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Update on the Grasberg and Kucing Liar block cave mines

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ABSTRACT

The Grasberg Block Cave mine (GBC) has been in production since 2018 and is a major contributor to P.T Freeport Indonesia's (PTFI) total production profile. Full production was achieved ahead of expectations and was made possible by many notable accomplishments. Record drawbelling and undercutting rates were set during the ramp-up, supported by a highly efficient rail haulage and ore flow system. The mine also continues to experience challenges, including the undercutting sequence, pumping, wet muck, and SO_2 gas. This paper will explore the accomplishments and challenges at GBC and provide an overview on the newest project at PTFI – the Kucing Liar Block Cave mine (KL). The KL mine is being planned as a 90,000 metric tonnes per day (mtpd) block cave mine, which lies below and adjacent to the GBC footprint. PTFI expects to leverage its extensive knowledge of successfully constructing and operating large, long-lived block cave mines in the planning, construction, and ramp-up to full production of the KL mine within 10 years.

1 INTRODUCTION

1.1 Overview

PT Freeport Indonesia (PTFI) began the development of the Grasberg Block Cave Mine (GBC) with initial access drifting in 2004, 14 years before the initiation of caving in late 2018 and about 21 years before achieving the full nameplate production rate of 150,000 tonnes per day of ore by 2023, which has since been exceeded.

The three currently active underground mining operations in the Grasberg Mining District are the GBC (nameplate 150 kt/d ore), the Deep Mill Level Zone Block Cave Mine (DMLZ) (nameplate 80 kt/d), and the Big Gossan Open Stoping Mine (BG) (7.5 kt/d). The Kucing Liar Block Cave Mine (KL) is currently under development, with production to commence in 2028 with a full production rate of 90 kt/d by 2033. Figure 1 is a schematic view of the Grasberg District orebodies. The concentrating plant has a capacity of 240 kt/d.

This paper provides a status update on the GBC mine, a retrospective analysis of accomplishments and challenges to date in the GBC mine, and an introduction to the newest PTFI project – the KL mine. Previous papers presented at MassMin 2016 (Brannon, et al., 2016) and MassMin 2020 (Lara Moran, et al., 2020) summarized the key design parameters of the GBC. A related paper discussing the GBC caving sequence and undercut planning was presented at the Caving 2018 conference in Vancouver (Beard & Brannon, 2018).

