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Challenges and operational management of block caving by JCHX in Pulang copper mine

Wang Huan [a], Hu Zhou [a], Wei Weiwei [a], Liu Wei [a,*]

[a] *JCHX Mining Management Co Ltd, China*

Abstract

The Pulang copper mine, with a designed annual production of 12.5 million tonnes, is the largest operational block caving mine in China. To address the two core challenges of mining – the stability issues of the undercut level drifts and the risk of underground mud rush disasters – the mine has developed and implemented a multilevel, intelligent integrated technical and management system. This system encompasses intelligent ore-drawing management, a graded drift support system and advanced production equipment, ensuring safe and efficient mining operations.

The successful operation of the Pulang copper mine marks a significant achievement for JCHX and for China in the management and operation of large-scale block caving mining under complex geological conditions. The core lesson learned lies in acknowledging and deeply understanding the specific risks, such as drift instability and mud rushes, inherent in the geology and mining method. Adopting a systems engineering approach integrates refined process control with the application of intelligent equipment, proactive disaster prevention, and digital monitoring and early alerts. This integration forms a dynamically adaptive and continuously optimised modern mine operation system.

Keywords: *block caving, mud rush prevention and control, automated ore drawing, drawpoint control, bottom structure support*

1 Introduction

Pulang copper mine, a benchmark for the successful application of block caving in large-scale operations, commenced construction in 2014, began production in 2017, and achieved an annual ore output exceeding 10 million tonnes by 2020 and 13 million tonnes in 2025. The mine is designed with adit development. The initial mining area primarily exploits the KT1 orebody above the 3,720 m level, with an average caving height of 200 m. Key operational levels established include the 3,736 m undercut level, 3,720 m extraction level, 3,700 m ventilation level, 3,660 m rail haulage level, 3,600 m crushing level and 3,540 m conveyor haulage level.

As of December 2025, the extraction system comprised 788 drawpoints. The primary production fleet consists of LH514E electric load-haul-dumps (LHDs) and LH514 diesel LHDs, all of which have been fully upgraded for automated remote control. Drawpoint management is executed via the iOreDraw software system, enabling full digital control from annual planning to daily execution.

