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Past learnings focus innovative solutions to future cave mining

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Abstract

Over the past 20 years, Rio Tinto have developed and managed five block cave mines, each presenting their own unique set of challenges. Every cave has demanded innovative solutions to manage the challenges at the time, whilst all have provided invaluable learnings that Rio Tinto has leveraged into the designs and operational plans of its future super caves. This paper describes some of the key learnings and challenges that Rio Tinto has faced over the past 20 years and how these have shaped cave design, cave management and cave operations, as well as helped focus on the innovative solutions currently being implemented at its Oyu Tolgoi mine in Mongolia and being planned for its Resolution project in the United States of America.

Keywords: *block caving, orebody knowledge, mine design, innovation*

1 Introduction

It will be obvious to even the most casual industry observer that our existing open cut copper and diamond mines are becoming deeper with attendant higher strip ratios, that we are witnessing a decline in the grade of remaining near-surface resources and that new high-quality discoveries are increasingly deeper, often well beyond the economic limits of open cut mining. This in itself highlights the fundamental attractiveness of those commodities to Rio Tinto. Rio Tinto believes that large-scale cave mining is a critical competency that enables the development and successful exploitation of deeper and high-quality copper and diamond resources. Rio Tinto's vision is that the new generation of cave mines will achieve levels of safety and productivity (scale and cost) equivalent to, and if not better, than its open cut mining operations.

2 Rio Tinto's caving experience

Rio Tinto's capability in cave mining stems from its initial investment in the Grasberg joint venture with Freeport in Indonesia, and its subsequent experience constructing and operating block cave mines at Palabora in South Africa, and Northparkes and Argyle in Australia. It is currently constructing the Oyu Tolgoi block cave mine in Mongolia and designing the Resolution mine in the United States.

Rio Tinto has been actively involved in the design, construction and operation of a series of block cave mines at Grasberg (managed by Freeport McMoRan) for the last twenty years. Over that period, the scale of underground production has risen to in excess of 60,000 tpd and is projected to exceed 100,000 tpd. From 2000 to 2014, Rio Tinto constructed and operated the 30,000 tpd Lift 1 block cave mine at Palabora, South Africa beneath a large open pit mine, managing the transition from large-scale open cut mining to underground mining. Following its acquisition of North Limited in 2002, Rio Tinto assumed management of the Northparkes Mines joint venture, which was operating the 16,000 tpd E26 Lift 1 block cave mine. In the subsequent 11 years, Rio Tinto constructed and operated the E26 Lift 2 and Lift 2N extension block caves and 18,000 tpd E48 Lift 1 block cave mine; the latter being the first mine to fully employ autonomous loading operations underground. Finally, Rio Tinto constructed and is currently operating the 18,000 tpd Argyle Lift 1 block cave mine in Western Australia, the largest diamond mine in the world. In 2015, Rio Tinto began construction of the 95,000 tpd Hugo North Lift 1 block cave mine at Oyu Tolgoi in Mongolia; production is expected to commence in 2020.

3 The caving challenges

Each mine has presented Rio Tinto with unique challenges across a range of dimensions, from safety to mine productivity to reserve recovery. Rio Tinto has had to continually adapt and innovate to move forward. In each and every case, Rio Tinto has attempted to learn from those experiences and incorporated the learnings into the way it designs, constructs and operates cave mines. It has been an iterative process; improvements are identified, evaluated and tested, and when proven to be beneficial, incorporated into Rio Tinto's caving playbook. The last 20 years of learnings and experience, which have come at considerable cost, are now being put into practice at the Oyu Tolgoi Underground Project. However, it also recognised that further innovation will be required to ensure Oyu Tolgoi is successful.

At Palabora, the early failure of the pit wall above the block cave caused significant early dilution and fines entry to the cave, highlighting limitations with the project's subsidence zone modelling and cave flow predictions. Approximately 5% of drawpoints were prematurely closed on the extraction level due to convergence attributed to incomplete undercutting, localised structures and uneven draw. In addition, the fine nature of the cave material presented dry inrush risks during mining operations.