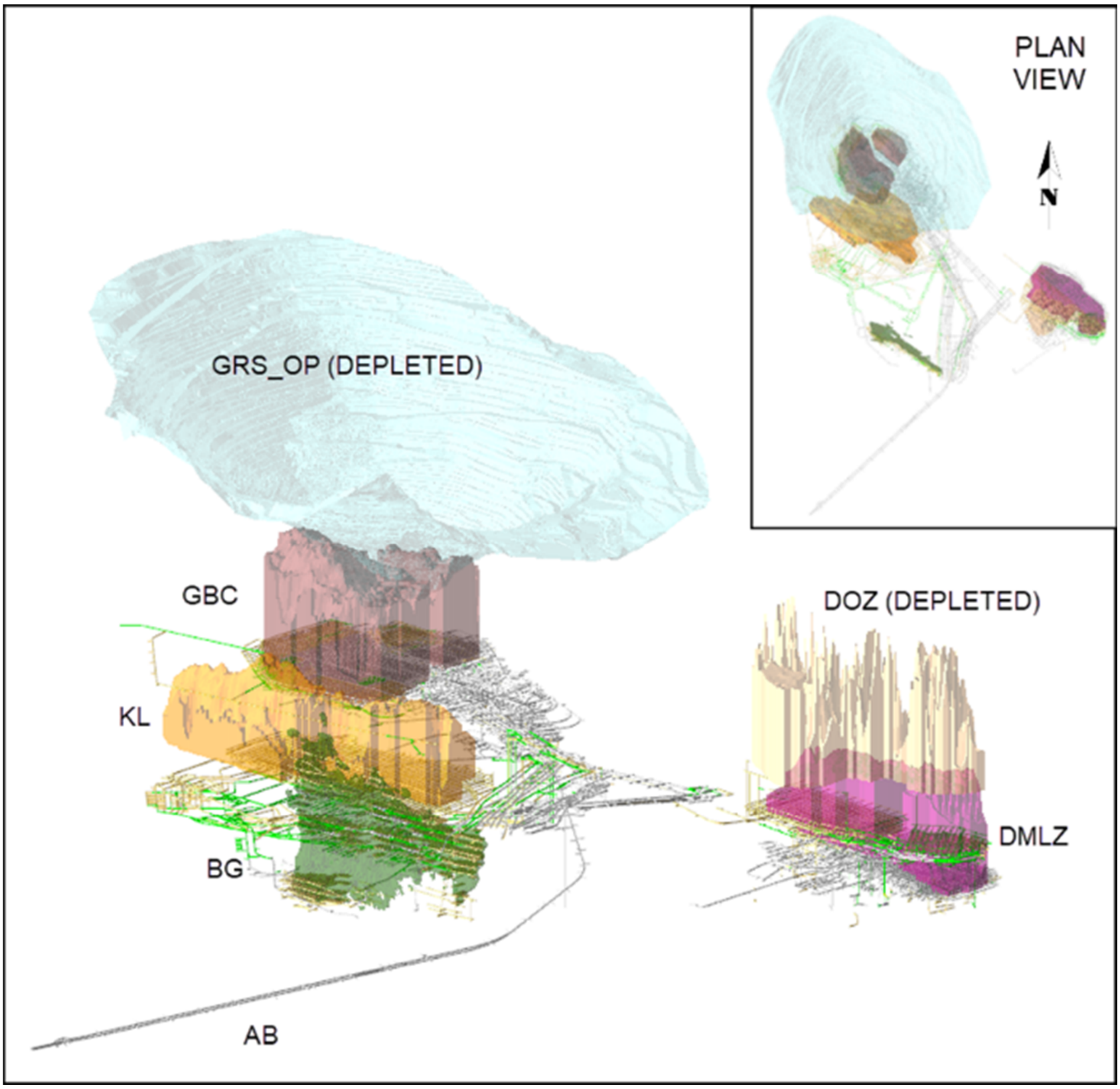

Figure 1 Perspective view of the Grasberg District orebodies and major accesses.

1.2 Ore Reserves

The GBC estimated diluted ore reserves (at the end of 2023) are 777 million tonnes at a grade of 1.02 percent copper and 0.68 g/t gold, representing payable metal of 15 billion pounds copper and 11 million ounces gold. Annual average metal production (at full production rates) is approximately 820 million pounds copper and 630,000 ounces of gold. Through 2023, the GBC has produced approximately 2.8 billion pounds of payable copper and 2.7 million ounces of payable gold.

The Grasberg deposit is a porphyry copper-gold deposit comprising a multi-stage dioritic intrusion emplaced into the center of a volcanic breccia complex. Mineralization extends more than 1,600 m vertically, from the 4,300-meter elevation at the original surface to at least a depth of 2,600 m. The width of the mineralization ranges from about 200 m to over one kilometer. The central Kali diorite late intrusive phase forms about a 100 m wide septum of barren and weakly altered rock that cuts through the otherwise roughly cylindrical, mineralized intrusive complex. The highest grades of the deposit are centrally located within the intrusive complex around the central late intrusive Kali barren zone.

The GBC is located below the now-closed two-kilometer diameter Grasberg open pit. The final pit bottom is just under 200 m above the Extraction Level. The cave reserve has average column heights of about 500 m. Pit slope stability and projected failure geometries, grades, and material types factor heavily into the production scheduling model for the GBC mine reserve.

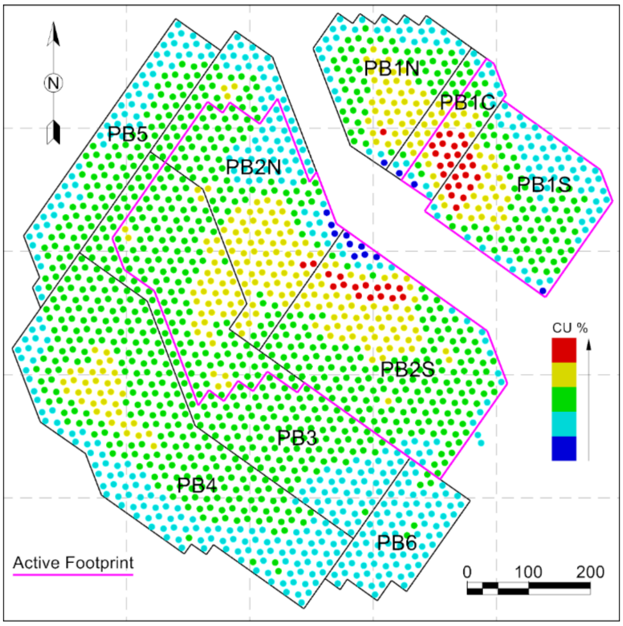

Figure 2 GBC footprint showing grade distribution (red = higher grade, blue = lower grade), production block naming conventions and year end 2023 active footprint.

