doi:10.36487/ACG_repo/2435_A-07

Implementation of major mining strategy changes at the Deep Mill Level Zone (DMLZ) mine, PT Freeport Indonesia

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ABSTRACT

The Deep Mill Level Zone (DMLZ) is one of the underground mines operated by PT Freeport Indonesia (PTFI), located approximately 1,500m below ground level and consists of multiple production blocks on the same extraction level. The DMLZ experienced significant seismic activity, and to mitigate the risk, Production Block (PB) 4 was elevated 225m above the current DMLZ footprint elevation. PB4 sits adjacent to the existing and future cave formed by the lower production blocks. The development of DMLZ PB4 mine started in late 2021 following conceptual and pre-feasibility level studies, and development continues concurrent with detailed engineering targeting undercutting start in early 2025. This paper presents the challenges encountered, evolution of the design and mining strategy of PB4 during the rapid development and engineering of this new block. Lessons learned and ongoing work related to project and change management, undercutting plan, development schedule, and overall mine design are discussed in the paper.

1 INTRODUCTION

PT Freeport Indonesia (PTFI) currently operates three block/panel cave mines: Grasberg Block Cave (GBC), Deep Mill Level Zone (DMLZ) and Kucing Liar (KL), and a long-hole open stope mine: Big Gossan (BG). The mine complex, excluding the future 90ktpd-rate KL that is currently under development, produces about 210,000 tonnes per day of material. Figure 1 shows all the past and currently operating mines in Grasberg mining district.

The DMLZ mine is the fourth lift of caving in the East Erstberg Skarn System (EESS) and lies about 500m below the recently decommissioned Deep Ore Zone (DOZ) mine and approximately 1,500m below surface. The feasibility study of DMLZ projected a mine life through 2041 with 2,450 drawpoints planned (700 active at any given time) and scheduled daily tonnage peak at 80,000 tonnes per day (Casten et al. 2016).

1.1 Seismicity and geology of DMLZ

DMLZ is a seismically active mining area due to its hard and massive rock mass combined with high stress environment being deep under surface, which represents a challenge to the cave propagation and mining operations.

The principal geological units around the extraction level of DMLZ consist of the Erstberg diorite, Waripi and Kembelagan limestones, and skarn at the diorite contact with some presence of major structures and faults (Leys et al., 2020; Haflil et al., 2020). Diorite is the most competent rock mass (160 – 180 MPa) dominating a larger part of DMLZ, specifically in the southern footprint PB1S and PB3 blocks, which strongly contributes to the seismicity of DMLZ. The remaining area is predominantly limestones and skarns (Figure 2).

1.2 Historical Background of DMLZ PB4

Initially, DMLZ mine was divided into three main production blocks, PB1, PB2 and PB3, with each later split into 2-3 smaller sequential blocks. By 2021, DMLZ footprint was divided into seven production blocks, sequenced relatively starting from center of footprint (PB2A) outwards (Figure 3).