The Northparkes E26 Lift 1 mine suffered a fatal airblast in 2009, which resulted in the deaths of four mine employees. This tragic event was triggered by rapid caving and the catastrophic failure of the crown pillar into a large airgap in the cave, which had developed over some time due to slow caving and overdraw of the muck pile. The scale and consequences of this failure were not foreseen. A small proportion of the mine reserves were subsequently isolated by waste ingress following the crown pillar collapse.

The E26 Lift 2 mine presented an almost completely different set of challenges. The cave propagated extremely quickly through to the base of the Lift 1 mine, resulting in significant seismicity and rockbursts around the top of the mine. Unfortunately, mine production ceased two years earlier than planned as a result of large-scale clay dilution with only 60% of the mine reserve recovered. Ultimately, it was established that this was largely the result of incomplete cave propagation, raising questions about the quality of orebody knowledge informing caving predictions and our ability to accurately track cave propagation in a timely manner. The significantly finer fragmentation in the Lift 2 cave was a small consolation, allowing high production rates to be achieved in both the mine and processing plant, although this in turn highlights the quality of fragmentation prediction. Considerable effort was made to reinitiate cave propagation at Lift 2 with little positive result. A subsequent extension to the Lift 2 cave, the Lift 2N mine, provided the opportunity to test caving beside an existing cave and recover some of the material not recovered in the first block cave.

The third block cave mine that Rio Tinto constructed at Northparkes, the E48 Lift 1 mine, achieved excellent cave propagation, in part due to extensive hydrofracturing of the orebody ahead of mining, although the cave propagated through to surface (600 vertical metres) in a little over 12 months, causing considerable disruption to surface ore handling systems. The major issue though was the heavy convergence on the extraction level that occurred in the early stages of mining, resulting in the closure of six of the 10 extraction drives and approximately 10% of drawpoints. The damage to the extraction level was attributed to unanticipated higher levels of stress-induced during the development of the post-undercut, a longer undercut face and to the rapid rate of cave propagation. The loss of extraction drives and drawpoints slowed cave ramp-up and implementation of autonomous loading operations, although by 2014, all extraction drives were recovered and most drawpoints had been put back into production.

The Argyle block cave mine has proved to be the most challenging. Extensive extraction level convergence was a challenge from the earliest stages of extraction level development and undercutting. Multiple extraction drives and drawpoints were lost due to convergence, slowing down drawpoint construction and cave ramp-up. Whilst the bulk of the 15 extraction drives have been recovered (at least two will never be fully recovered), as many as 40% of drawpoints were closed prematurely, many permanently. Based on current mine reserves, less than 60% of the original mining reserve will be recovered. In addition, mine production has only reached a maximum of 20,000 tpd, considerably short of the planned 25,000 tpd envisaged in the original feasibility study. The extensive convergence is attributed to a highly faulted and weak rock mass and to the extensive stress-induced damage associated with the undercutting and drawpoint construction sequences; which raise serious questions about the quality of orebody knowledge, mine design and cave management practices. To compound these challenges, the material handling system has not operated to design, which has routinely interrupted cave draw, and high levels of water inflow have generated significant wet inrush risks, particularly during the pronounced monsoon season.

4 Lessons learned

So, what has Rio Tinto learnt and how has it innovated over this 20 year history, and why do we think we are ready to take on the challenge of constructing and operating the Oyu Tolgoi block cave mine in Mongolia – a mine that is more than 50% larger than any mine that Rio Tinto has operated before, and which is characterised by a relatively weak and heavily faulted rock mass? The starting point has been to dispassionately reflect on what has happened and how we could have better prevented or mitigated the challenges we have faced. Whilst the list of challenges has been long, each and every failure has been catalogued in 'lessons learned' documents that seek to detail what happened and why. Where clear causes could not be identified, considerable effort has been invested in research to unlock the root causes.

