

Organising for the successful management of complex underground caving mines

J Nguz Tshisens *Freeport-McMoRan, USA*

A Moss *Sonal Technology Inc., Canada*

M Sullivan *PT Freeport Indonesia, Indonesia*

A Yuniar *PT Freeport Indonesia, Indonesia*

T Casten *Freeport-McMoRan, USA*

C Zimmer *PT Freeport Indonesia, Indonesia*

Abstract

The number of caving mines is increasing worldwide, with several new mines under development. While the technical challenges of caving are well known, they are not necessarily well understood. The execution of a development and operations plan is a complex process constrained by the realities of access, construction, ventilation, and mucking requirements, as well as uncertainties in ground conditions and rock mass response during caving. An equally important challenge exists around the organisation and management of resources to build and operate such mines. The challenges require a flexible and collaborative approach from the start that is based on sound engineering and performance measurement. The success of such an approach is illustrated through the progress of the PT Freeport Indonesia (PTFI) caves from the study stage to access development, infrastructure construction, cave establishment and ramping-up to the current production rate of 200,000 tons per day. Many technical lessons were learned along the way and various technologies were used to meet the challenges. More importantly was the creation of a coherent execution group with a clearly defined leadership team. Central to this was an underground steering committee comprising senior representatives from operations, engineering, geo-engineering, and safety. The committee's mandate was to determine solutions that addressed the strategic and tactical needs of the business rather than the short-term gains of the project. The collaborative leadership model used by PTFI was instrumental in the successful ramp-up of one of the largest caving complexes in the world.

Keywords: *caving, mines, collaborative, leadership, committee*

1 Introduction

PT Freeport Indonesia (PTFI) operates in the remote highlands of the Sudirman Mountain Range in Mimika Regency, the province of West Papua, Indonesia. The PTFI mining complex is composed of the Grasberg open pit that was closed at the end of 2019, five underground mines, the Deep Ore Zone (DOZ) which closed at end of 2021, the Deep Mill Level Zone (DMLZ) currently in operation, the Grasberg Block Cave (GBC) currently in operation, the Big Gossan (BG) stoping mine in operation, and Kucing Liar (KL) in early access development and feasibility study stages. PTFI production comes from its underground operations that are approaching 200 ktpd and on target to reach 240 ktpd. This makes Grasberg one of the largest underground operations in the world. Figure 1 shows the Grasberg mining complex.

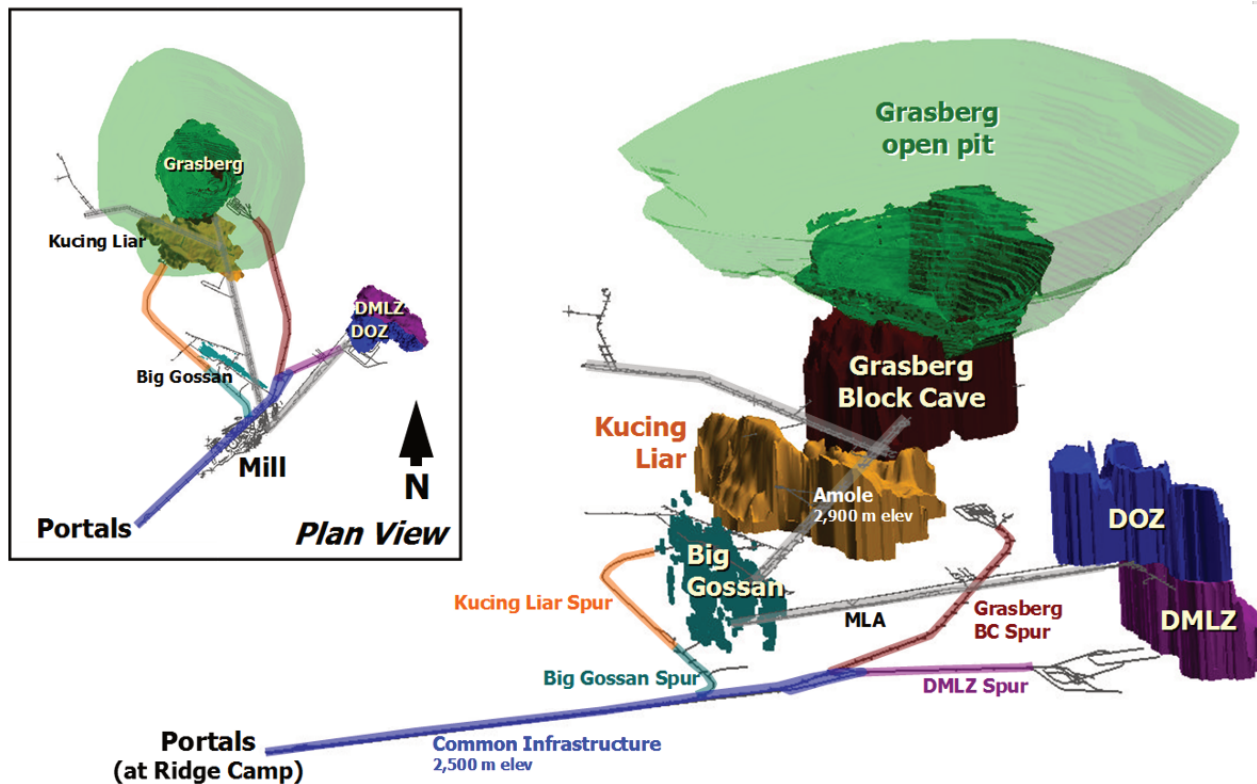


Figure 1 Overview of the Grasberg mining complex

Grasberg started the transition process from open pit to underground in the late 1990s with a series of technical studies that culminated in the start of construction of the underground access, the AB Tunnels, in 2004. Figures 2, 3 and 4 (modified from Casten et al. 2020) summarise the key milestones for DOZ, GBC and DMLZ respectively.