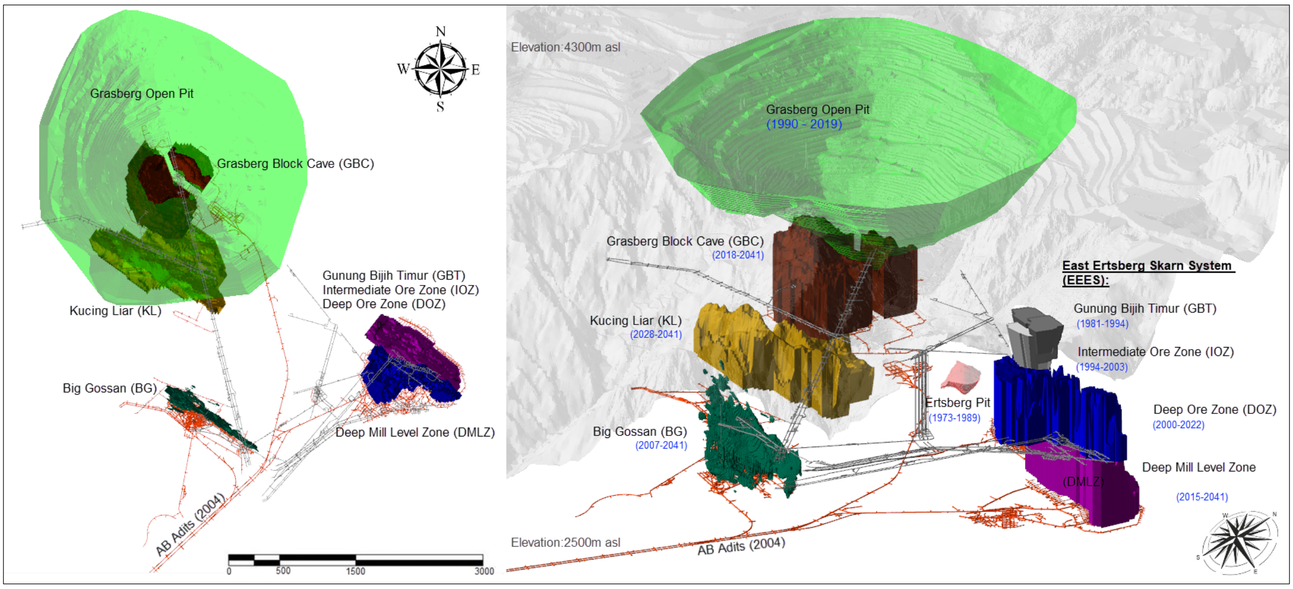

Figure 1 **Overview of PTFI mining district.**

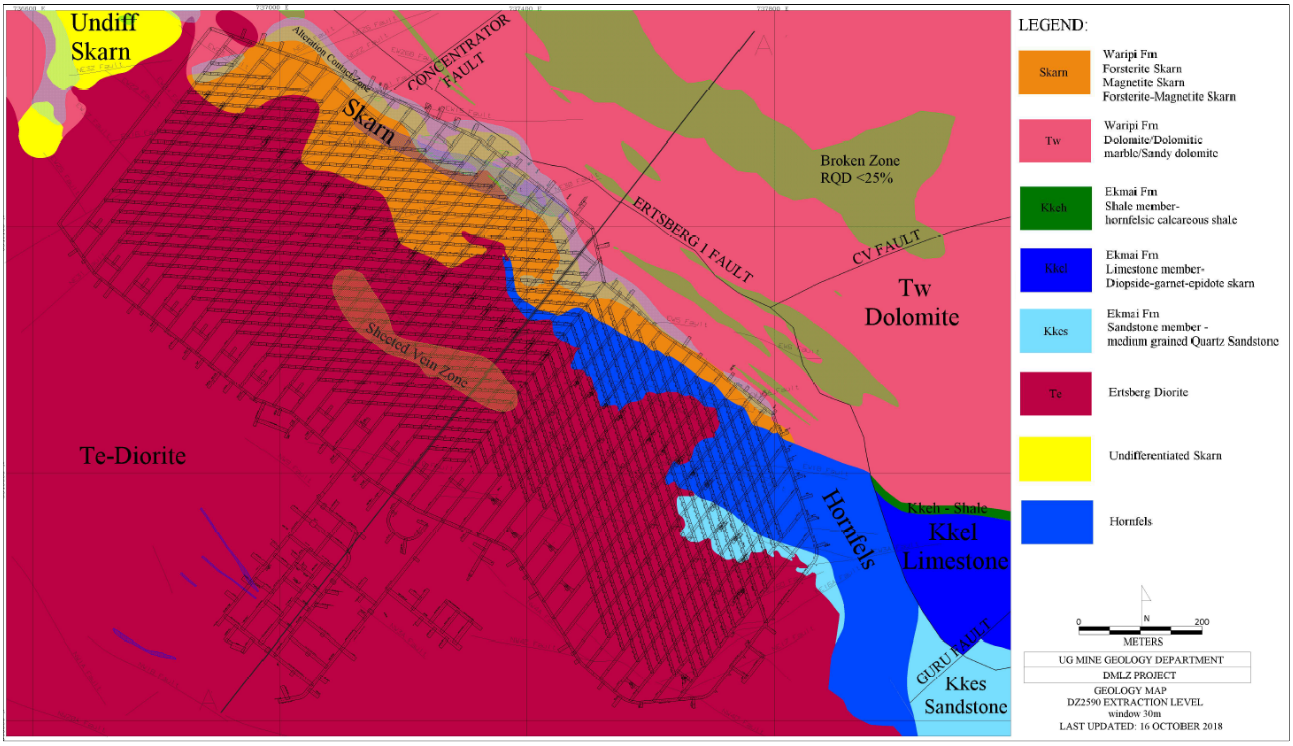

Figure 2 **Geology and footprint of DMLZ extraction 2590L (courtesy of PTFI Geology Department).**

DMLZ initiated caving and started ramping up production in 2015. During these years, DMLZ experienced several seismic events, with the most significant occurrence in January 2018 at a recorded magnitude of 2.0 Mw. This event caused a 14-month delay for the undercutting plan until March 2019 and extensive improvement of stress and seismic management (Simanjuntak et al., 2020; Edijanto et al., 2022).

It was apparent that mine-induced seismicity was a much larger issue than originally anticipated. More recently, a 2.5 Mw seismic event occurred in January 2021, triggered by a production blasting, and followed by a flurry of seismicity, damaging nearly 6,000 meters of drift in DMLZ southern areas.

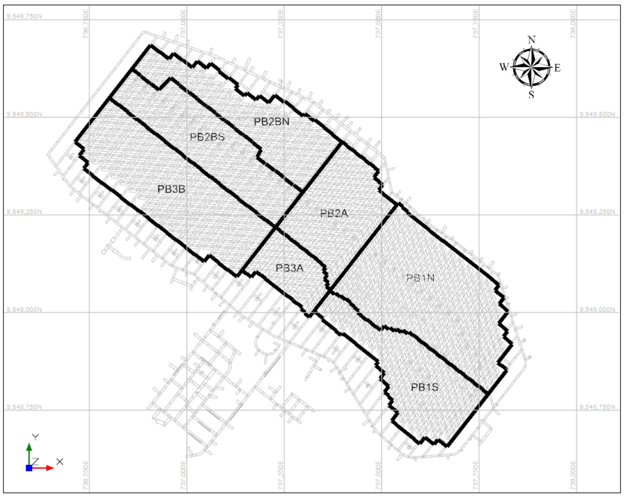

Figure 3 2021 Original DMLZ production block plan (Y2021).

The resulting damages from the event spread across multiple working levels including undercut, extraction, service, and haulage, leading to a decision of deferring two mining blocks, PB1S and PB3, to complete necessary rehab and to manage the abutment stress particularly in the southern vicinity where fixed facilities are, in addition to changes in ground support design and maintenance, re-entry protocol, undercutting sequence and hydrofracking plan (Nugraha et al., 2022).