1.3 Caving and Production

The GBC orebody has a large mining footprint of 588,000 m^2 with a diameter of about one kilometer. The Extraction Level (2,830 m elevation) is an El Teniente-style layout with production panel drifts spaced at 30 m and drawpoints spaced at 20 m. The Extraction Level contains 1,896 drawpoints. The Undercut Level is 20 m above the Extraction Level. The overall footprint is divided into nine production blocks. The mining sequence prioritized the blocks with the highest grades in the early years. Production is now well underway and has achieved steady-state status.

The mine is a panel caving operation with peak production of 150,000 tonnes per day and mine closure in 2041 when operating permits expire. To meet production targets, multiple production blocks operate concurrently. During the life of the mine, as many as seven production blocks will be operating. With the highest value of the mine concentrated into the central core of the deposit, the initial two production blocks started caving simultaneously on either side of the barren central Kali diorite. The production block sequence moves progressively away from that central zone.

The currently active production blocks are undercut using a “crinkle-cut” drill ring design and blasting pattern similar to that successfully employed in the now-closed DOZ mine and the currently active DMLZ mine. The mine uses an advanced undercut mining sequence, with the leading edge of the undercut a minimum of 20 m ahead of drawbelling on the Extraction Level.

Caving has progressed very well, and the mine achieved sustained caving at a hydraulic radius of 36. During the ramp-up, the mine achieved a peak undercutting rate of 10,300 m^2 per month. Production blocks will continue undercutting at rates significantly below the peak during the ramp-up, averaging around 2,500 square m per month. Lead-lag targets vary but are typically 13 m on a 2.2 m ring spacing. The production forecast drawbell opening rate matches the undercutting advance with a maximum of five drawbells per month. The mine has also been successful at transitioning from active to new production blocks along production block boundaries.

The current planned caving sequence is shown in Figure 3. Undercutting has been completed in blocks PB2S, PB1S, and PB1C. Undercutting is continuing in PB2N and PB3.

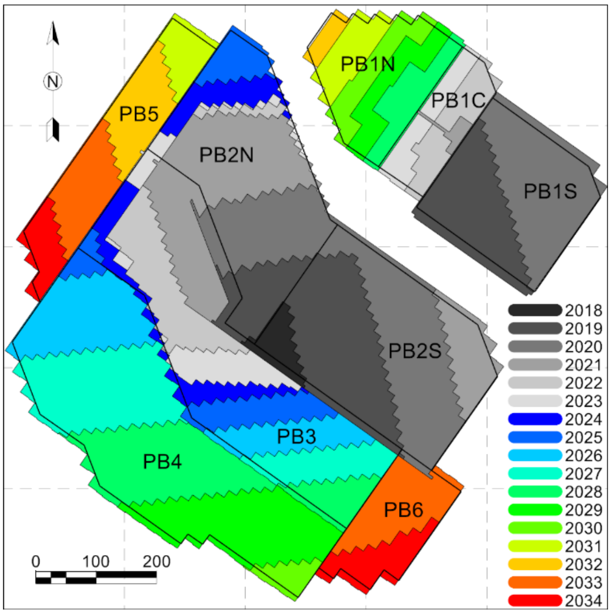

Figure 3 Current overall GBC undercutting sequence – Ring blasting by year.

As of January 2024, the total area undercut comprises about 287,000 m^2 from five production blocks. About 429 drawbells have been blasted (858 drawpoints). Current daily production is about 140,000 tonnes per day. Figure 4 below shows the status of drawbelling and Figure 5 shows undercutting and drawbelling progress.

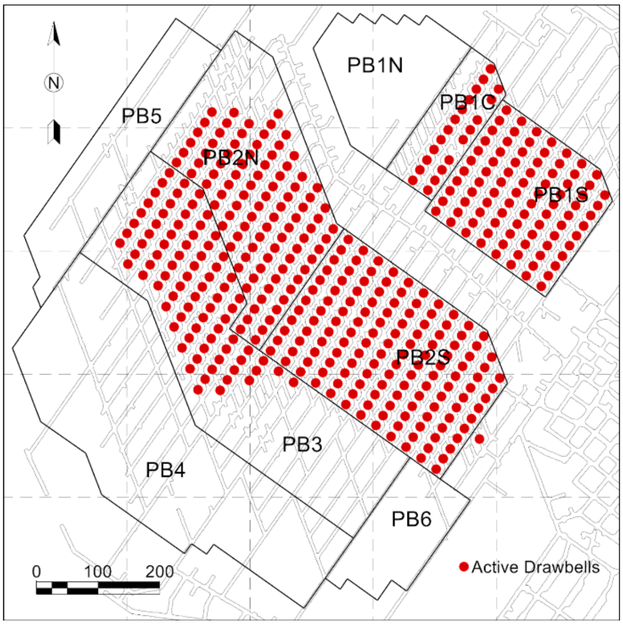

Figure 4 Drawbelling status in the GBC mine.