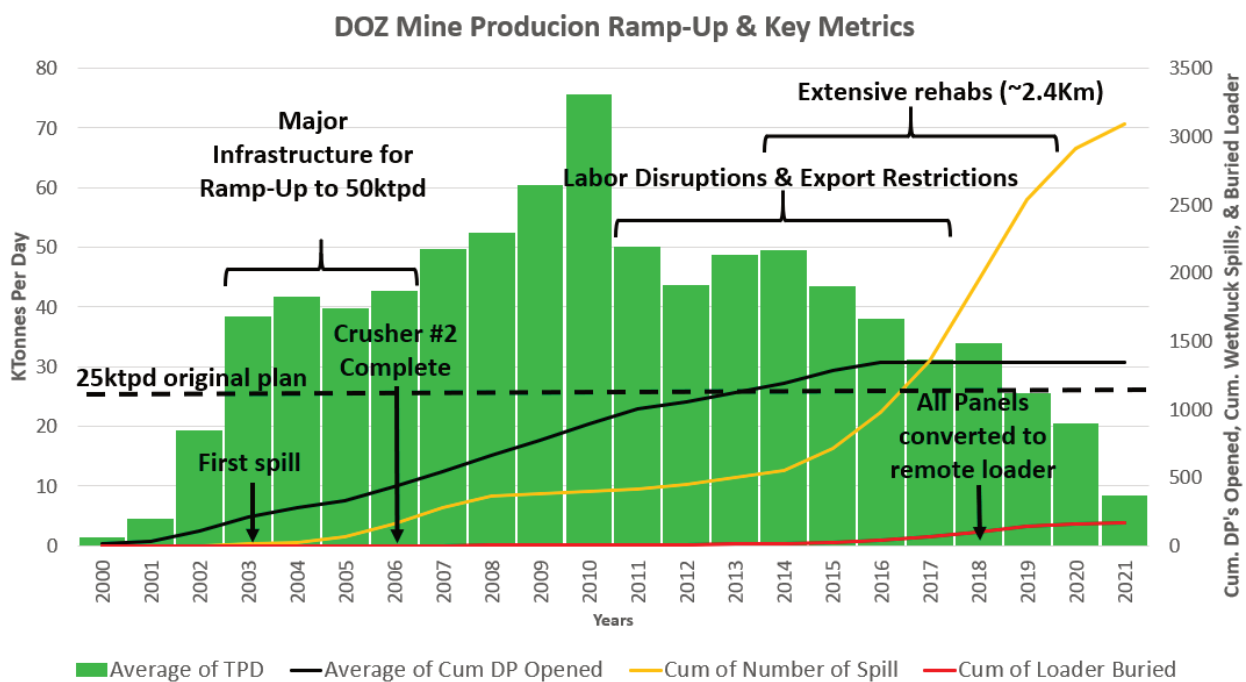


Figure 2 Key milestones for DOZ

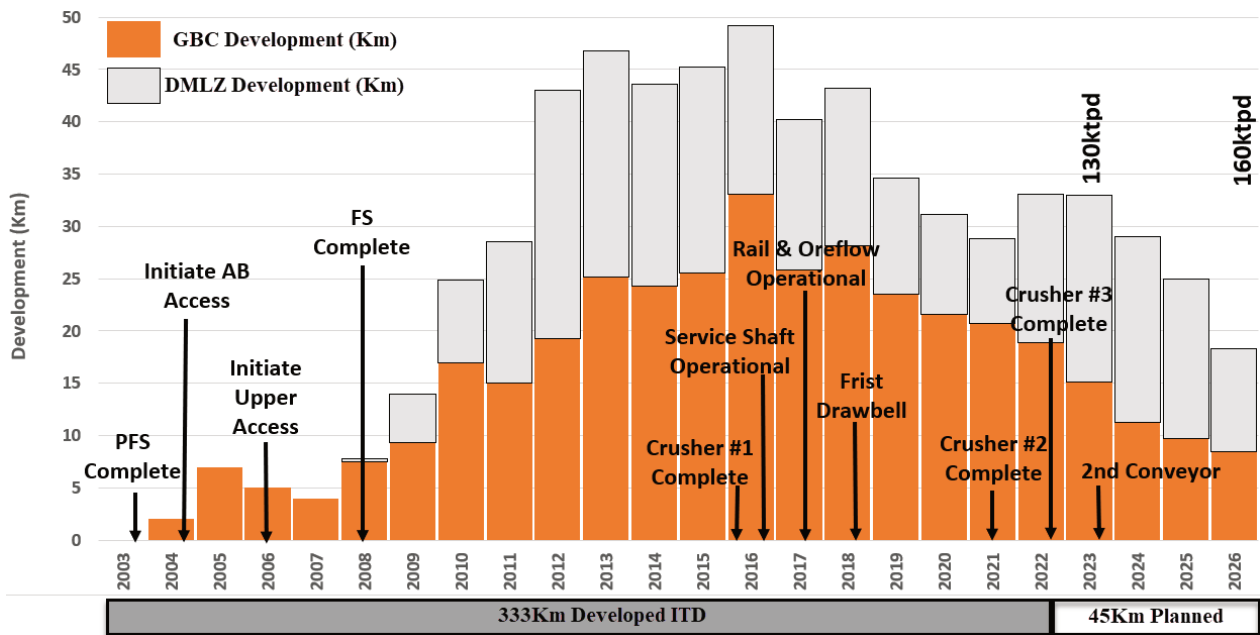


Figure 3 Key milestones for GBC

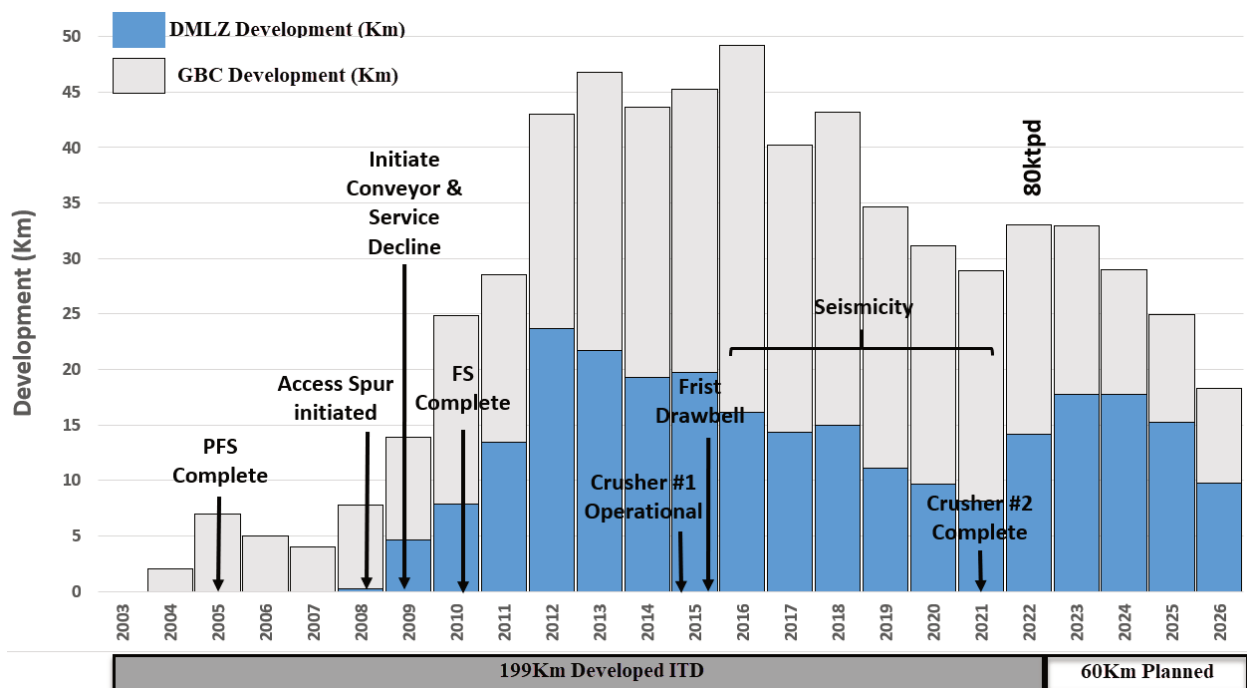


Figure 4 Key milestones for DMLZ

Nameplate production is forecast to occur in 2026 for GBC, thus taking approximately 22 years to reach target production. Given the level of investment, the pressure on the site team to achieve metal schedule is immense. This means the site team must respond rapidly to conditions in the cave but with the forethought of looking ahead to ensure that decisions today do not compromise future production – the need to think fast and slow at the same time. Technical, operational and management challenges were encountered and overcome, and many lessons were learned. Though technology has an important role, one of the most significant lessons was around establishing an integrated organisation that responds in a timeframe that matches the technical, operational, and external challenges – while concurrently managing the uncertainties in cave performance that require care in the way the caves are developed and shaped, focused on the intricacies of cave establishment, initiation, and propagation.

Developing a caving operation on a remote brownfield site at depths of 1,000 m is challenging, not only due to uncertainties around ground conditions but also the extensive supply chain required to maintain mine construction. Building two cave mines at the same time with a combined nameplate capacity of more than 200 ktpd while transitioning from one of the world's largest pits is perhaps one of the bigger challenges within the global mining industry.

2 Context

A mine is a system developed for the purpose of economic production of ore. In the simplest state, a mine can be a person with a shovel and a wheelbarrow; a simple system that is reasonably robust (depending on the strength of ore being dug and the strength of the person). However, if the person digs too deep, the walls