* Corresponding author. Email address: liuwei@jchxmc.com

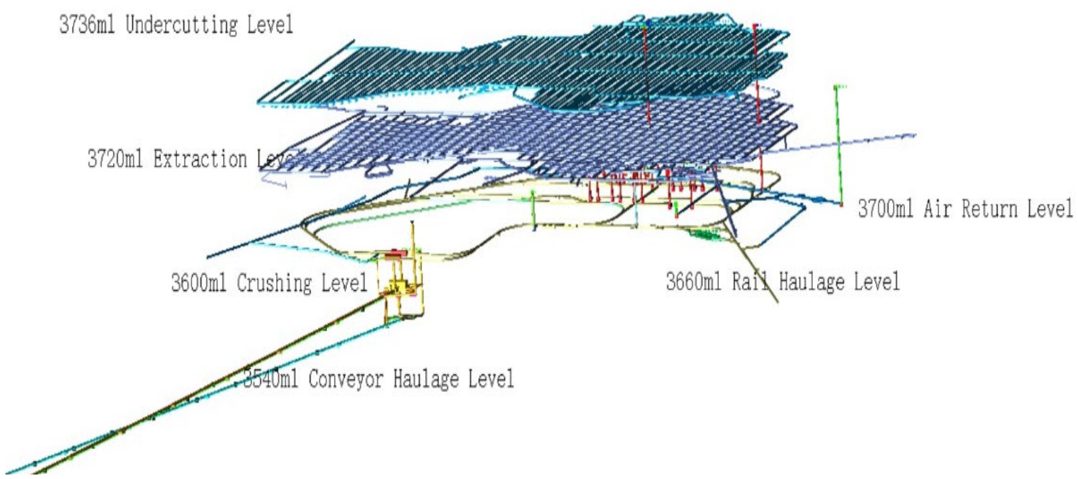

Figure 1 System schematic diagram for Pulang copper mine underground

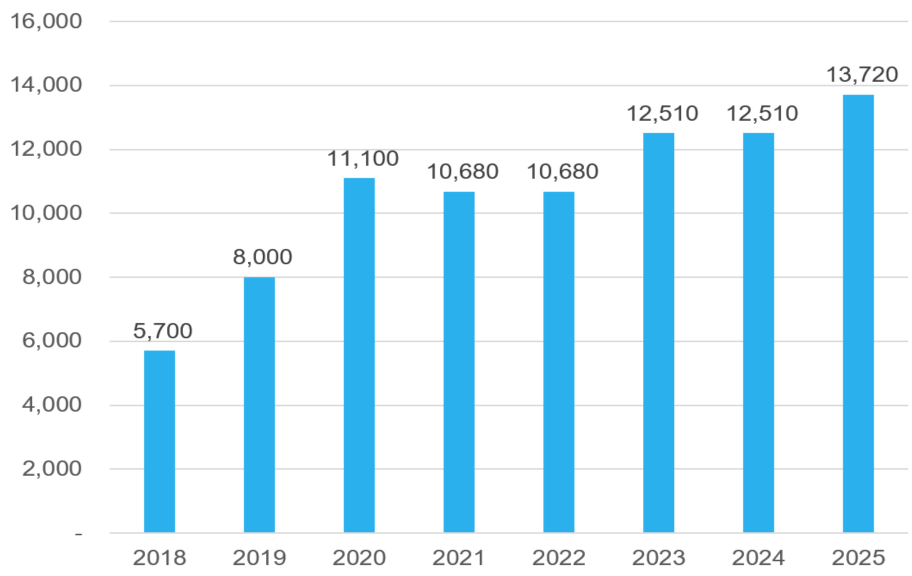

Figure 2 Production rate per annum (thousand tonnes)

The advance undercut method is adopted for the longhole and narrow section inclined undercut with a maximum height of 15 m. The interval between the extraction crosscut is 30 m, and the interval between the extraction access is 15 m. The drawpoint is arranged in a branched fishbone type, and the extraction access intersects with the extraction crosscut at an angle of 50°. The drawbell is 14 m long, 16 m high, 4.2 m wide at the bottom and 10 m wide at the top. The blasting of drawbell lags behind the undercut progress line by at least 20 m, and the ore-drawing lags behind the undercut progress line by 40–50 m.