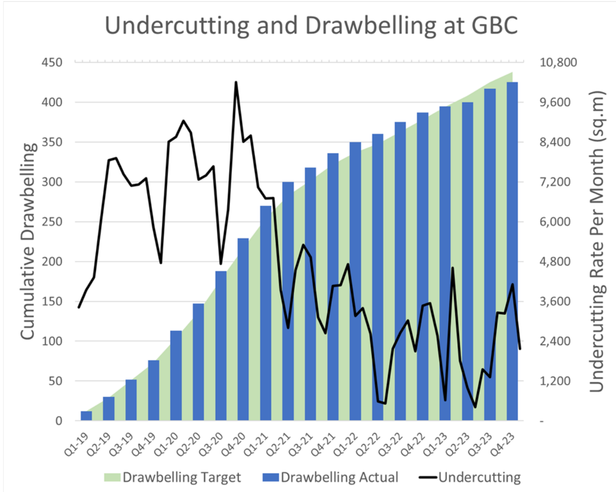

Figure 5 Undercutting and drawbelling progress to date.

2 ACCOMPLISHMENTS

A key objective of this paper is to highlight some of the many accomplishments during the production ramp-up period. The success to date in the GBC mine was possible because of these achievements. The following sections describe three of the most consequential achievements; 1) production ramp-up, 2) undercutting rates, and 3) rail haulage performance.

2.1 Production Ramp-Up

The PTFI mining complex at the start of GBC caving was undergoing a significant transition from dominantly open-pit mining to exclusively underground mining. Key to this transition was the successful ramp-up of the GBC mining rate. The aggressive production ramp-up was necessary for the overall economic health of PTFI and for maintaining metal output. Perhaps the biggest achievement to date within GBC was meeting the production targets throughout the ramp-up period.

Figure 5 shows the rate of blasting drawbells with 76 drawbells (152 drawpoints) opened in the first year of production. During the second year of production, GBC operations were able to blast 153 drawbells (306 drawpoints). This high rate of drawbelling and undercutting, 140,000 m2 in 2 years, required a significant amount of footprint and rail haulage development and construction. Effective and well-advanced construction of drawpoints, rail tracks, chutes, wayside equipment, and supporting infrastructure enabled the mine to deliver on the production targets.

2.2 Undercutting Rates

The forecasted GBC maximum undercutting rate was around 8,000 m^2 per month during the initial ramp-up period. This maximum undercutting rate comprised the total of all active production blocks. Once the initial ramp-up was achieved the total undercutting rate was to be reduced to an average of 3,000 to 4,000 m^2 per month during steady-state full production. The minimum and maximum undercut advance rates were set at two rings per month (4.4 m) and eight rings per month (17.6 m). The production forecast assumed a maximum drawbell opening rate of five drawbells per month per production block and about 12 drawbells per month across all active production blocks (Brannon, 2020).

Actuals show that the achieved maximum undercutting rate in GBC was 10,300 m^2, met in October 2020. During the ramp-up period, the average undercutting rate was 4,890 m^2 per month. The achieved peak drawbell blasting in GBC was 21 drawbells, met in September 2020. During the ramp-up period, the average drawbell blasting rate was 8 drawbells per month. A total of 290,800 m^2 were undercut in the first 4 years of production.

Achieving these actual undercutting and drawbelling rates proved fundamental to meet the forecasted production rate and the production milestones. Without fast and efficient undercutting, the mine could not build the required inventory of drawpoints to meet the various challenges of pulling from new drawpoints. Additionally, the ability to quickly undercut a large area added flexibility to the production plan.

2.3 Rail Haulage Performance

A fundamental component of the GBC mine is the rail ore haulage system. The primary function of the rail haulage system is to collect ore from the GBC production areas via a series of ore passes and loading chutes. The rail haulage system is a closed loop system, divided into five main production tracks, with a total of 20 chute galleries, three unloading stations for three underground crushers, and a maintenance and office areas (Figure 6). The layout of the rail system is designed to accommodate the geometries of the production blocks in the caving sequence.