of the excavation become unstable and may collapse. The system has moved from being robust to fragile simply due to depth and geometry. Figure 5 illustrates the concept of fragility for complex systems (Flyvbjerg 2017). For many years, mining has been recognised and classified among complex systems (Perrow 1986, 1999).

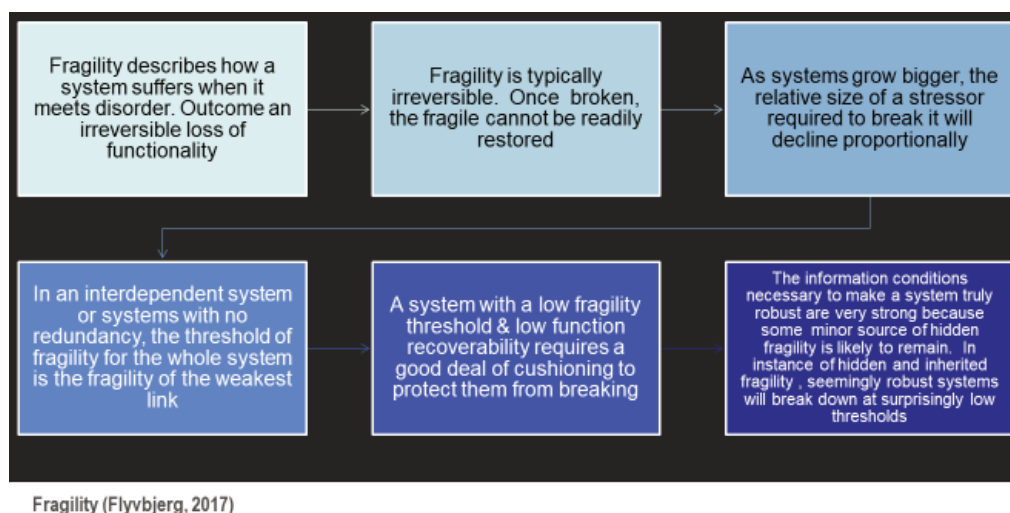


Figure 5 Concept of fragility

By comparison the design, construction and operation of a modern cave represents one of the most complex undertakings in the spectrum of mining. As a cave moves from study to production, the options for change decrease and the overall production system becomes increasingly inflexible and fragile; that is, production becomes less reliable and more volatile. Depth at which the mine is located amplifies this fragility.

Fundamentally, caving is not a robust mining method due to limited optionality when things go wrong. This is an aspect not well understood. While optionality is an aspect that quickly comes to mind (since the mine is tangible), another aspect associated with dealing or solving the implications of fragility in caving (and not often considered) is the role or influence that people play in successfully or unsuccessfully solving fragility problems. Part of the issue lies with the complexity of a modern cave, a challenge for the designers to tackle. Equally challenging is describing the risks and opportunities to the decision-makers so they can decide wisely. A further challenge arises from the time horizons that exist with bringing a large cave into production, which can stretch out many years from initial concepts to target production (Figure 6). Designers, planners, and decision-makers rely on feedback loops to calibrate the veracity of their plans and decisions. Without feedback plans, forecasts and expectations can become unrealistic and typically close to best case scenarios. Twenty years is a long planning horizon, and much can change, technically, organisationally, and with people.