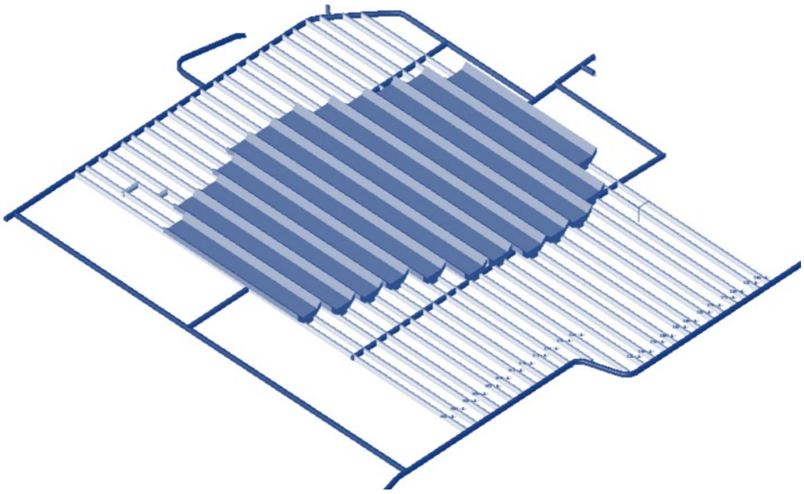

Figure 3 Diagram of the undercut level

2 Core challenges in the mine production process

As mining operations continue to expand, the mine faces significant technical challenges. The connection between subsidence areas and stopes has resulted in frequent mud rushes, while the 3,720 m extraction level suffers drift damage due to complex geological structures (Fan 2017). Traditional manually operated LHDs struggle to maintain safe ore extraction under these challenging ground conditions. Against this backdrop, this paper systematically presents technological breakthroughs and operation practices implemented at Pulang copper mine in recent years, focusing on key areas such as mud rush prevention, automated remote-controlled ore drawing, digital-platform-based drawpoint management and reinforcement of bottom structures under complex geological conditions. The insights provided aim to serve as a valuable reference for block caving mines pursuing intelligent, safe and precise operational transformations.

2.1 Ground pressure and drift stability in the underground structure

The drifts of the bottom structure at the 3,720 m extraction level are reinforced using a combined support system comprising double-layer steel fibre-reinforced shotcrete, bolting with mesh and anchor cables. At the drawpoint brow, four sets of H-section steel arches provide additional support. The rockbolts are ϕ22 mm threaded steel, fully grouted with cement mortar, arranged at 1.0 × 1.0 m spacing and 2.7 m in length. Anchor cables are fully grouted with cement mortar, with two 15.2 mm strands per hole, spaced 2.0 m apart in both directions and 8 m long. Shotcrete is applied in two layers, each 100 mm thick, of grade C25, with steel fibres added (diameter 0.5 mm, length 30 mm, aspect ratio 60, tensile strength >1,100 MPa).

Deformation in the drifts commonly occurs in zones with well-developed joints and fissures, interlaced faults and poor rock stability. The orebody is affected by five faults – FI-1, FII-1, FII-2, FIII-1 and FIII-2. After mining, the vertical principal stress continues to act due to fault slip. In the intersection zones of these faults within the S3, S4 and S5 extraction drifts, ground pressure induces substantial deformation which has resulted in approximately 200 m of drift collapse.

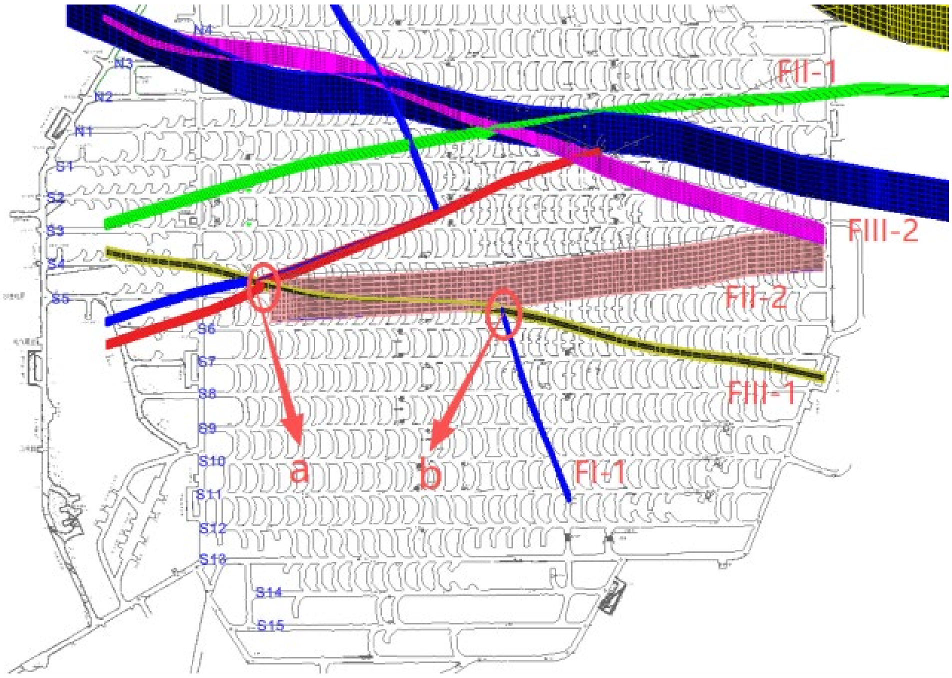

Figure 4 Diagram of the fault zones (FI) in the initial mining area of Pulang copper mine