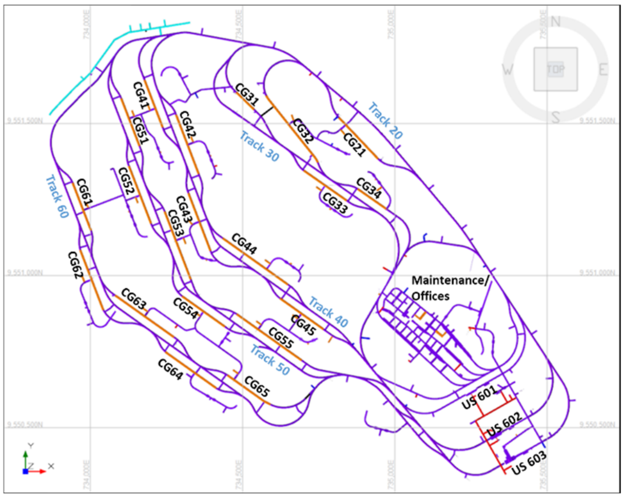

Figure 6 Rail Haulage Layout showing the main line, chute galleries, unloading stations and maintenance facilities.

The loading chutes are organized into “chute galleries” which are on spurs alongside the main track loops. There are up to nine chutes per chute gallery. The trains load the ore from the chute galleries and deliver that ore to one of three unloading stations that feed the underground crushers. Crushed ore is then delivered to the surface concentrating plant via twin inclined conveyors. The haulage operation is supported by a substantial underground rail shop.

Ore trains consist of 11 to 12 bottom-dump 20 m3 muck cars, driven by a 45-tonne electric locomotive: about 350 tonnes per trainload. Twelve trains and two spares are required to maintain full production at an average 150,000 tonnes per day. The locomotives are powered by an overhead catenary system on the main lines and move through the chute galleries and unloading stations on battery power. The rail system is designed to operate in a fully automated mode, including chute loading, muck hauling and dumping. The rail system is controlled from a central dispatch and control room that is located on the surface.

There will be about 26 kilometers of track in the fully developed rail haulage system, with about 120 loading chutes. As of February 2024, fifty of the loading chutes in the current ten chute galleries are operational, and an additional six chute stations are in various stages of construction and commissioning. After ramp-up, chute galleries are being built sequentially as required by the production plan. Sixteen kilometers of track has been installed to date. The three unloading stations contemplated in the life-of-mine design are fully operational.

During the fourth quarter of 2023, the rail haulage system in GBC transported a total of 11 million tonnes of ore. The system totaled a physical availability (PA) of 93% and an effective utilization of 74%. As a reference, several simulation analyses during the early stages of the project expected a PA of 85% and effective utilization of 70%. The performance of the system has been demonstrated in numerous high production days, with a single day peak haulage record of 184,000 tonnes (Dec 25, 2023).

Overall, the GBC production ramp-up has been possible due to the highly reliable and efficient rail haulage system. The successful designing, planning, construction, and commissioning of the system is a significant achievement. The rail haulage system implementation also demonstrates Freeport's ability to successfully manage and execute large projects at low risk.

3 CHALLENGES

While PTFI has been overall successful in bringing the GBC mine online, there have been challenges. No large mining project will avoid all pitfalls, and the GBC mine has some notable challenges from which lessons can be learned and applied to the mine and to future projects. This section describes some of these challenges and how negative impacts were corrected or mitigated.

3.1 Pumping

The PTFI concentrator requires supplemental water sources from the underground operations as the historical supply of process water has been impacted by caving at GBC. Water from the mine levels can report to the main pumping system. The Main Pumping System (MPS) is comprised of three areas: 1) the drainage level channel, capture sumps and overflow system, 2) the lower pump station (LPS), and 3) the upper pump station (UPS). The design pumping capacity of the system is 1260 l/s with a standby bank of pumps capable of 315 l/s. The pumping system comprises 10 GIW 10 x 8, 600 hp centrifugal slurry pumps at both the LPS and UPS which will receive the mine water from the drainage level sumps and deliver the water to the concentrating plant. Sixteen-inch diameter pipelines are installed in this dewatering application – one pipeline per pump circuit.

The primary challenge to the pumping system design was the expected quality of feed water. To date, the feed water to the pumps contains much higher levels of contained solids than specified by the initial design. This higher-than-expected solids content has resulted in higher maintenance costs and poor performance of the system. Work is ongoing to improve solids capture, and future projects at PTFI will spend extensive effort on implementing lessons learned to optimize those systems.