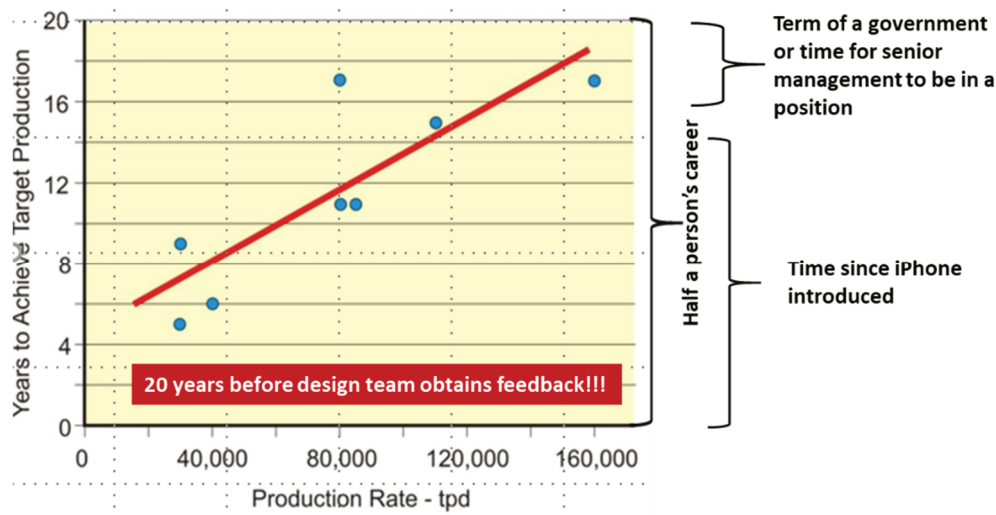


Figure 6 Time to production for selected projects (taken from Sonal Mining Technology, Inc.'s database)

The fragility of caving, which manifests itself in limited upside and substantial downside (performance asymmetry), is exacerbated by often overly optimistic design and production estimates at the study stage that focus on specific economic criteria (e.g. the net present value mind set). Designers and constructors and more critically, decision-makers, are wooed by the value proposition which gets absorbed into the project mythology and a belief in their design, construction, and decision-making abilities; with the harsh reality of developing a cave glossed over. This can result in misalignment of agendas and tension between the various groups that can ultimately result in the reporting of an unachievable metal schedule. Human traits and the way we organise ourselves to build and operate caves can contribute as much to the success and failure of an operation as the technologies or design methodologies used.

Few caves in recent years have achieved the performance targets hoped for, underscoring the fragile nature of caves together with often unrealistic expectations of performance. The reasons for fragility of caves are varied, for example insufficient orebody knowledge and limited understanding of cave mechanics (geology and rock engineering are typically the reasons given for any shortcomings). The technical challenges of caving are well known if perhaps not necessarily well understood and are reasonably well documented (Flores-Gonzalez 2019; Ginting & Pascoe 2020; Edgar et al. 2020; Simanjuntak et al. 2020; Casten et al. 2020).

An equally important challenge exists around the organisation and management of resources to build and operate such mines. The execution of a development and operations plan is a complex process constrained by the realities of construction, such as ventilation and muck clearing requirements. Management is also faced with uncertainties around ground conditions and response of the cave during the production ramp-up. One difficult lesson has been that the cave requirements come well ahead of schedule requirements. This human component is commonly ignored.

With any human endeavour, there are always different views. Figure 7 provides an example of views on how to deal with secondary breaking challenges that were delaying the production ramp-up of a cave. Though the problem was understood – large rock jumbles in the drawpoint – the potential solutions lead to substantial debate with often the loudest voice winning the demand for additional equipment. However, after key measurements were introduced into the conversation, it was found that there was indeed enough equipment and ground conditions were manageable. The central problem was not technical (e.g. ground conditions) or operational (e.g. equipment) but rather around perceptions, fixed ideas, and poor organisation.

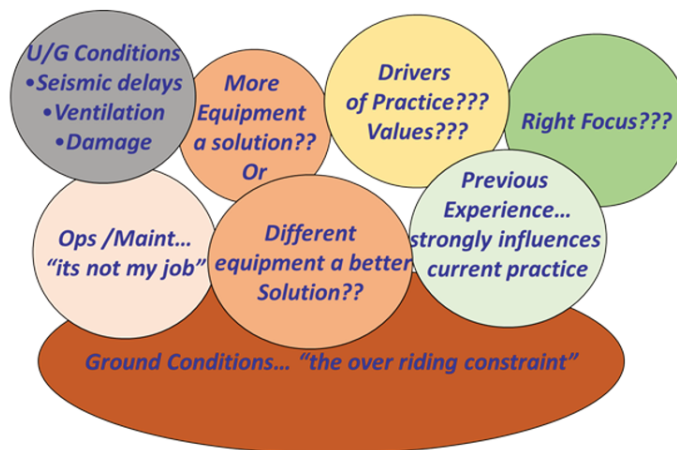


Figure 7 Views on how to deal with secondary breaking challenges that were delaying a cave's production ramp-up

It is critical that the human aspects of cave design, implementation, and production are robust and recognise the fragility and performance asymmetry associated with caving. Comments attributed to Alf Robens, the head of UK's National Coal Board, that mining is '10% physics and 90% people', is as true today as it was in 1970. However, the style of the physics and human components have changed beyond recognition. 'King' miners (highly skilled and experienced miners that could be found in cut and fill operations and coal mines) have been replaced by specialist operators, which in turn are being replaced by automation.

Technology and innovation have come to the fore but are not robust solutions unless there is an appropriate structure in place to support the changes required. Some technologies, such as automation, are being adopted and adapted but there remains resistance, for example to the acceptance of drill automation and advanced communication systems that are central to rapid development. Human beings are typically slow to accept change whether it be doing a task differently or the introduction of new concepts and ideas. Only when there is a burning platform does change happen rapidly. Indeed, the human component is more important than ever with questions like the following needing to be addressed:

- How do decisions get made around the application of complex and sophisticated technologies?
- How should the belief/perception that technology will solve the problem – the 'silver bullet' belief – be handled?

Thus, the question arises as to whether we have the right organisational structure to deal with the necessary changes to reduce the delays and cost overruns that are synonymous with the caving industry. One of the key issues, complexity, is the burning platform that must be addressed if the next generation of deep high-capacity caves are to be successful. The first step is to acknowledge that caving is a fragile method with strong downside asymmetry. This provides the framework for organising and developing the cultures required to upgrade the design, construction, and operational approaches.

The second step is to acknowledge that cave mines are changing as they become deeper (different rock masses and different rock mass behaviour) necessitating a design methodology change – the rules developed for shallow caves are being consistently shown not to apply. This is followed by much more rigorous construction and operations planning that incorporate lessons learned from those caves currently under construction. It is important not to take short-cuts because experience has shown that the cave always wins when short-cuts are taken.