(a) (b)

Figure 5 Occurrence of ground pressure at the 3,720 m extraction level in (a) S4 crosscut and (b) S6 crosscut

2.2 Risk of underground mud inrush

Since mining began at Pulang copper mine in 2017 the surface subsidence area has expanded gradually. A large volume of surface soil has collapsed into the subsidence pits. As ore drawdown continues, the soil undergoes comminution and particle segregation during its downward movement, resulting in a high proportion of fine particles and reduced permeability upon deposition. During the rainy season from June to October, underground mud inrushes triggered by intense rainfall have occurred intermittently. Of particular note is the mud inrush in 2021, which was especially severe: roughly 15,000 m^3 of material surged from the S1–E28 drawpoint, burying adjacent drifts and facilities and causing disruption to normal mining operations.

Statistical analysis of the mud rush over the years found that large-scale mud rush generally occurs within 12 hours after heavy rain (daily rainfall ≥50 mm), and the occurrence of mud rush is also affected by other factors such as occurrence at the drawpoints near to the main faults, the emergence of mud at the surface subsidence and ore extraction volume at the drawpoints in a single day.

(a) (b)

Figure 6 Underground mud rush hazards in the 3,720 m extraction crosscut. (a) S1 west side; (b) S1 east side

3 Establishment and management of the technical response system

To address these challenges and maintain safe and efficient operations, the mine has developed and implemented a multitier, intelligent framework integrating engineering solutions and management systems.

3.1 Formation mechanism and comprehensive mitigation of mud inrush

3.1.1 Failure mechanism of mud inrush

Mud inrush events at the Pulang copper mine result from the coupled interaction of four controlling factors: material source, flow pathways, water supply and operational disturbance. The subsidence pit contains abundant unconsolidated and weakly cemented materials, including quaternary deposits, weathered debris, fault-fractured rock masses and broken overburden above mined-out stopes.

The large subsidence pit characterised by relatively steep slopes, together with through-going fractures and caving voids induced by the block caving mining method, forms an efficient conduit system for rapid mud migration. Precipitation accumulates within the subsidence pit and infiltrates underground through bedrock fractures and surface run-off, providing a sustained water supply.

Uneven ore draw induces localised caving disturbances that accelerate the development of flow pathways, while highly fractured rock masses in fault zones are more prone to sudden inrush events.

Mud inrush typically occurs in two modes:

1. Slurry migrates through the broken ore column and is discharged directly from drawpoints.
2. Slurry accumulates in voids between the ore column and the caving rock mass, and is suddenly released once the mechanical equilibrium is disrupted (Song et al. 2009).

3.1.2 Prevention and control system

The Pulang copper mine has established an integrated four-component risk mitigation framework – monitoring and early warning, source control, engineering mitigation and scientific ore-draw management – to address debris-flow hazards. A surface–underground integrated monitoring system tracks key precursors such as discharge water turbidity, roof seepage and abnormal rock mass sounds. Ore-draw operations are carefully managed to avoid abrupt, concentrated extraction, with strict control of draw intensity in fault zones, moraine-rich areas and long-inactive draw zones. During the rainy season, zonal risk management is implemented and ore production in high-risk areas is dynamically reduced based on rainfall analysis of the subsidence pit.

Engineering mitigation measures are implemented through coordinated water control, sediment management and interception/storage strategies. These include the construction of 3.1 km of interception ditches, 10 drainage shafts, and multiple check dams to limit surface water inflow; backfilling and compaction of the subsidence pit, combined with slope shotcrete sealing and drainage channels to reduce solid material supply; and the installation of sediment retention facilities and settling basins to intercept potential debris-flow materials. Through the integrated operation of monitoring-based early alerts , source control through ore-draw management and engineered interception systems, the overall risk of debris-flow hazards has been significantly reduced (Huang et al. 2020).