3.2 Gas

The geology of the Grasberg deposit includes various zones of material with high pyrrhotite. In certain areas of the mine this high pyrrhotite material causes significant health and safety issues. As the material begins to react and oxidize, that process can result in high temperatures, spontaneous combustion, and generation of high concentrations of SO_2 gas. To date, the PB1S area of the mine has been the primarily affected area.

The main consequence of high gas concentrations in areas of hot muck has been the inability to draw from affected panels. In order to recover the metal in these areas, all work must be completed remotely which impacts productivity.

3.3 Wet Muck

Uncontrolled wet muck spills (inrushes) from drawpoints have been a recurrent issue at PTFI operations. The high rainfall, groundwater, and high fines percent of the caved material create the conditions for the wet muck hazard. GBC has experienced several large wet muck events, and the concern of these events occurring throughout the life of the mine remains.

The challenges for predicting, controlling, and preventing wet muck incidents and the associated hazards include a number of factors. First, wet muck spills are the result of fine material size and water. This means accurate predictions of both water inflows and fragmentation are required to estimate the probability of incidents across the footprint. Additionally, for areas where wet muck spills are more likely to occur, estimating the size of the spill and the extent of the spill proves challenging.

To reduce the risk to personnel and mitigate the impacts of wet muck spills, operations have implemented various strategies. The use of remote equipment systems removes people from areas of highest risk. Establishment of exclusion zones and re-entry protocols further protect personnel from entering hazardous areas.

Downstream of the extraction level, wet muck can also impact and cause issues with the trains, crushers, and conveyors. Strategies are being developed to implement appropriate blending of wet and dry material. Proper blending strategies will reduce the risk of spills throughout the haulage and oreflow systems. Efforts are underway to safeguard critical infrastructure from spill events.

3.4 Rail Maintenance and Geotechnical Hazards

The rail haulage system faces ongoing challenges with maintenance. High water and humidity levels, along with sulphide minerals like pyrite, contribute to corrosion, leading to concrete degradation, track delamination, and rusting within months. Poor track conditions increase derailment risks, disrupting operations and requiring speed constraints. Additionally, wet muck spills necessitate cleaning which leads to increased cycle times and disruption of normal operations.

The rail haulage system has also experienced the impact of the caving front passing the rail lines and causing ground movement and floor damage from the abutment stress. Improved ground support for future development can help mitigate the risk of damage, but in existing areas rehabilitation has been required.

As the rail network continues to expand in line with the growth of the caving footprint, maintenance activities require continuous improvement and optimization.

3.5 Cave Modeling

The GBC mine is a large deposit with complicated geology. Modelling the cave flow to produce accurate production schedules is an ongoing effort. The production scheduling team uses knowledge gained from drawpoint samples, caving beacons and smart markers, and surface subsidence and pit failure shapes, to generate a calibrated model for improved correlation to actual production and a reasonable estimate of future production. These efforts are continuous and require constant diligence.

One of the most significant factors affecting the cave modelling is that GBC lies under a very large open pit.

The proximity to the pit means that subsidence and pit failures can have significant impacts on the complex mixing mechanisms. Ongoing calibration efforts ensure that tonnes mined to date closely match the official metal produced.

4 KL OVERVIEW

The Kucing Liar (KL) mine is located in the Grasberg Mining District in Papua, adjacent to and at a lower elevation to the GBC footprint. Discovered in the mid-1990s from a >1,000-meter surface diamond drill hole that intersected the orebody, exploration drifting and underground delineation drilling proceeded from that point. A series of mining studies were carried out from 1999 to 2021. The Kucing Liar (KL) block cave mine has been included in the PTFI 10-K annual ore reserves since 2010. Annual production planning updates have been completed each year since then. The KL estimated reserve is 385 million tonnes at

1.05%Cu and 0.92 g/t Au at a peak production rate of 90 ktpd. Production is expected to initiate in 2028.

4.1 Geology

Kucing Liar (KL) is a copper-gold calc-silicate-magnetite rich skarn deposit associated with minor attendant porphyry mineralized dykes. Mineralization is emplaced along the sedimentary strata and along the main Idenberg#1 (ID#1) fault. The KL deposit is localized within the lower Waripi and upper Ekmai Formations, situated between the Grasberg Intrusive Complex (GIC) contact and the WNW-trending ID#1 Fault zone. The bulk of the KL deposit lies between the 3,100 m and 2,400 m elevations, with the top of the ore approximately 800 m below the topographic surface. Figure 7 shows a cross-section of the KL and GBC geology.