3 Challenges faced at PTFI during cave planning, ramp up and operations

Technical, operational, and external challenges occurred that impacted mine development and production schedules. DMLZ experienced slow cave propagation, induced seismicity, and associated damage; while GBC encountered poor ground conditions arising from strong rock masses juxtaposed against weak yielding rock masses and the early influx of water leading to wet muck. The DOZ mine experienced technical challenges mainly related to poor draw management leading to wet muck and associated production interruptions. Adjustments were made to sequences, layouts, and development protocols to deal with these conditions. New technologies and processes were introduced, including loader automation, hydraulic post and preconditioning and advanced monitoring systems. PTFI also recognised the need for good operational governance through robust cave, ground, and water control management.

Many technical lessons were learned along the way. There was recognition that building a cave was different from the more typical mine project, such as mill expansion, due to the very substantial exposure to ground conditions and the caving process; the burning platform that enables change. But one of the key lessons was the organisational approach required to manage up to 5 km of development a month, the introduction of new technologies and the rigour required in ramping up two very different caves, the GBC beneath the 1,200 m deep Grasberg pit and the DMLZ cave at some 1,700 m depth in some of the strongest rock masses to be caved.

When the construction of the two caves started, a traditional approach to development was undertaken; with a design team located offshore; and at the mine site a dedicated project team, an operations team serving the producing cave and mine service teams. This traditional command structure led to a very siloed approach with each team functioning somewhat independently, responding to their specific needs rather than the needs of the business. These siloes of accountability and responsibilities are not unusual in large organisations with competing and at times conflicting agendas.

Thus, one of the more important changes that were enacted were organisational and process related. While technology contributed substantially to operational success, the 'softer' aspects of having a fit for purpose organisation, informed decision-making, and transparent communication perhaps were the key enablers of safety and production performance.

The challenges and constraints required a flexible and collaborative approach in the first instance based on sound engineering assessments of performance measurements. This provides the framework for informed decision-making at both the strategic and tactical level. Due to long-term nature of cave establishment and initiation processes, it was essential that there was consistent and repeatable process of design, approvals, implementation and change management in place. Regular project status reviews and decision points were essential to control the projects as they progressed.

The success of such an approach is illustrated through the progress of the Grasberg Caves from the study stage to access development, infrastructure construction and cave establishment and ramping-up to the current production rate of approximately 200 ktpd.

4 Organisation and management approach

Developing a cave requires decision-making under complex and uncertain conditions. The silos that exist tend to amplify human traits such as hoarding information, a natural tendency to withhold bad news and the general information churn that occurs in any large organisation (Pitzer 2006). This can result in poorly informed decisions that impact the business.

Kahneman (2011) has described the workings of the mind as an uneasy interaction between two fictitious characters: the automatic System 1 and the effortful System 2. Figure 8 shows the graphical representation of Kahneman's model of cognitive thinking, in which intuition (System 1) acts quickly and reasoning (System 2) plans more carefully. This is an important factor in planning and operating a mine, particularly the

modern deep super caves that face challenges at a scale not encountered in the industry previously. This implies that the management team cannot simply react based on prior experience (thinking fast) but must reflect on a complex series of technical issues that often require developing solutions from first principles. This requires, effort and thought – thinking slow.

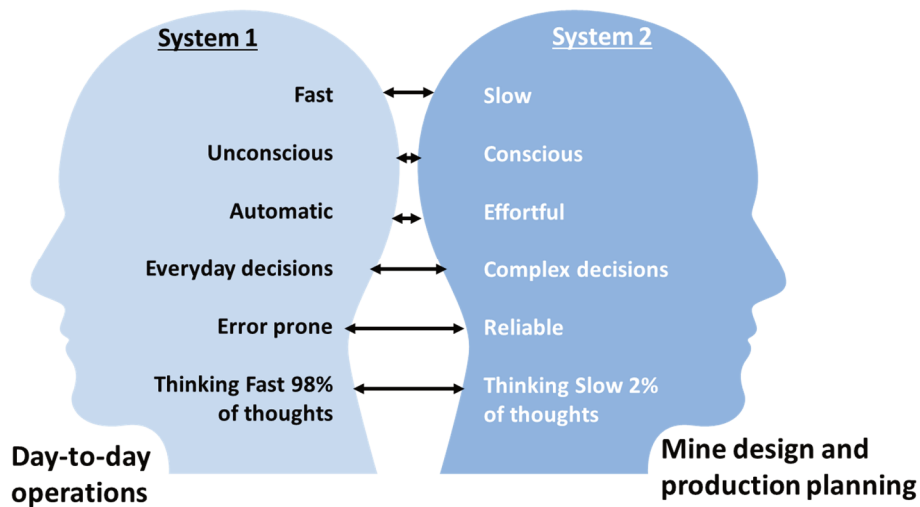


Figure 8 Graphical representation of Kahneman's model of cognitive thinking

Design and planning are slow processes involving complex decision-making based on reliable metrics and thus they are governed by System 2. Operations execute the plan and live in the realm of everyday decisions often under considerable pressure around plan performance, thus they are governed by the fast process and belong to System 1 as shown in Figure 8. This can result in a conflict of agendas between the plan makers (who expended considerable effort in developing the plan) and the plan executors (who are measured on the outcome of the plan). Experience has found that the plans are often optimistic realisations of the production process, resulting in metal schedules that are difficult to achieve. Recognising and resolving this potential disconnect is important to help ensure a reliable cave operation.

The approach to managing the Grasberg caves evolved over time. Initially, the focus was on access development and the excavation of major facilities such as crusher stations and workshops. This focus was substantially operational to complete the task at hand. Management recognised, however, that workforce safety, ground conditions and development rates were significant project risks that required attention. A major update was carried out to the Ground Control Management Plan (GCMP) and the Underground Steering Committee (UGSC) was formed to provide guidance and help ensure plan implementation. The committee is comprised of senior representatives from operations, planning, and safety.

Committee meetings were initially robust due to conflicting agendas from the different functional areas. One of the bigger clashes was between those who saw no issues and those who only saw problems. As discussions evolved and the various parties became more aware of other views, a more integrated and collaborative approach to managing the way forward developed. In effect, the UGSC provided a forum of 'equals' and focus given to the key task of reaching target production and providing a reliable revenue stream safely and expediently.