The foundation of our approach has been the development of comprehensive Rio Tinto safety standards for the key underground mining hazards: fall of ground, fire, hoisting and shafts, hazardous atmospheres, heat, inrush, surface subsidence, airblast and explosives. The hazards were identified from a detailed taxonomy of underground mining fatalities over the last 100 years, together with an assessment of hazards specific to cave mining. The standards and accompanying guidelines are based on the critical controls determined from comprehensive bowtie risk assessments of all of the principle underground hazards. The standards continue to be refined in response to significant underground safety incidents. The critical question that we ask in response to a major incident is, 'if fully implemented, would our safety standards have prevented this incident from occurring?'. For example, the Rio Tinto ground control standard D1.1 (Rio Tinto 2014) is designed to ensure that no one is exposed to fall of ground hazards at any of our underground mines. We re-examined D1.1 in response to the fatal incident at the Big Gossan Mine at Grasberg, Indonesia in 2013, deciding that further controls were required to ensure installed ground support remains fit for purpose over the life of the excavation, recognising that ground support elements can degrade and that the duty of a particular excavation could change over time, and the ground support initially installed may not match the new duty.

The failure to predict the premature collapse of the Palabora pit wall, the slow caving at Northparkes Lift 1, the incomplete caving in Northparkes Lift 2 and extensive extraction level damage at Argyle highlight the criticality of orebody knowledge, particularly how we geotechnically characterise the rock mass we seek to cave. Back-analysis of these events has allowed Rio Tinto to identify the rock mass characteristics that need to be measured in order to predict these problems and make corrections to mine designs. Rio Tinto has developed extensive and painstakingly detailed core logging procedures to ensure we collect the necessary data in order to create the best possible geomechanical model of the caving volume. Manual logging is being supported by core scanning techniques that improve the consistency and detail of the data collected. Drilling is also focused on defining the major structures in the rock mass, including those structures that extend beyond the caving volume. Such data are critical to inform our rock strength assumptions, fragmentation predictions and subsidence models. We have also learnt that it is not sufficient to develop our geotechnical and geological models on drilling data alone; it necessary to calibrate our models by direct exposure to the orebody through underground exploration drives in the early stages of project studies and then further refine the models by extensive mapping of underground development during mine construction. At Oyu Tolgoi, more than 90% of development face is scanned and mapped using face mapping technology.

Our second key learning is that we must protect our rock mass. Whilst we have developed considerable skills in redeveloping collapsed drives and drawpoints at Northparkes and Argyle, prevention is without doubt better than cure. Our predictions of mining-induced stress have improved, but so too have our ways of managing this stress, including through ground support designs and undercutting sequences. Building on a very detailed knowledge of the rock mass, we have learnt the importance of confining the rock mass and preventing pillar failure but also the subtle difference between strong and dynamic ground support.

At Oyu Tolgoi, we are installing the heaviest ground support ever installed in a block cave mine, building on our experience at Argyle.

The third lesson is that we must treat extraction level construction like the construction of a critical engineered facility. This begins with a focus on design; balancing drawpoint spacing for reserve recovery and drawpoint stability. Our experience has shown that there is little value seeking to maximise reserve recovery by reducing pillars to the point where they cannot withstand caving-induced stress and the load of the muck pile, resulting in the premature loss of drawpoints. We have learnt that it is likewise critical that we actively control the quality of the extraction level excavation, driven by careful monitoring of overbreak and underbreak in every cut. Intuitively, everyone understands overbreak reduces extraction level pillar size and hence drive stability. We have established the CaveCad system so that we can maintain accurate records of all ground support designs, as-builts, QA/QC tests of installed ground support and the frequency of inspection to the point where we know where every rockbolt and cable is installed, how it was installed, when it was last inspected and when it will next be inspected. This philosophy is entrenched in our D1 Underground Safety Standard (Rio Tinto 2014).