Further assessments identified that the dipping nature of the orebody mean the highest grades were above the current footprint towards the south as shown in Figure 4. In addition, moving the planned elevation for these blocks higher would reduce seismic risk without significant loss of metal. PB1S, PB3A and PB3B were subsequently elevated 225m from the original level 2590L (and later named "PB4" to distinguish from original level) while maintaining the other blocks primarily in Skarns, PB1N, PB2A, PB2BN and PB2BS on 2590L.

2 GEOTECHNICAL CONSIDERATION

2.1 PB4 Extraction Level Selection

Geotechnically speaking, continuing extraction of southern blocks on original 2590L level presents potential hazards and issues such as:

- Underbreak in Diorite leading to loss of recovery
- Large seismic events associated with the expanding cave and interaction with large faults
- Increasing stresses and strainburst potential acting on development within and adjacent to the abutment zone
- Increasing frequency and extent of undercut, extraction and inter level pillar failure
- Maturation of the flow in the cave would potentially worsen dilution and probable increasing inflow of wet muck

PB4 extraction level was selected as 2815L, 225m above the original DMLZ extraction elevation by considering high grades, recovery, and anticipated mining and lower stress conditions (Figure 4).

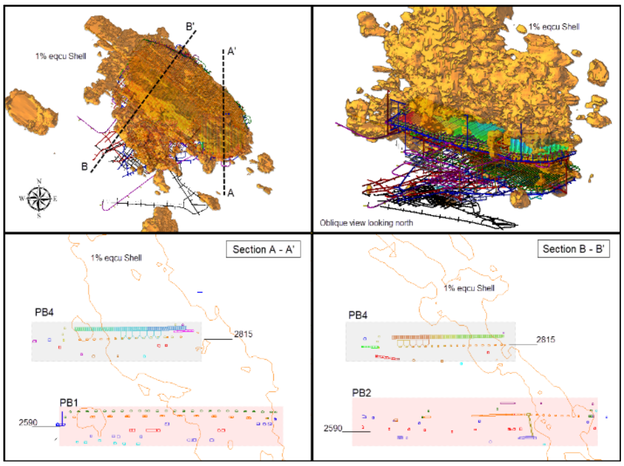

Figure 4 PB4 extraction level selection with north-dipping high grade 1% eqCu isoshell.

2.2 Cave Connection Strategy

PB4 presents unique challenges due to essential interaction with existing PB1-PB2 cave in the northern footprint that continues to grow laterally on the PB4 extraction 2815L due to ongoing production on 2590L. The cave resulting from PB4 must connect to existing PB1-PB2 cave to ensure good recovery, no air gaps or material stalling. Simulated material flow for the current production plan is illustrated in (Figure 5).

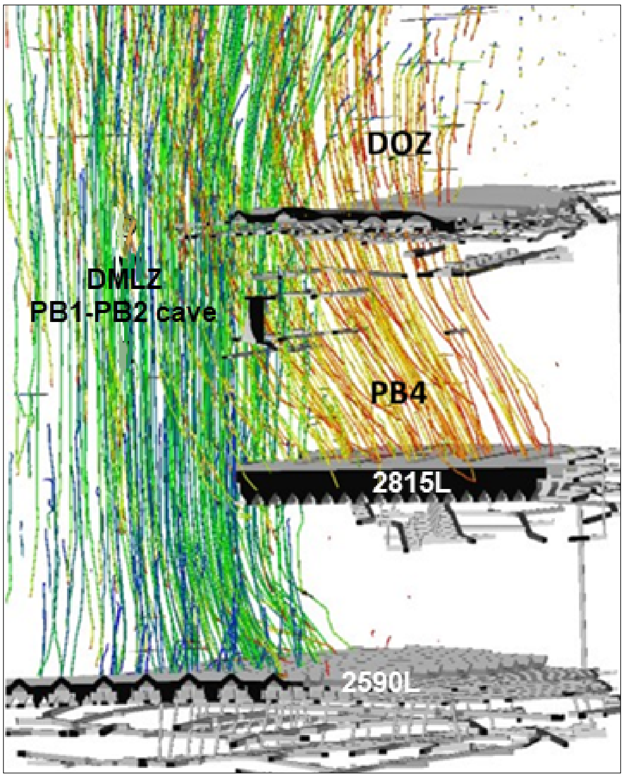

Figure 5 Simulated material flow between lower DMLZ and PB4 (facing east, courtesy of Beck Engineering).

Critical development areas that lie proximal to the current and projected cave positions and are susceptible to cave interaction. Development designs are continuously assessed for field-fitting as excavations advance towards the exiting cave and the PB1-PB2 cave continues to grow. Based on cave monitoring and numerical forecasts, development-to-cave standoff guidance has been established for all development horizons in PB4. The measured cave shapes, defined on an ongoing and monthly basis, are based on T1-T2 boundaries as described in Figure 6.

Although the modeled cave position has been considered as part of the overall life-of-mine design process, detailed mine design explicitly references forecasted cave position as part of the standoff assessment. For planning purposes, a general 30m standoff distance between development parallel to the cave and the current cave (T1) boundary for all levels excluding apex and undercut levels. For both apex and undercut levels, near field (30m) cave tagging drilling will be used to determine development stop position, though for design approval purpose, a 10-15m standoff distance is recommended.