3.2 Ore-draw management and control system

With iOreDraw software as the core platform, the mine has established a closed-loop management framework integrating planning, execution, monitoring and feedback. By calculating key indicators such as the caving index and ore-draw grade, and adopting a bidirectional scheduling approach combining forward and reverse planning, balanced ore draw and production-rate matching can be achieved. This approach plays a critical role in mitigating debris-flow hazards and maintaining effective ground pressure control.

3.2.1 Core control principles

The core principles of ore-draw management include uniform ore draw, rate matching, grade balancing and production constraints. Uniform ore draw is implemented to maintain a relatively flat caving surface with the inclination angle controlled below 40°, thereby minimising waste rock dilution. Rate matching ensures that the ore-draw rate does not exceed the caving rate (with an upper limit of 0.2 m/d), preventing the formation of excessive void spaces. Grade balancing is achieved through stratified ore blending based on a 3D geological model to stabilise the mill feed grade. Production constraints emphasise the priority of recovery and compaction of drawpoints, optimisation of ground support systems and timely clearance of drawpoint hang-ups, thereby ensuring the safe and efficient operation of the ore-draw system.

3.2.2 Intelligent production scheduling process

Pulang copper mine has constructed an intelligent production scheduling process with iOreDraw ore-drawing software as the technical platform. First, parameter input is carried out to define basic data such as economic indicators and the optimal average draw height. Then index calculations are performed, dynamically solving the caving index of each drawpoint and conducting reverse calculation and calibration in combination with the undercut progress while determining the production scheduling index (1/6–1/8) according to production capacity. In terms of the core production scheduling strategy, a bidirectional scheduling mode is adopted: forward scheduling generates a reference plan based on the ideal caving model, while backward scheduling reversely allocates ore quantities according to the total production target and the actual capacity of each crosscut. Pulang copper mine organically combines the two, using backward scheduling to meet actual production needs and forward scheduling results as the calibration basis; greatly improving the flexibility of production scheduling. Finally, in the monthly plan preparation stage, the system automatically generates production scheduling schemes using various built-in algorithms of iOreDraw such as drawbell management methods, caving ratio weighting, ore blending, etc. and supports chart-linked manual fine-tuning, achieving a deep integration of intelligent algorithms and human experience.

3.2.3 Plan execution and data closed-loop management

The monthly plan is broken down day by day, with the cumulative shortfall function automatically incorporating the previous day's production deficit into the current day's plan, thereby forming an executable daily plan. Actual daily ore output and grade are entered each day, and the system automatically generates multidimensional analysis reports covering draw quantities, draw heights, open/closed status and more, providing managers with clear data-driven decision support.

The draw schedule directly serves as the task list for automated LHD machines, achieving seamless connection from planning to execution; at the same time, ground pressure monitoring data from the bottom structure feeds back to guide dynamic adjustments of draw intensity.

3.3 Graded ground support system for underground openings

In response to damage in the bottom structure, a graded and zoned governance scheme has been developed: depending on the degree of damage, flexible application of strong reinforcement measures such as rigid medium-to-long anchor cable reinforced support, yieldable steel arch frames, concrete-filled steel tube arch frames and their combined support systems is implemented (Li et al. 2021).

3.3.1 Proactive prevention measures

In response to drift development and support under complex geological conditions, Pulang copper mine has adopted a series of technical measures centred on controlling surrounding rock deformation. During the excavation process, smooth blasting is strictly implemented, combined with the 'short excavation, short support and timely sealing' technique to minimise disturbance of the surrounding rock to the greatest extent possible; at the same time, by optimising the construction sequence of rockbolts, anchor cables and shotcrete layers, QC process research is carried out to continuously improve support quality. For extremely unstable sections such as fault fracture zones, steel arch frame support is added and backfill grouting is implemented to enhance load-bearing capacity; for particularly fragmented areas, a strategy of delayed construction of ore-gathering drifts or ore-drawing drifts is adopted to proactively avoid the influence of stress peaks (Wang & Zhu 2023).

