical work is needed to understand and mitigate geotechnical risk, to achieve high recovery.



Cave Front Tracking using Active and Passive Microseismic Data

PRINCIPAL AUTHOR: STEPHEN MEYER (FOR THE INSTITUTE OF MINE SEISMOLOGY, TASMANIA)

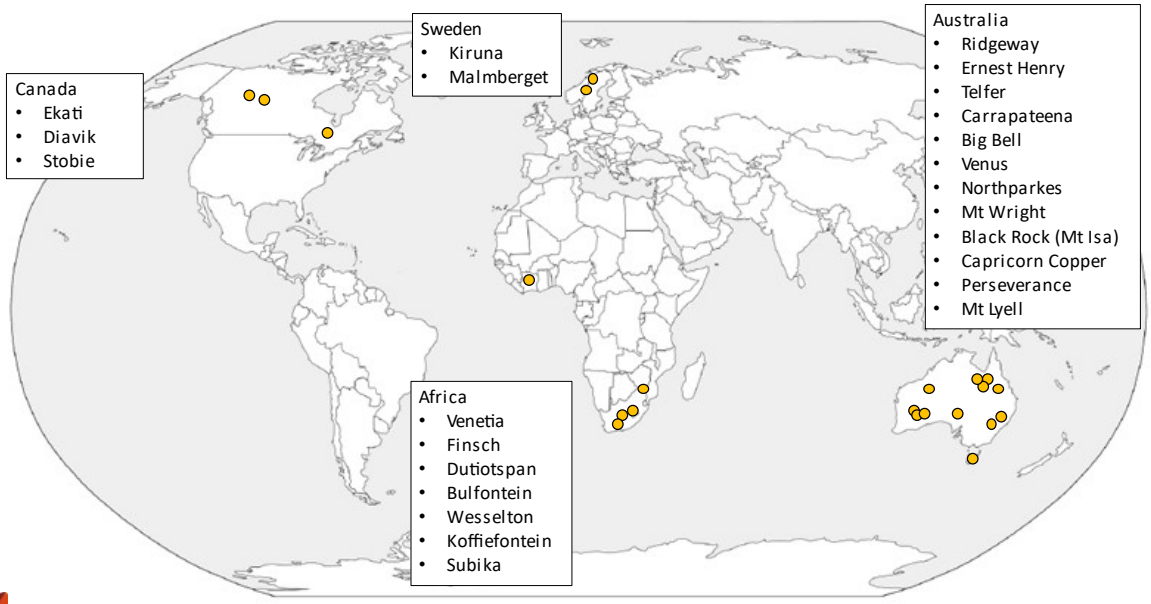
Microseismic monitoring is widely used in caving mines to help track the progression of the cave and associated yield zone. Historically, the common approaches focus on event locations only, and depend on an individual person's subjective interpretation. This project aims to provide engineers on site with a tool that utilizes seismic data previously ignored, and, additionally, allows results to be generated in a repeatable manner, reducing the potential impact of user bias. Various sources of seismic data, including event locations, source parameters, source mechanisms, shear wave splitting, and travel time and attenuation tomography are examined and how they relate to the yield zone around a cave. Other, more unconventional aspects of seismic data, such as ambient noise and active sources, are also investigated. The information from these different sources is combined to give a more comprehensive understanding of the state of the yield zone.



Review of Global Sublevel Caving Best Practice

PRINCIPAL AUTHOR: DR ALEX CAMPBELL (AS BECK - ENGINEERING)

The global review documents and compares operational practices, technical aspects, and hazard management techniques across 24 sublevel caving mines (SLCs) around the world. The benchmark is the largest of its type completed for any underground mining method. Comprehensive reports for each mine and extensive benchmarking document current practices across global SLC operations. The project reports act as a both a reference and guideline for practitioners and future mining studies. Key learnings from the project were that most SLC mines are the best in at least one aspect of mining such as drill and blast or mine development, for example, and that every mine has plenty to learn from other SLCs, no matter how new, old, or technologically advanced the mine is.



Documenting and sharing the learnings from each mine and current best practices ensures mines do not reinvent the wheel, enables mines to learn from each other, and encourages the industry to advance forward.

Mining3 Cave Mining 2040

Program Management

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GIDEON CHITOMBO

Gideon is a Mining3 Technology Leader specializing in Cave Mining. Gideon's research is focused on mass underground metalliferous mining specifically using cave mining options, which are conventional block, macroblock, panel, inclined and sublevel caving through applied international industry-funded projects (consortia). He has been involved in several renowned caving operations for extended periods including in Australia, South Africa, and Chile.

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LEEANNE BOND

Project Sponsor for Mining3

Leeanne Bond is the Chair of the Board and Interim Executive Director of Mining3 and has over 30 years corporate experience including almost 20 years as a professional company director and board member. Leeanne is a non-executive director of Aurecon Limited, ASX listed Synertec Corporation Limited and Australian government business enterprises Snowy Hydro Limited and the Clean Energy Finance Corporation. She is a member of the Board of One Basin CRC and the advisory board of Battery Storage and Grid Integration at the Australian National University (ANU) and Master of Energy at The University of Queensland (UQ).

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G CHITOMBO BRIEF CV

Gideon's research is focused on mass and hard rock underground metalliferous mining specifically using caving mining variants, which are conventional block caving, macroblock, panel, and sublevel caving through a suite of applied international industry-funded projects or consortiums. The application of the inclined caving variant is now being trialled by some, given the requirement for caving at significant depths and high stress environment.

Gideon was appointed as an international advisory board member (Chairman) of a European Initiative (I2Mine) designed to focus on the technological challenges the European mining industry was likely to face in the future including the exploitation of ever deeper deposits and the aspiration for an invisible, safe, zero impact mine. The project was being carried out by a consortium of 26 organizations from 10 European countries.

He was a 2012 recipient of a prestigious Australian's Academy of Technological Sciences and Engineering (ATSE) Clunies Ross Award.

Gideon is currently working with the mining industry consortium including supervision of company part-time and site-based PhD and MPhil postgraduates. This is to develop new knowledge and methodologies needed to apply caving mining methods effectively and safely at depths approaching 2000m from the surface, and in potentially challenging geotechnical environments.

The project designated as Cave Mining 2040 Horizon 1, superseded the then suite of research consortium, the Mass Mining Technology (MMT) to become a milestone-driven industry and knowledge transfer consortium, producing a paradigm shift in the application of caving mining variants to increasingly deepening and geotechnically challenging deposits.

The corresponding work commenced in February 2019, with Gideon designated as the Research Director, monitoring project scopes and research quality. The CM2040 H1 consortium is scheduled to complete 2022.

Gideon has been working on the development of a follow-up consortium proposal, arbitrarily named 'Cave Mining 2040 Horizon 2', and his role will be as an advisor to the consortium.