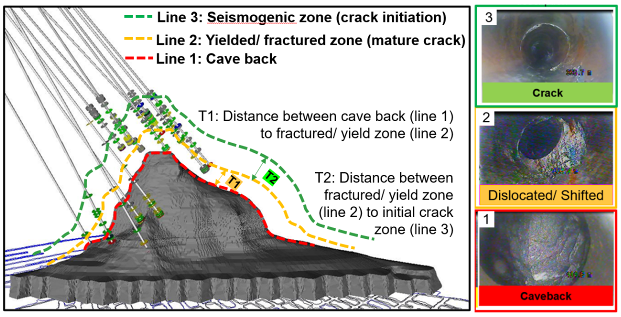

Figure 6 Method and terminology related to cave shape wireframe definition (courtesy of DMLZ Geotechnical Department).

On the extraction level, drawpoints and drawbell drifts should not be placed closer than 30m to the cave position while panel and egress segments, perpendicular to the cave, may be allowed closer if local observations allow and is operationally feasible. Underneath the extraction level, exhaust services are connected via vertical raises. To accommodate ventilation looping through the end of panels, the exhaust development including the raises may exist within 30m of the defined cave boundary.

The cave connection plan primarily constrains the extent of near-cave development such as apex, undercut, extraction and exhaust levels. This offset distance concept serves as initial guidance in the overall strategy. As the cave continues to grow and evolve, this distance will constantly be revisited and refined with site-level Standard Operating Procedures (SOPs).

3 MAJOR MINING STRATEGY CHANGES

3.1 PB4 Footprint and Working Levels

PB4 purposefully replaces the original southern production blocks of DMLZ but on elevated level. Figure 7 shows the pre-feasibility study (PFS) layout of lower DMLZ footprint (2590L) overlaid by PB4 extraction level (2815L) in actual position as a red outline and then offset to the south with detail. The current End 2023 footprint represents a Feasibility Study (FS) layout which reflects a major change of which PB4 splits into two main production blocks, separated by a pillar of low-grade zone (Figure 7).

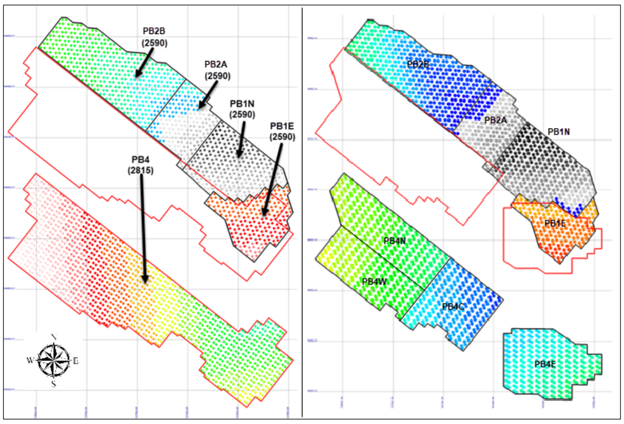

Figure 7 Changes of PB4 footprint layout from original PFS (left) to current End 2023 footprint (right).

As described in Section 2.1, the selected level of 2815L is approximately 225m above the original level of 2590L, at which the other DMLZ production blocks sit (Figure 8). With location between recently commissioned DOZ and active DMLZ, PB4 is benefited from having major shared infrastructures to reduce capital costs such as ventilation, crushers, and existing fixed facility.

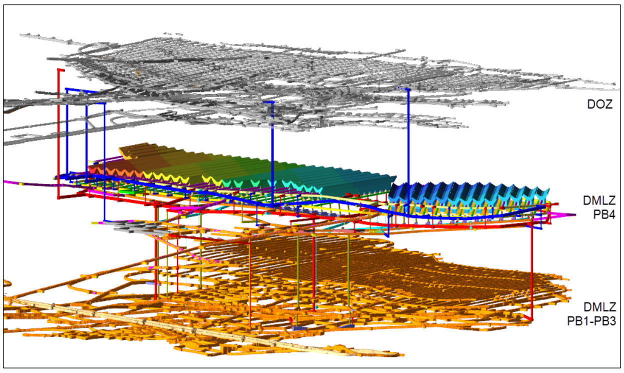

Figure 8 Oblique view looking north of DOZ, PB4, lower DMLZ (PB1-PB2).

PB4 was designed toward the best practice implemented in PTFI and benchmarked industry. From the ideation of PB4 to the first blasting of access drift, the mine plan was developed and executed in 10 months. This urgency was driven by the need to sustain sufficient working inventory of drawpoints, and the timing of the decision based on the seismic response at the DMLZ. The current mine plan has somewhat evolved and improved from the initial concept, with major changes on apex, undercut, extraction, service, and haulage levels. The footprint has also changed to two principal areas, East and West, split by a triangle-shape pillar of a low-grade zone.

3.1.1 Apex

Apex drilling drift as a primary method to confirm the established major pillar becomes less significant with the advanced technology in drilling, blasting, and surveying. As an interim step to elimination of apex level, drilling drifts are now planned at a 60m spacing. The slot drift is placed no closer than 15m from the existing cave boundary, in accordance with geotechnical guidance.

Several investigations and trials are currently being undertaken to substitute apex level function with improved design and operational practices on undercut level.

3.1.2 Undercut

PB4 implements an advanced W-undercutting, similar to lower DMLZ. Drilling drifts are 30m spacing. The latest undercutting footprint covers an area of approximately 318,000m^2, excluding the pillar between eastern and western blocks (Figure 9).

Figure 9 further shows the optimized orientation of undercut drifts following extensive assessment by Geotechnical group. While western blocks orientation remains the same, the eastern mining block has been adjusted to true N-S (N1800E), relatively normal to the cave shape, from originally NE-SW orientation parallel with the western blocks. Direction perpendicular to the existing underlying or adjacent cave will result in a more favorable condition to promote the cave.