Six guiding principles that led to the success of the UGSC can be identified as:

1. *Safety is paramount.* Safe systems make for efficient and effective working environment; safety first, production will follow.
2. *People are the key.* This starts with a fit for purpose organisation that drives a culture of collaboration, respect as well as empowerment to act and make decisions.
3. *Value defines the business.* Value can be expressed in different ways. Safety is an intrinsic value as is economics. Without an appreciation of value, it simply is not possible to make informed decisions.

4. **Communication** is critical, not only within the UGSC but across all the functional areas. The ability to openly communicate with management, engineering, and the workforce on challenges and successes is a keystone to the approach.
5. **Planning** must be flexible to respond to the realities of uncertainties around cave performance and behaviour.
6. **Work must be actively managed** through real-time monitoring of key metrics and through a continuous improvement culture.

As the UGSC evolved, there was a greater appreciation of the complexity of developing two of the world's largest caving projects. The importance of collaboration between the different teams was recognised and achieved through the development of a governance framework. This framework was not instantaneous nor clearly recognised but was created over time in response to needs. Once components were in place, the need for production teams to continually debate aspects of cave design and operations was reduced, and they were able to devote more time to planning and operational challenges (thinking slow) and to daily workflows (thinking fast).

The hierarchy of key processes developed at PTFI is shown in Figure 9, with the foundation of operational controls, Standard Operating Practices (SOPs), Trigger Action Response Plans (TARPs) and performance metrics that management uses to implement and control production. Examples of key metrics in risk mitigation for mining-induced seismicity included compliance to development sequences (to maintain correct lead/lags), compliance to draw strategy and progressive support maintenance plan achievement.

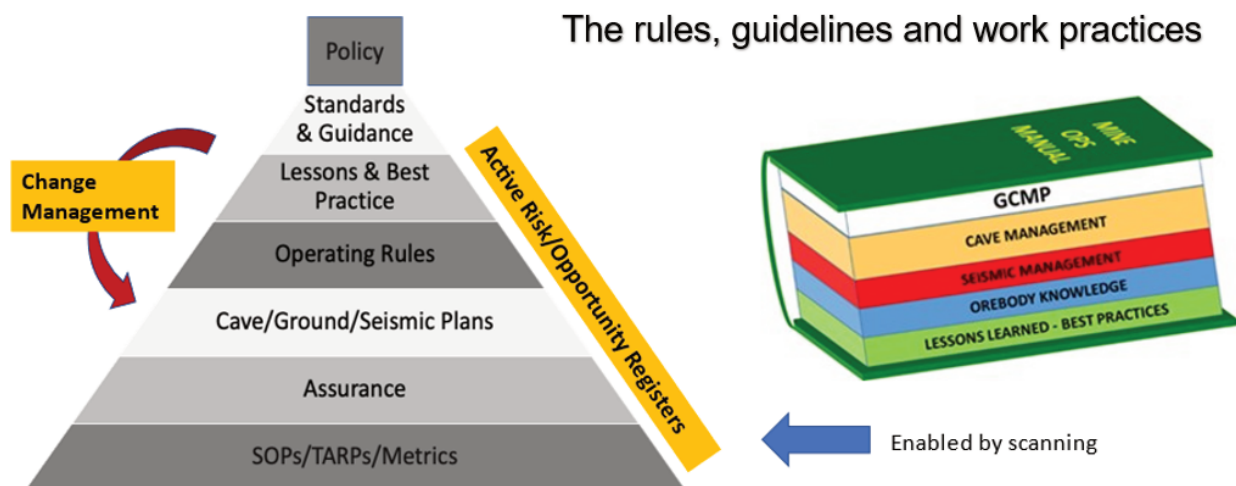


Figure 9 Operational governance: the chain of control

At the top end is policy, set by senior management, that specifies key business objectives and implicitly states the risk tolerance of the business. After policy, come the standards and guidance, lessons learned and best practices, operating rules, the various operating plans, assurance, and SOPs and TARPs. Caving rules, guidelines and standards provide the confines for design and operations that define best practices and articulate the consequences of non-compliance.

The various plans are strongly linked, setting out the rules and guidelines that will ultimately determine the cave ramp-up requirements and production schedule. These articulate the consequences of deviation from the plan. A formalised system for capturing operational lessons learned is important, likewise, a system for capturing best practice seen at other operations.

At PTFI, a series of guidance documents were developed that provides an integrated framework for planning and operations including:

- Ground Control Management Plan.
- Cave Management Plan.

- Seismic Hazard Management Plan.
- Water Management Plan.
- Infrastructure Health Management Plan.
- Lessons Learned registry.

These plans describe roles and responsibilities, objectives/expectations, design procedures and outcomes, implementation, and verification procedures and finally, the change management process. Integrating everything is a risk register that provides an overarching management tool.

Several Phoenix-based teams, PTFI teams and some external parties are involved through effective collaboration at the different stages of the various management plans. To name a few examples, Figure 10 shows the relationship and collaboration between the teams and their scope of accountabilities through the design, implementation, and verification stages of the Ground Control Management Plan and Figure 11 presents a broader scope of collaboration for Seismic Hazard Management Plan.