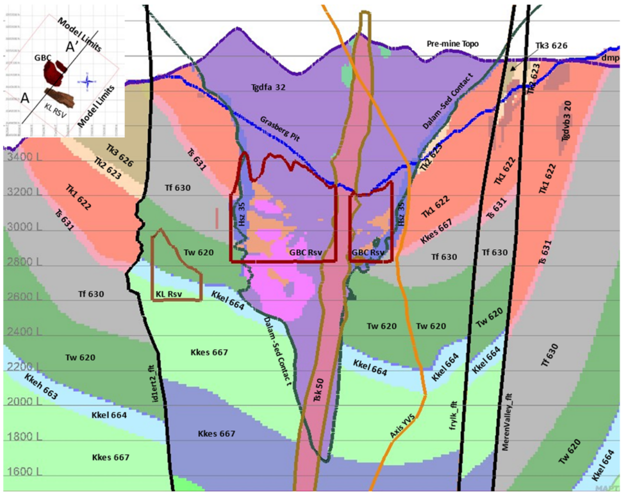

Figure 7 Section through KL and Grasberg showing Rock Units, Faults and Mine Areas.

4.2 Mine Plan

The mine design basis is driven by equipment size, ventilation requirements, drainage requirements and geotechnical constraints. The mine layout has a large footprint that will have 1,382 active drawpoints through 2041. The Extraction Level (2,595 m) is an "El Teniente" style layout with a 30m by 20m spacing. The overall footprint is divided into two main Production Blocks that are active within the 2041 contract of work. The target production rate is 90ktpd.The primary access to the mine will be through the AB adits. **Error! Reference source not found.** shows the overall mine layout. The KL initial development began in Q4 2021 with the initiation of three development headings to serve as main accesses to the mine.

The KL mine is designed with four main operations levels; Apex Slot Level, Undercut Level, Extraction Level and Haulage Level. The mine is also designed with additional support levels for ventilation, drainage, geotechnical monitoring, and oreflow.

The ore handling system comprises gyratory crushers receiving run-of-mine ore from Haulage Level rubber-tired trucks and delivering crushed product to the conveyor system.

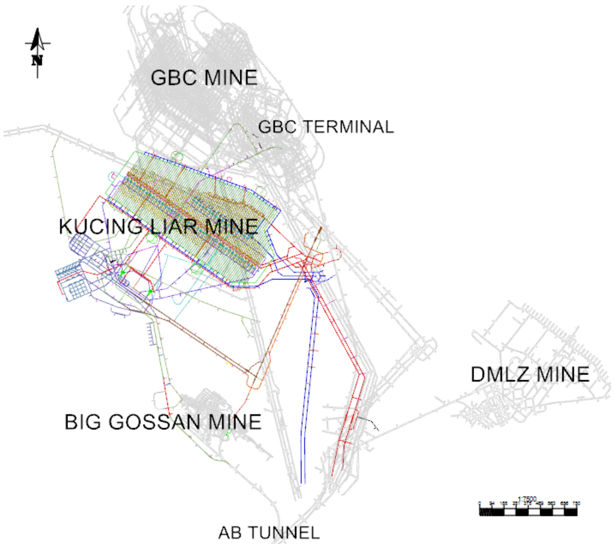

Figure 8 The KL Layout and footprint dimensions

4.3 Equipment

The mining will be conventional drill and blast and standard ground support. The support equipment fleet is like both GBC and DMLZ. The mine is currently trialling several newer equipment models offering cleaner engines and better operator protections and it is anticipated these or similar will ultimately be adopted for Kucing Liar.

4.4 Drainage and Pumping

Water in the mine will be channelled via drain holes to the service levels to drain directly to the AB Tunnels, or down to the drainage level and pump station where it will be lifted back to the

AB level for discharge or onward pumping to the mill via a series of pump stations similar to those installed at the GBC.

4.5 Fixed Facilities

The Kucing Liar fixed facilities are largely based on those at DMLZ with updates to the design from the experience gained there. The fixed facilities will include shops, offices, explosives magazines, lunchrooms, and other required infrastructure.

4.6 Mine Ventilation

To meet planned production requirements, the proposed baseline ventilation design increases total airflow through the combined GBC + KL primary system. The primary surface system design requires an additional two exhaust drifts serving two primary fans. In addition, two intake drifts are required. Air to KL is delivered from the intake system via four intake raises and exhausted via four exhaust raises. In operation overall ventilation strategy is similar to both the GBC and KL with the use of ventilation-on-demand technologies to effectively distribute air to active work locations on a dynamic basis.