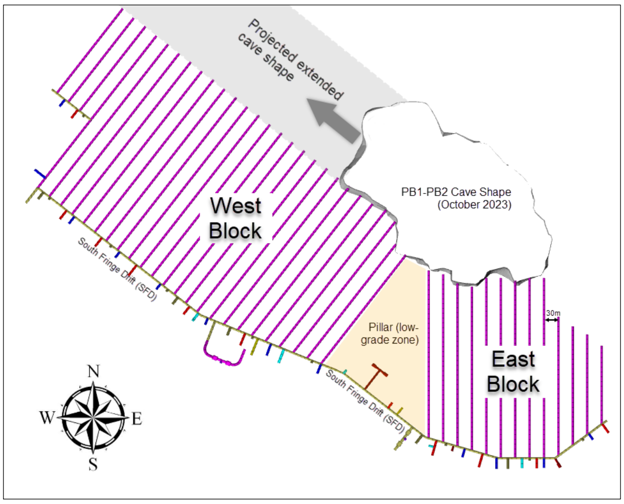

Figure 9 **Undercut footprint and drilling drifts orientation.**

For mine planning, a standoff distance of 10-15m from the cave is applied to undercut drifts. At the end of each drift, a ring firing toward the existing cave (high undercut) will be executed to promote early cave connection. A slot drift designed for regular slot will also be usable for this high undercut firing. Figure 10 illustrates ring drill plan with the slot drift used for regular ring firing.

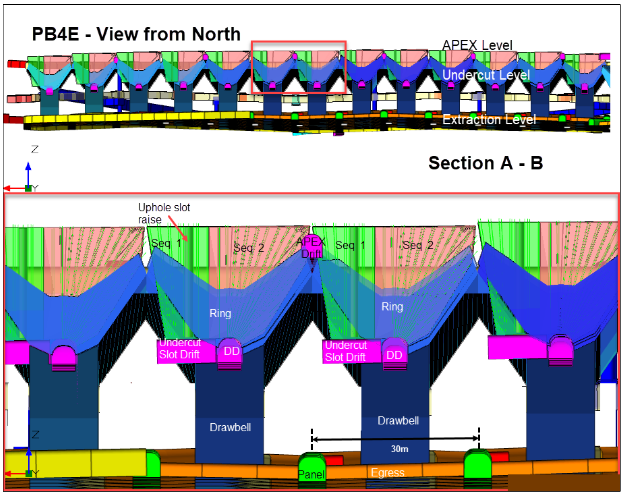

Figure 10 **Currently proposed ring setup and slot from undercut level.**

3.1.3 Extraction

In the original conceptual study, a herringbone layout was selected for PB4 due to possible single access for production Load Haul Dump (LHD) from south direction. In PFS and FS, the layout was reassessed and found resulting minor pillar to be less favorable compared to El Teniente style, and thus PB4 extraction plan has changed to utilize the latter.

Figure 11 shows the snapshot of PB4E El-Teniente layout with 20m x 30m drawbell spacing. The current layout comprises of some 1,046 drawpoints, with opening sequences adhering to four production blocks as shown in Figure 7 (PB4E, PB4C, PB4N and PB4W).

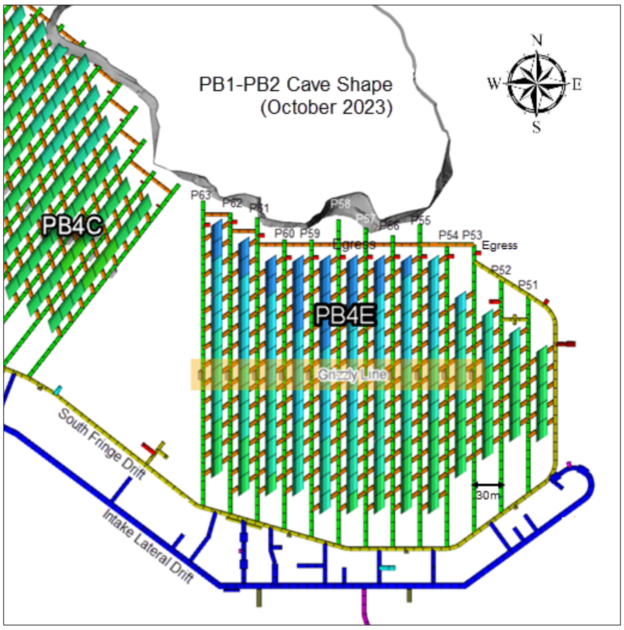

Figure 11 **Extraction level development modification toward the existing northern PB1-PB2 cave.**

Panel egress has been the focus of the design review post-PFS. The potential PB4 cave connection in the north with the existing PB1-PB2 cave presents a challenge to any long-term development nearby. As a secondary access and escapeway, the egress is positioned in the north end of panels and must maintain its accessibility at least until the operation is no longer active in the area. Initial guidance called for egress no closer than 15m to the existing cave (Figure 7). Maintaining sufficient pillar between egress and most northern drawpoints, the regular drawbell will be within 30-40m at most from the existing cave. The egress, exhaust and northern panel will eventually sit under the cave which should de-stress the pillar with cave passing.

A simple ventilation setup was designed for extraction level where fresh air flows in through panels from south (where fringes and access exist) and to be exhausted in the north exhaust raises.