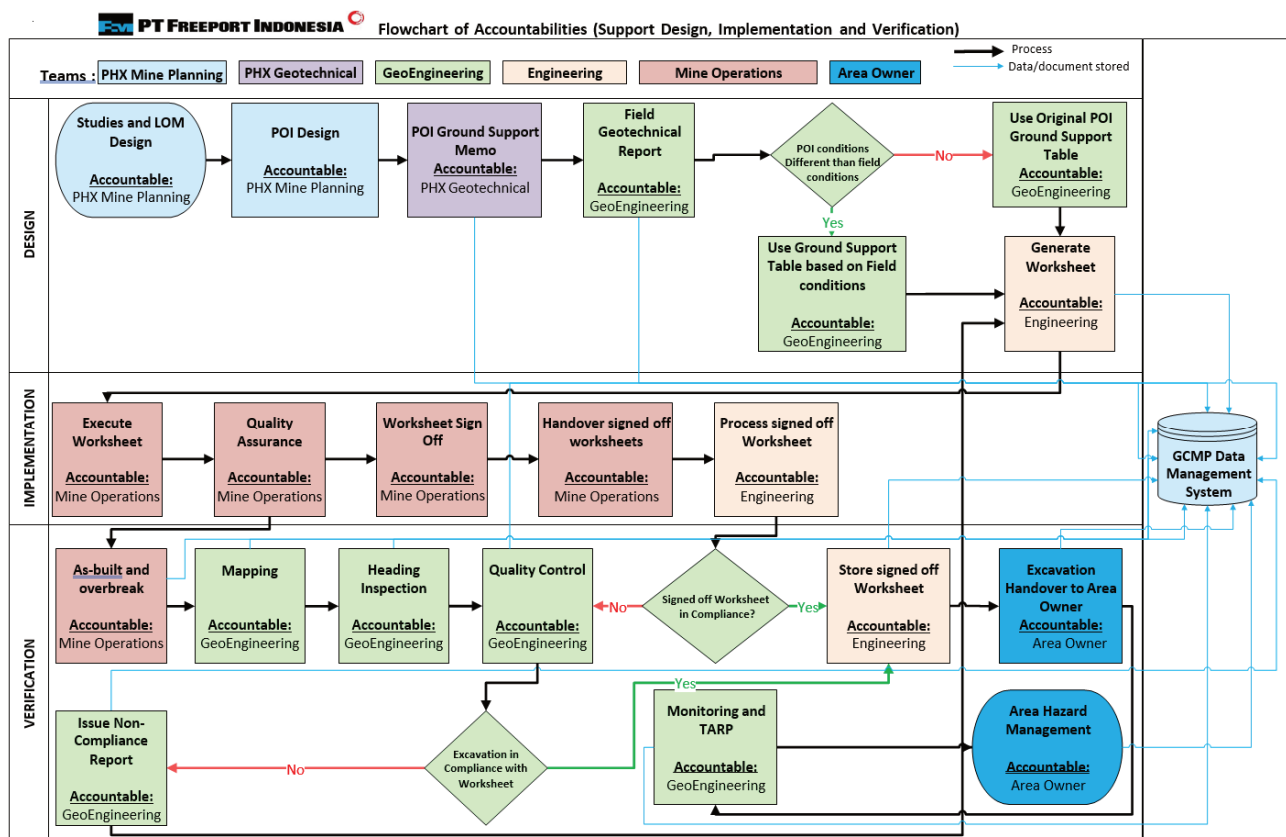


Figure 10 Flowchart of accountabilities and collaboration for Ground Control Management

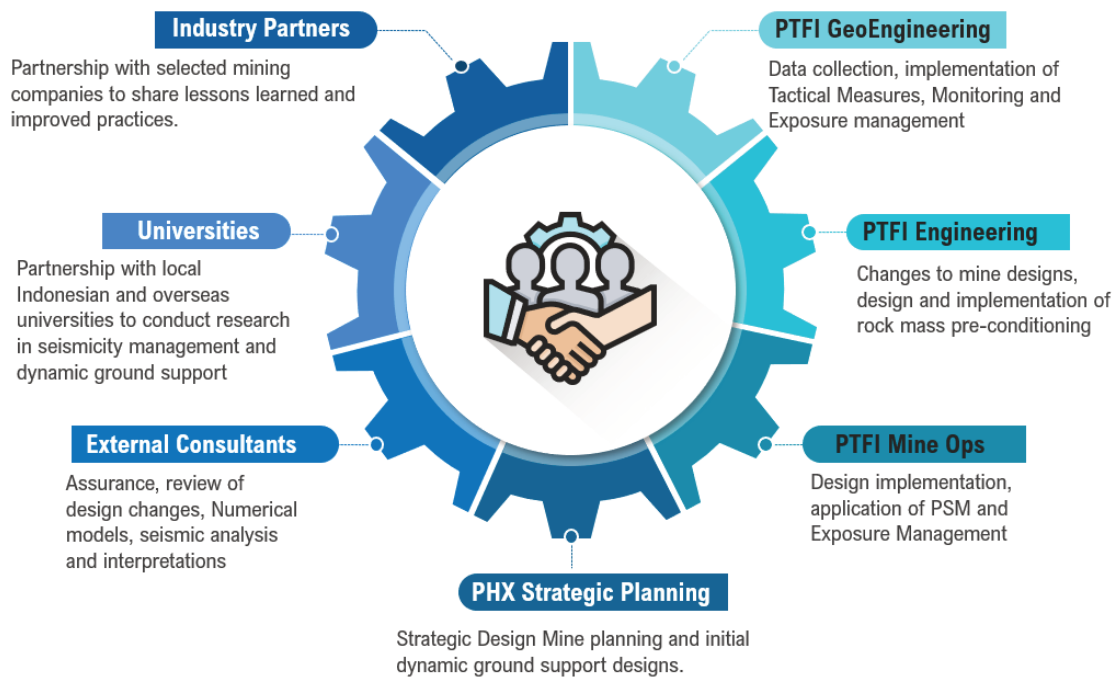


Figure 11 Broader view of scopes and collaboration for Seismic Hazard Management

Assurance then provides the link between the Policy, Standards, Plans and the reality of the operations (SOPs, TARPs, and metrics). Assurance provides senior management with an indication of how well an operation is implementing and complying with the plan and whether the plan is in fact realistic and achievable.

The driving force behind the development of the governance framework, the UGSC, also evolved, morphing into the broader UGSC of today. The committee's mandate is to oversee the implementation and socialisation of the development and production plans. The UGSC is an integrated leadership team with a clear chain of command that provides direction and decisions on the way forward based on key metrics, business objectives, experience, the various management plans, and the risk registers. The UGSC is comprised of the following members:

- Vice President Technical Expert – GeoEngineering, Chairperson
- Senior Manager – GeoEngineering
- Senior Vice President Operations – PTFI
- Vice President Operations – DMLZ
- Vice President Operations – GBC
- Manager Geotechnical Engineering – Phoenix Corporate

In addition, several observers and advisors attend the UGSC at the invitation of the committee. The role of these observers is to provide specific technical expertise and advice to the UGSC. It is only the UGSC committee, however, that can vote to accept or reject proposals or changes to the plans.

5 Value

The UGSC has been in operation for approximately seven years. The committee was born out of adversity, and the first committee meetings were adversarial and followed the agendas of the various silos that existed. However, with time and some procedural rules, the committee began to function with a more unified agenda and decision-making process.

Importantly, though the committee has accountability and responsibility, it also had authority. This change was due in part to the realisation by the members that they must operate as a team if the business was to

be successful and generate value. This realisation grew from a merging of agendas that were often technically, or operationally narrow, into one broad agenda focused on safety followed by production performance (initially measured in terms of development schedules, production ramp ups, metal schedule, resourcing, and costs).