3.3.2 Graded treatment scheme

In response to varying degrees of damage a technical solution library has been established, ranging from localised reinforcement to complete reconstruction.

Table 1 Reinforcement scheme for underground drift at the 3,720 m level bottom structure

Scheme name	Core components	Applicable scenarios	Key technical parameters
Cable bolt and grouting	Extra-long cable bolts (2 × ϕ15.2 mm steel strands) and ultra-fine cement grout	Severely fractured rock mass with multiple fault interlayers and significant stress concentration	Full-length mortar anchoring of cable bolts, 3 rows × 3 bolts per row
Steel arch and concrete	Telescopic U-shaped steel arches Steel tube concrete arches	High deformation zones, faulted and fractured areas or ore drawpoints requiring extremely high support strength	29 U-shaped steel arches spaced 0.5 m apart ϕ219 mm steel tubes filled with concrete
Bolt and cable bolt and reinforced concrete	Systematic bolts, cable bolts and thick reinforced concrete lining (double-layer reinforcement)	Areas with extremely severe ground pressure damage	Concrete lining thickness 500 mm, C30, differentiated reinforcement
Forepoling and combined support	Forepoling, steel arches, steel tube concrete columns and long cable bolts	Drifts with severe collapse and roof subsidence, impassable for personnel and equipment	Forepoling ϕ42 mm HW200 steel arches ϕ530 mm steel tube concrete columns

Figure 7 Performance of ground pressure control in the 3,720 m level

3.4 Automated remote-controlled ore handling system

3.4.1 System architecture and functions

To thoroughly liberate operators from the high-stress and high-risk underground ore-drawing sites, JCHX has implemented automated remote-control upgrades on all LHD machines, establishing a technical platform consisting of a surface control centre, high-speed industrial Ethernet ring network, onboard intelligent controllers, environmental perception units and video surveillance systems. This system mainly achieves three core functions: First, by remote monitoring and teleoperation. Operators obtain a full panoramic view of the underground works through multiple high-definition infrared cameras and precisely control all actions of the LHD, including travelling, scooping and dumping, by relying on a simulated operation console; Second, by partial autonomous driving. Within ore-drawing crosscuts, the vehicle can autonomously navigate based on real-time scanning of the drift contour by lidar, automatically shuttling back and forth between designated drawpoints and ore passes. Third, by the 'one operator controls two machines' efficient operation mode. One operator can simultaneously manage two LHDs. While machine A is in autonomous driving mode, the operator remotely controls machine B for scooping; once machine B enters autonomous mode, the operator switches back to remotely control machine A for scooping. This mode increases the effective working time per shift by more than 40%, improves equipment utilisation by 35%, and achieves enhancements in manpower reduction, efficiency improvement and the intrinsic safety level.

3.4.2 Safety protection system

To ensure the reliable operation of the remote-control system in complex underground environments, JCHX has established a multilevel safety interlock system covering communication, spatial isolation, dynamic monitoring and equipment self-protection. At the communication level, the system monitors network latency in real time and automatically triggers parking when the delay exceeds 150 ms to prevent control commands from failing due to signal interruption. At the spatial isolation level, safety access gates and light curtains are installed at the entrances of ore-drawing crosscuts to physically separate personnel during remote operations, completely eliminating the risk of human-machine crossover. At the dynamic monitoring level, onboard lidar scans the distance between the vehicle body and drift walls in real time, with the interface dynamically displaying data and triggering anti-collision warnings, while electronic fence technology defines the autonomous driving area and forces an immediate stop if the vehicle crosses the boundary. At the equipment self-protection level, when critical operating parameters exceed limits, the system automatically alarms and executes protective actions. This multilevel interlock mechanism forms a complete protective closed loop from the communication link, spatial isolation and dynamic monitoring to the equipment itself, providing reliable safety assurance for remote-control operations.