The evaluation on PB4 extraction level also happened on allowed pre-caving development. PB4 initially proposed an advanced undercutting with deferred stubbing, similar to lower DMLZ. This rule restricts many developments ahead of undercutting. With increased confidence on PB4 rock mass condition, further assessment allows significantly more development to be open earlier before cave passes including drawbell drift, drawpoint, and ore passes, though the drawbell opening remains in the de-stressed zone behind the undercut face.

3.1.4 Ventilation Services

The existing cave in the north of footprint presents a geotechnical stability risk to development. Incorporating proper risk assessment in mine planning, most of critical infrastructure and such as ventilation drift, main access, main drain holes, and fixed facilities are located as far as possible from cave.

The ventilation philosophy of PB4 was developed slightly differently from the lower DMLZ ventilation system. With the existing cave in the north posing risk on long term infrastructure, PB4 would need to keep critical development along the south fringe. Figure 12 shows the ventilation distribution where fresh air, sourced from intake shafts positioned in south fringe, flows through panels and drilling drifts into the footprint and working area, and subsequently returns south where multiple exhaust shafts exist.

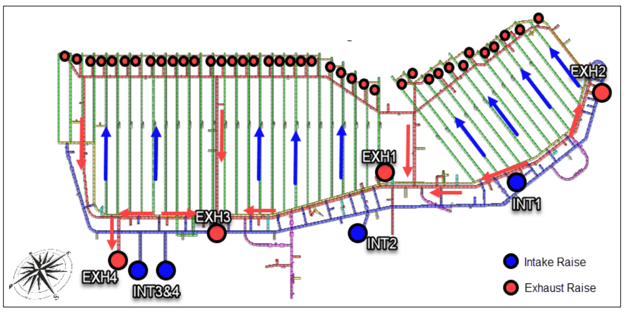

Figure 12 Ventilation strategy in the footprint.

At full production, PB4 would require 1,700m^3/s of airflow – delivered through 4 (four) intake and 4 (four) exhaust shafts on the south fringe; all sized up 6m diameter. The air is distributed over footprint via main intake and exhaust lateral connection, also positioned along the fringe. In contrast to the lower DMLZ system, exhaust lateral is kept at a safe distance from potential cave growth. The integrity of these shafts and main drifts should be maintained in case of PB1-PB2 cave growth.

3.2 Undercutting Timing and Sequence

Large underground block cave projects are normally envisaged to take 10-15 years for establishing accesses, pre-production development, and constructing facility needed to start production, followed by another few years for a ramp up to full production. For PB4, time allowance is much restrictive in attempt to achieve relatively the same production target pre-PB4 plan.

PB4 production is scheduled to commence in the second quarter of 2025, 28 months after the first blasting of main ramp access. During this time span of over two years, development critical path continues to be developed, including two main accesses, required working level development, ventilation raises, and a dedicated fixed facility. Figure 13 shows the targeted caving start dates for each PB4 block, as earliest as January 2025 in PB4E.

PB4 undercut initiation and direction have been optimized through comprehensive analyses – caveability, geotechnical considerations and column values. The chevron sequence in PB4E and PB4C aligns with the plan to accelerate propagation rates during early years of production, in addition to being favorable for:

- improved caveability (i.e., cave will grow earlier from a hydraulic radius standpoint)
- improved fragmentation profile (less oversize associated with skarn material)
- improved stress/loading conditions associated with a chevron/half circle undercut arrangement, and
- cave connection to existing DMLZ cave

Such benefits are less important later in PB4 mine life and thus the single-front initiation point in PB4N and PB4W.

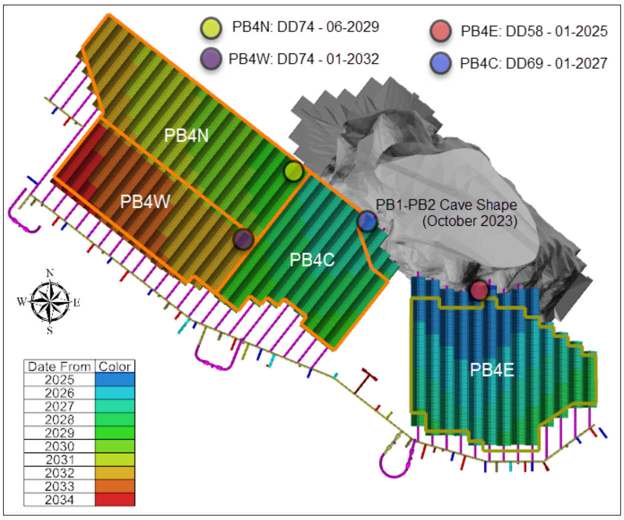

Figure 13 **PB4 undercutting sequence as per End 2023 budget plan.**

3.3 Cave Connection Plan

As the cave continues to grow, the mine plan must maintain flexibility. Monitoring the dynamic cave position is critical and cannot be overlooked. Corporate and PTFI Geotechnical group have established three types of cave position identification to monitor the Lower Wedge Volume (LWV) adjacent and below the 2815L northern footprint. Monitoring continues to be conducted using a combination of open holes, Elexon's CaveTracker system, Elexon's networked smart markers, TDR, seismic data, and HOD projection to establish confidence level on the cave shape as shown in Figure 14.