4.7 Mine Controls, Automation and Communications

The principle for the design of Mine Controls, Automation and Communications Systems in Kucing Liar is to provide two distinct Networks: Production Control (PCN) and Business (Corporate). The PCN network will host all critical control and safety systems in use for within the Kucing Liar footprint. The Business Network will host all other systems.

The fiber optic backbone will consist of sufficient Fiber cores and Fiber routes from within the Kucing Liar mining footprint to the centralized surface infrastructure locations at office buildings OB4 and OB1. The Fiber backbone cores are to be physically isolated routes from any other path to maintain stability and performance for safety systems.

Within the Autonomous Mining Area (AMA) the Production Control Network areas require seamless coverage with overlapping redundant signals. In these areas the Network will require 100 percent coverage with overlapping redundancy built into all automation zones. Current production levels at GBC and DMLZ utilize standard 802.11G/N Wi-Fi Access Points. The preference at Kucing Liar is for Access Points to be able to support both 2.4Ghz and 5.8Ghz Wi-Fi capability and the KL design will consider technologies for tracking integration.

4.8 Production Schedule

The reserve process utilizes a block model developed by the geology team that estimates copper, gold, and silver by block (15m x 15m x 15m). The calculation of Net Smelter Return (NSR) per block uses ore type recovery and mining cost estimates. The reserves are based on resources developed using the standard measured, indicated, and inferred classification, with inferred grades set to 0.001 so that they would not be included in the value estimations.

The drawpoint production schedule through life-of-mine is set at a maximum rate of 90,000 tonnes per day. Scheduling of the undercutting sequence follows the accepted site cave management rules and determines the drawbell opening sequence and rates. Maximum drawbell opening rates are ten drawbells per month and maximum draw rates per drawpoint are 240 tonnes per day. The sequence has been designed to maximize the early grade and to delay caving-induced impacts to the GBC for as long as possible.

4.9 Project Execution

The Kucing Liar mine will be the seventh underground mine brought into production at the PTFI mine site. Five of these previous mines utilized cave mining techniques for production. PTFI has been successfully developing and operating caving mines since the 1980s and is recognized as an industry leader in this field. The KL mine is very similar to the recently developed and currently producing DMLZ mine in design and this will enable the PTFI Team to draw on recent experiences to successfully execute the KL project. The Kucing Liar mine is adjacent to the currently operating GBC and is accessed from the existing AB adits. The proximity to existing access and infrastructure allows the Kucing Liar development and production operations to leverage off of the existing mine infrastructure, access routes, established processes and systems, an experienced and mature workforce and extensive site support infrastructure. The previous design and execution of the GBC and AB adits considered the future plans for the KL mine and synergistic elements were incorporated to assist in the future development of the KL.

The following are the major scope items:

- Establish and ramp up a 90 kptd Panel Cave by 2033.
- Construct and commission mine infrastructure, including the items listed below:
- 2 × 5 MW Primary Fans
- 2 × 63 × 89 Gyratory Crushers
- 10 Conveyors
- Pump Stations
- Fixed Facilities

Modifications are being made to the mill as required due to changes in ore types in different life-of-mine production mining cases. Primary power generation and supply also require expansion, and this too is not exclusively due to KL and is addressed as a separate project.

5 CONCLUSIONS

The Grasberg Block Cave mine is a very large and complex mining operation. Since the completion of the feasibility study in 2008 there has been process of continual improvement in the mine design that carries on to the current status. The caving performance of the GBC was very good from the beginning of undercutting and continues to this day. Ambitious undercutting and drawbelling targets were largely achieved as planned, in no small part due to the outstanding efforts of the construction and mining teams tasked with building and operating the mine.

Kucing Liar is the next large operation to be developed and operated in this impressive mining district. KL will use lessons learned in the design, construction, and caving of the deposit. There will be unique challenges specific to KL as well that will have to be understood and managed in order to achieve the production targets throughout the life of the mine.

ACKNOWLEDGEMENT

This paper is a brief summary of the mine design and early caving results of the Grasberg Block Cave Mine and an introduction to the KL mine. Contributions to this paper are acknowledged from the underground technical staff at PT Freeport Indonesia as well as from the FCX Strategic Planning team in Phoenix. Development, construction and operations successes at GBC, and KL in the near future, are truly a credit to the massive and undaunted efforts of the GBC-KL operations and engineering teams.

GBC is a world-class operation and could not have been developed without the number of contractor groups that are an integral part of the team at PTFI, including Redpath, RUC, Granitor, Bombardier, Siemens, Nordic Mine Technologies, Stantec, Hatch, Golder, Beck Engineering, Schalke and Aecom.

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