Fourthly, knowing what is going on in the cave is fundamental to managing for safety, productivity and reserve recovery. This includes understanding how the cave is propagating, as well as the detailed shape of the caved volume, the presence or absence of an air void within the cave and the height of the muckpile, how stress is being redistributed around the propagating cave and how material is flowing within the cave. The opportunity to influence cave propagation reduces rapidly after surface break through. Extensive microseismic systems, open holes, time domain reflectometers (TDRs) and surface subsidence monitoring proved critical for tracking cave propagation in the Northparkes caves; all of which behaved differently to the point of surface breakthrough. Rio Tinto first undertook trials of cave markers and smart markers at Northparkes and has worked with Newcrest and Elexon to develop the Cave Tracker technology (Elexon Mining 2016) that allows spatial monitoring of markers inside the cave. We undertook our first successful test of the Cave Trackers at Argyle, which provided the opportunity to track marker movement inside the cave – not just where the markers were recovered from. Smart Markers are now being deployed at Oyu Tolgoi.

The fifth and final lesson is the criticality of draw strategy to manage loading and convergence on the extraction level. Extensive convergence monitoring of extraction level drives and drawpoints is required to identify areas of increased loading and stress accumulation within extraction level pillars. Increasingly, extensometers imbedded in the pillars provide earlier and more subtle indications of loading and stress build-up. This detailed knowledge of pillar behaviour then enables the draw strategy to be customised to prevent serious damage to the pillars. Whilst there is an overall desire to achieve an even height of draw in the early stages of cave propagation, we understand the need for differential draw strategies to balance stress and load accumulations in the cave. Draw compliance is at the heart of our draw strategy. We also recognise that the final defence against drive and drawpoint convergence may be to promptly fill drives and drawpoints with concrete until extraction level loading can be controlled. This technique has been successfully applied at both Northparkes and Argyle to control convergence; the drives and drawpoints are then re-mined when convergence reduces.

5 Application to Oyu Tolgoi underground

Each of the lessons learned have been applied to the design and subsequent construction of the Oyu Tolgoi underground mine. However, we recognise that the mine design is not static and that as we excavate and start caving, we will learn more about the rock mass and how it behaves, and modify our mine designs accordingly. As a consequence, we have established a high level Technical Assurance Committee for the Oyu Tolgoi project that is tasked with regularly reviewing construction performance and our increasing understanding of the rock mass, and testing our mine designs and operating plans. In addition, we have established the Oyu Tolgoi Geotechnical Review Board with international subject matter experts to regularly review our progress on the project. Fundamentally, we accept that we still have a lot to learn about caving. To that end, we appreciate the opportunity to collaborate and learn from other cavers like Codelco, Freeport and Newcrest.

6 The future

Our focus for the future is based on a constant desire to improve the way we design, construct and operate our mines. We believe we cannot improve without a healthy appetite for learning, which starts with detailed measurement and monitoring of every aspect of the caving process. Key improvement opportunities that we are actively pursuing include:

- Improved instrumentation to better characterise the rock mass and to monitor rock mass response during every step of the caving process.
- Integrated operational control of the caving process, beginning with the assimilation of multiple dispersed data to allow our subject matter experts to manage the cave through making informed decisions on cave construction sequencing and draw strategy.
- Specialised mining equipment for construction and cave operation, ranging from mechanical excavation (that improves both the quality of the excavation and reduces damage to the rock mass), pass mining and liner installation, and high-speed ground support installation to dedicated drawpoint mining equipment. This compliments our focus on a switch to fully electrical and automated underground mining.

At Rio Tinto, we fundamentally believe in the future of large-scale block cave mining but appreciate there is still much to do to de-risk cave mining from a safety, technical and financial perspective. Sharing information with our peers at the Fourth International Symposium on Block and Sublevel Caving is part of that learning process.

Acknowledgement

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