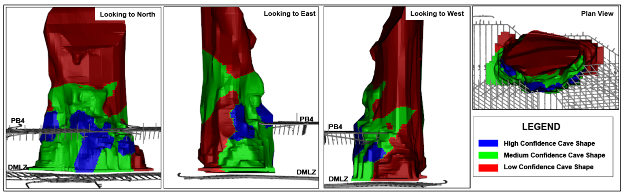

Figure 14 **Cave shape confidence level based available monitoring data sources (courtesy of DMLZ Geotechnical Department).**

As introduced above, recommended offset against the defined cave shape/boundary provides initial basis for development stop lines. The cave boundary estimate is determined from tagging and monitoring drilling.

On apex, undercut, and extraction levels, drifting development advances up to 10-15m from cave boundary or potentially closer if deemed safe to do as per relevant SOPs. At the stop line, a breakthrough to the existing cave will be undertaken with drilling and blasting (Figure 15).

A lintel brow will be set up at the end of extraction panels to draw the broken materials from the pillar blasted from apex and undercut. This conceptually acts as drawpoint with a highly controlled pull rate to primarily establish PB4 cave connection with the PB1-PB2 cave.

The regular production drawbells sit between 30 and 40m from the cave boundary (Figure 16), leaving considerably sufficient pillar for egress drift and exhaust ventilation raise between these bells and the cave.

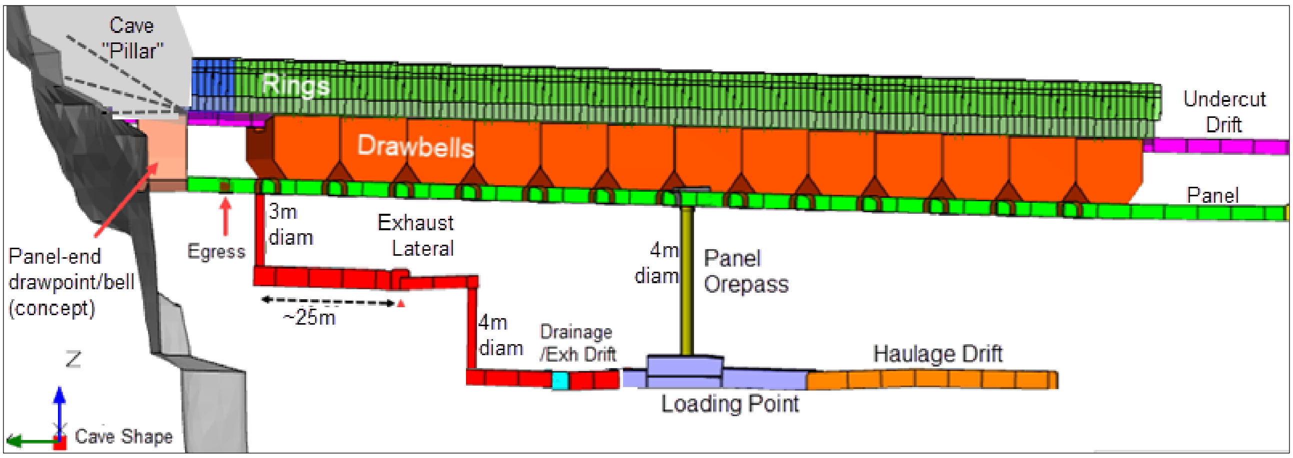

Figure 15 **Long section diagram of proposed cave connection plan.**

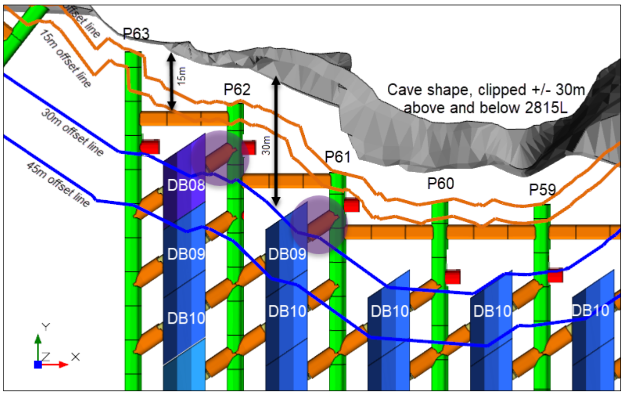

Figure 16 **Offset guidance on the northern footprint for extraction level development (2815L).**

3.4 Ore Handling System

The ore handling concept of PB4 was primarily focused around the shareability of crusher and conveyor facility on lower DMLZ level. PB4 has dedicated development and system such as fixed facility, services level, etc., separated from lower DMLZ system, though it also shares some major infrastructures such as crushers and ventilation network.

With elevated footprint, minimizing the number of ore rehandling and size reduction process while efficiently transporting the ore to existing facility located 300m below PB4 extraction level was the focus of ore handling method selection. The entire arrangement occurs on three distinct levels: PB4 extraction, PB4 haulage and lower DMLZ crusher levels (Figure 17).

The ore from drawpoint on extraction level is transported by 7m3 LHDs, dumped onto 0.8 x 0.8m grizzly-set ore passes located on each production panel, which then be trucked out to a large intermediate ore pass that connect PB4 haulage level to DMLZ crusher level. The panel ore pass length ranges between 20-30m with the intermediate ore passes (5m diameter) are much longer, 180 – 195m.

The haulage system in lower DMLZ provides a blueprint for PB4. From early concept to current design, PB4 haulage level has evolved from a rudimentary intermediate truck hauling drifts to more elaborated design as it is now.

There are four intermediate ore passes planned (Figure 18) with three at least are required to be in operation at full production years. These ore passes are critical components in the entire system and thus ensuring these available and uninterrupted has been the focus of early studies and assessment involving multiple stakeholders.