3.4.3 Operational assurance

In addition to the multilevel interlock mechanism, an intelligent dispatching management system has been constructed in coordination, achieving integrated functions of production instruction issuance, vehicle positioning, operation measurement, and report generation. A dedicated professional maintenance team has been established, along with standardised remote operation procedures, to ensure long-term stable operation of the system.

(a) (b)

Figure 8 (a) Automated load-haul-dump ore hauling operations; (b) Surface control room

4 Conclusion

Pulang copper mine is China's largest currently operating natural caving method mine. Its successful operation marks a major breakthrough achieved by China in the field of large-scale natural caving mining under complex geological conditions.

In terms of debris-flow disaster prevention and control, the mine has deeply revealed the disaster-forming mechanism coupled by the four elements of source, topography, water source and disturbance, and clarified the two main outburst modes: direct debris flow and indirect debris flow. Based on this, a four-in-one prevention and control system of monitoring and early warning, source control, engineering governance and scientific ore drawing has been established: precursor information is captured through a surface–underground joint monitoring system, source risk reduction is achieved by relying on ore-drawing optimisation and zoned control during the rainy season, major engineering measures for water control, mud control and interception/storage are implemented to block sources and water sources, and, ultimately, monitoring data is dynamically linked with the ore-drawing plan; realising a fundamental shift from passive governance to active prevention and effectively curbing the frequent occurrence of debris-flow disasters.

In terms of ore-drawing management and control, with iOreDraw software as the core, a closed-loop control mechanism of planning, execution, monitoring and feedback has been formed. By implementing the four core control principles of uniform drawing, speed matching, quality balance and constrained production, combined with forward and backward bidirectional scheduling strategies and intelligent algorithms to automatically generate monthly plans, supplemented by daily plan shortfall accumulation and multidimensional report analysis, precise control of the caving surface morphology and a stable and balanced ore output grade have been achieved. The operation of this system not only significantly improves the refinement level of ore-drawing management but also provides key process support for debris-flow prevention and ground pressure control.

In terms of bottom structure drift support, addressing the severe deformation and collapse issues caused by intersecting faults and stress concentration, the mine has adopted a combined strategy of proactive prevention and graded governance. During excavation, smooth blasting and short excavation with short support are strictly implemented, and support quality is improved by optimising the construction sequence of rockbolts, anchor cables and shotcrete layers; for different degrees of damage, a graded reinforcement solution library has been established, ranging from anchor cable grouting reinforcement and steel arch frame support to reinforced concrete lining and advanced pipe roof combined support; successfully achieving effective governance of drifts under complex ground pressure conditions and ensuring the smooth and safe operation of the ore-drawing system.

In the intelligent transformation of ore-drawing operations through automated remote-control upgrades applied to all load-haul-dump machines, a complete technical platform has been built encompassing a surface control centre, industrial ring network, onboard controllers and environmental perception units. The system realises remote monitoring and teleoperation, autonomous driving within crosscuts and the 'one operator controls two machines' efficient operation mode. This has formed a comprehensive technical system for natural caving mining adapted to high-altitude and complex geological conditions, with its engineering practice and theoretical innovations holding significant reference value for similar mines both domestically and internationally.

The operation practice of Pulang copper mine demonstrates that, in operating large-scale natural caving mines under complex geological conditions, the core experience lies in fully acknowledging and deeply understanding the special risks brought by geology and processes, and adopting a systems engineering approach to deeply integrate refined process control, intelligent equipment application, forward-looking disaster prevention and control, and digital monitoring and early warning, thereby forming a dynamically adaptive and continuously optimised operating system. This series of technological breakthroughs and management innovations not only provides a solid guarantee for safe and efficient production at Pulang copper mine but also offers a replicable successful example for the intelligent, safe and refined transformation of similar mines both at home and abroad. In future the mine will continue to deepen the application of intelligent mining technologies, explore intelligent prediction models for ground pressure and debris-flow disasters, further improve the full-process unmanned operation system.

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