The UGSC relies on the right data to make the right decisions. To gain the most value from the UGSC, it is important that different teams feed the UGSC with meaningful and understandable data. Ill presented, or incomprehensible data, can jeopardise the ability of the UGSC to make informed and timely decisions. Usable data on the other hand, facilitates clear communication and correctly represents the current state of mining events. Trends are more informative than point data and can help the UGSC to see the big picture and decide based on a broader view of the mines and the value to the company.

It is now clearer, with hindsight, to articulate what unlocked value at Grasberg under challenging conditions. Good engineering, technology and planning all played important roles. But having an organisation that had a mechanism for reducing silos in the business was equally important.

The UGSC created a culture of collaboration, which is a step beyond just cooperation, coordination, and teamwork. The UGSC allowed the different functional teams to work together not only to produce something, but to support shared goals. Shared goals provide the guidelines for expectations and defines roles, responsibility, and accountability of the different teams that are critical for successful collaboration. Shared goals require the different PTFI teams to have more interaction with each other to foster the trust and mutual respect required for working together effectively. The UGSC has allowed the different PTFI teams to share processes, knowledge, and expertise in a collaborative way and provides its members the opportunity and freedom to exchange ideas to solve issues and achieve the shared goals or safe production.

By getting the different teams to collaborate towards achieving the shared goals and vision, PTFI was able to keep development and production schedules on track, budgets in check and several risks mitigated. The teams worked together to manage the risks of wet muck in the DOZ and bring it to closure in late 2021 with zero fatalities related to ground control and wet muck rushes. Similarly, seismicity was carefully managed in DMLZ and GBC such that the major events that the mines experienced did not result in any Loss Time Injury cases (LTI) nor in fatalities. This safety performance speaks to the importance of teams working together in a collaborative manner to achieve shared goals and vision.

6 Conclusion

Though the various technologies applied to meet the specific challenges were extremely important, it is considered success was founded on a coherent execution group that focused on collaboration instead of coordination and cooperation. Central to this was an underground steering committee. The collaborative leadership model used by PTFI was instrumental in the successful ramp-up of some of the largest caving complexes in the world.

Caving is a risky business full of surprises that are generally not well recognised or articulated. As projects increase in size, they become more complex. Often substantial organisational optimism exists particularly at the design and project stages, therefore, effective controls against optimistic biases are required. It is about people and how forgiving the orebody is. The caving method is not suited to marginal projects and requires a constant need to improve margins with reliable cave-to-mill production. The mining teams need to be able to access and establish the cave faster. This requires a fit-for-purpose design, which in turn requires better orebody knowledge and rock mass characterisation, which is a cornerstone of better mine design and improved predictions of cave performance.

The challenges and uncertainties of the PTFI caving mines require some flexibility in the mine plan and design. Flexibility in the mine plan is driven by flexibility in thought of those involved. One of the biggest issues we have had in the past was people starting with 'no, that's not possible', or 'we have never done it that way' type attitudes. A lot of what we have accomplished is the ability to challenge that attitude by aiming high and setting up bold and achievable targets, pursuing and maximising value, engaging people of different

backgrounds and expertise to collaborate as one team and empowering them to act and make decisions that add value to the business.

A core competency of the UGSC includes people who in general act as a translator. They understand the different sides of the plan and can help integrate the different expertise and different ideas from the geotechnical teams, the seismologist, the engineering as well as cave planning and production operations teams.

The chairperson of the UGSC is the storyteller. He summarises what is being said and why it is important for the group, almost like a translator but more like an interpreter. He must be able to explain the topics to all parties that are involved in a simplified way for all to understand.

Asking for others' feedback is critical in the UGSC, so the leader of the group seeks to engage others to speak and have an opinion. Critical decisions require every member of the UGSC to vote on the decision once discussion is complete. This may result in a delayed vote, as additional information is required for voting members to finalise their choice. This voting process forces participation and ownership on the UGSC and fully engages the different team members on the issue being discussed.

The UGSC includes key stakeholders within operations, engineering, and geoengineering teams. These are the critical decision-makers in the organisation and can form quite a diverse group with differing backgrounds and opinions. The UGSC allows for each of these stakeholders to have a clear voice and an equal opinion during key discussions and decision-making. Senior management and other technical advisors also participate in the discussions. This ensures clear and open communication on UGSC decisions, as they are being made.

The collaborative approach of the UGSC has allowed various PTFI teams to share common goals and values to better manage the challenges and achieve safe ramp up and production from its underground mines.

Acknowledgement

The authors would like to express their special thanks and gratitude to PT Freeport Indonesia for providing technical background information and allowing publication of this paper. Special thanks go to Sonal Mining Technology for guidance and support in completing this paper.

References

- Casten, T, Johnson, M, Zimmer, C & Mahayasa, M 2020, 'The transition to underground production', *Proceedings of MassMin 2020*, Santiago.
- Edgar, I, Prasetyo, R & Wilkinson, M 2020, 'Deep Ore Zone mine wet ore mining empirical learnings, mining process evolution and development pathway', *Proceedings of MassMin 2020*, Santiago, Chile.
- Flyvbjerg, B 2017, *The Oxford Handbook of Megaproject Management*, Oxford University Press, Oxford.
- Flores-Gonzalez, G 2019, 'Major hazards associated with cave mining: are they manageable?', *MGR 2019: Proceedings of the First International Conference on Mining Geomechanical Risk*, Australian Centre for Geomechanics, Perth.
- Ginting, A & Pascoe, NM 2020, 'Grasberg open pit to Grasberg block cave transition wetmuck and mine design', *Proceedings of MassMin 2020*, Santiago.
- Kahneman, D 2011, *Thinking, Fast and Slow*, Farrar, Straus and Giroux, LLC., New York, USA.
- Perrow, C 1986, *Complex Organizations. A Critical Essay*, 3rd edition, McGraw-Hill, New York, USA.
- Perrow, C 1999, *Normal Accidents, Living with High-Risk Technologies*, Princeton University Press, Princeton.
- Pitzer, CT 2006, *When Organisations Fail: New Thinking on Catastrophes*, The Australasian Institute of Mining and Metallurgy, Melbourne, and Pacrim Abridged, October 2006.
- Simanjuntak, K, Primadiansyah, A, Soumilena, N & Teweng, W 2020, 'Driving and managing stress in the Deep Mill Level Zone caving mine', *Proceedings of MassMin 2020*, Santiago.