Ongoing review to mitigate the risks associated with developing long ore passes through active and existing development of lower DMLZ, maintaining the integrity of these ore passes over mine life, securing for maintenance and potential interruption due to material hang-ups or blockage.

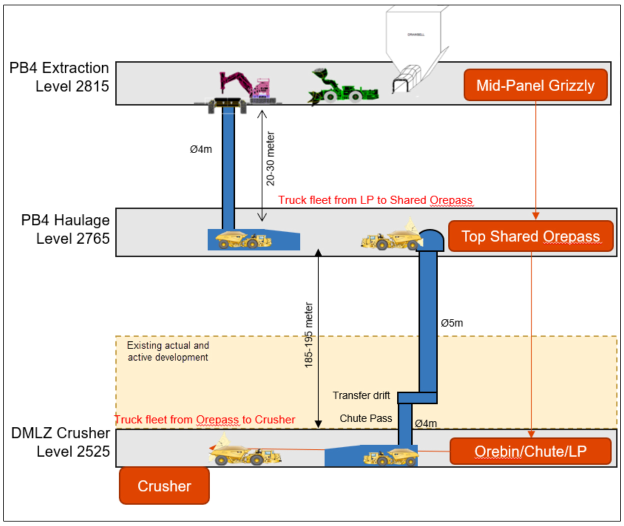

Figure 17 **Ore handling arrangement from PB4 to DMLZ crusher system.**

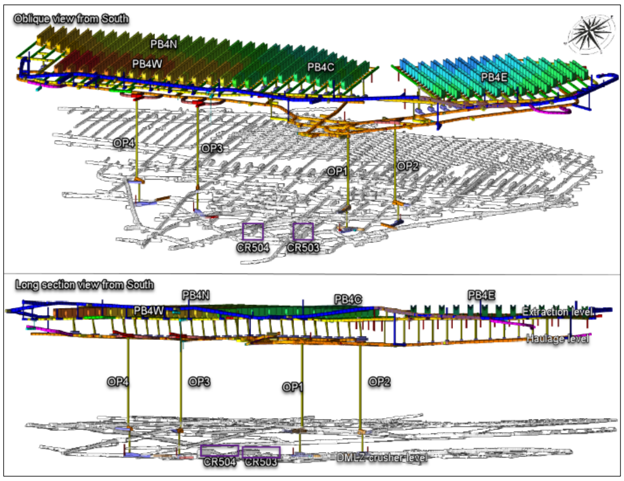

Figure 18 **Intermediate ore passes as a method transporting ore from PB4 to lower DMLZ crusher facility.**

4 LESSONS LEARNED FROM PB4

4.1 Dynamic Planning Process with Uncertainties and Unknowns

Since PB4 plan conception, uncertainties and unknowns are two traits that uniquely define the mine plan. Geotechnical aspect to operational viability of developing footprint towards existing cave and in between two mining extraction levels including seismicity risk were not all well understood at conceptual level. Through continuously improved process and data collection, PB4 mine plan has well navigated through dynamic environment with uncertainties.

Several key components that enable the process include collaboration and communication of people and expertise internally and externally, proactive involvement of management and stakeholders, and proper change management.

From the conceptual to the FS stage, engineering and operational personnel together work on details of the mine plan. A risk register and response system are developed to mitigate the risk and provide contingency plans. PTFI has world-renowned expertise that is valuable for the PB4 project. Lessons learned and experience obtained from other mines in Grasberg complex has brought valuable knowledge into the project. More specifically, most of DMLZ PB4 site personnel were transferred from the DOZ mine, which was recently decommissioned after 22 successful years in operation.

Proactive involvement from management and other stakeholders demonstrates continuing support and is critically needed in project like PB4, which has tight deadlines and rapid development advances. Fast-track decisions on major changes are frequently needed from management and stakeholders allowing the project to keep up with milestones schedule.

4.2 Change Management and Process

In such a complex and rapid progress project, the changes can be overwhelming and easily overlooked. The strategic mine planning group provides the life-of-mine design, production sequences, and long-term development schedules, together with ground support recommendation for site operations to use as basis for tactical and short-term executable activities. Changes can occur throughout the process.

To help record and control these changes, a change request (CR) system was used via the existing online approval system. The CRs are sent to all the stakeholders for review and approval. The CR system has greatly increased the collaboration between various teams and ensured the change be considered in the mine plan.

5 CONCLUSIONS

The PB4 mine plan development began in early 2021 upon decision to cancel PB1S and PB3 blocks. PB4 envisages three years of pre-production development and construction before commencing first drawbell blast, followed by another three years ramp up. As part of DMLZ mine, PB4 will support the mine’s 80ktpd target, but is uniquely challenging due to seismic activity and its geospatial location between two extraction levels and next to active cave.

Management of cave growth and its dynamic impact to development during rapid advance of development and production milestones characterize the mine planning and undoubtedly provides valuable lessons along the way. Responses to changes such as those presented in this paper are ongoing effort by multi stakeholders for continuous improvement and collaboration.

ACKNOWLEDGEMENT

This paper is a brief update of major mine plan strategy changes that occur in DMLZ mine with the development of a new production block, PB4. The authors want to thank Freeport-McMoRan Inc. and PT. Freeport Indonesia for permission to publish this paper and for their continued support; particularly over the past three years since the envision and development of PB4. Acknowledgement is also extended to Beck Engineering and PTFI underground technical staff for valuable contributions to the genesis and development of the PB4 mine plan.

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