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Design and production practice of block caving in Pulang Copper mine

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Abstract

With a design ore production capacity of 12.5 million tonnes per year, the Pulang copper mine is China's second largest block caving mine. It is located 63 km northeast of the city of Shangri-La in Yunnan Province. The orebody outcrop has an altitude of 3,868-4,023 metres above sea level (masl) and its bottom is below 3,500 masl. As a porphyry copper deposit, it is ideal for open-pit mining but, for environmental reasons, can only be mined from underground. Moreover, due to its low ore grade, only block caving is economical. The production level is set at the 3,720 m level. Due to the orebody's thickness and size, it is divided into three mining areas: the central, southern and northern areas. The central area, which has a relatively higher copper grade and offers greater early-stage economic benefit, was selected as the first mining block with a footprint of 500 m × 330 m and a mining column height in the range of 85-295 m. The ore passes are arranged within the panel. Under its advance undercut strategy, undercutting advances from the centre of the first mining area to both its ends in parallel. Long-hole drill rigs are used for undercut drilling and 14-tonne electric LHD loaders for ore extraction. To tow the 20-m^3 tramcars for ore haulage, 65-tonne electric locomotives are used. The ore is crushed underground before being transported to the concentrator by a 3,064-m belt conveyor in a tunnel. The mine started trial production in March 2017 and ore production capacity has so far reached 30,000 tpd. Cave propagation is smooth and has connected through to the ground surface. As of March 2019, the surface subsidence zone measured 85,000 m^2. This paper briefly describes the mine's geotechnical engineering, design scheme, production practices and current problems.

1 Introduction

China's second largest large-scale block caving mine, the Pulang copper mine, is located 63 km northeast of Shangri-la in the Diqing Tibetan Autonomous Prefecture in the northwest of Yunnan Province. The mine has good transport connectivity through external roads

The northeastern part of the Hengduan Mountains, where the mine is located, is an alpine valley region at the southern edge of the snow-covered Qinghai-Tibet Plateau where the overall terrain is relatively high, with an altitude of 3,600-4,500 metres above sea level (masl). The area has a cold temperate climate, with an average annual temperature of 4°C and a coldest monthly average of minus 8°C. The temperature is below freezing for a long period and, on average, there are 127 days of permafrost per year. The average annual rainfall is 619.9 mm, concentrated mainly between May and September.

The first phase of the Pulang project involves mining the orebody above 3,720 masl or, in other words, Lift 3,720 m. The mine has a design production capacity of 12.5 million tonnes per year. The orebody is accessed through adits. Remote-controlled unmanned electric locomotives on the haulage level transport the ore from the ore chutes below the production level to the ore-discharge stations above the ore-crushing station. A 3,064-m conveyor belt then carries the crushed ore to the coarse ore pile at the concentrator. The mine began trial production in March 2017 and produced 5.82 million tonnes of ore in 2018. It is expected to produce 9 million tonnes of ore in 2019 and will reach its design production capacity in 2020.

2 Characteristics of orebody and mining technical conditions

2.1 Characteristics of orebody

Mineralisation of the Pulang ore deposit occurred in composite porphyry bodies. The metallogenic elements are predominantly composed of copper, accompanied by gold, silver, molybdenum, sulphur and other useful components. The mineralised zone has a length of more than 2,300 m, a width of 600–800 m and an area of approximately 1.09 km^2. A main KT1 orebody (Figure 1) is delineated and five other small orebodies, KT2-KT6, are distributed around KT1. KT1 occurs in the potassium silicide-Phyllic belt at the centre of the Pulang N° 1 porphyry orebody and is controlled by the rock mass, structural fissure and country rock alteration. The host rocks are mainly quartz dichlorite, followed by quartz diorite porphyry, granodiorite porphyry and, in the south, a little hornstone.

The orebody's outcrop altitude ranges from 3,868 to 4,023 m and the orebody has a total length of over 1,400 m. The orebody delineated between axes 7 and 20 in the initial mining area is 1,200 m in length and has a vertical depth of 17-750 m. The orebody is cylindrical, spreading in the north-northwest direction. In the south, it has a width of 360-600 m and, in the north, narrows to 120-300 m. The orebody has a copper grade of 0.20%-3.74%, averaging 0.49%. The middle section of the orebody is thick and massive with high copper grades that decrease gradually towards the periphery. Figure 2 shows the ore grade distribution at the 3,720 m level.

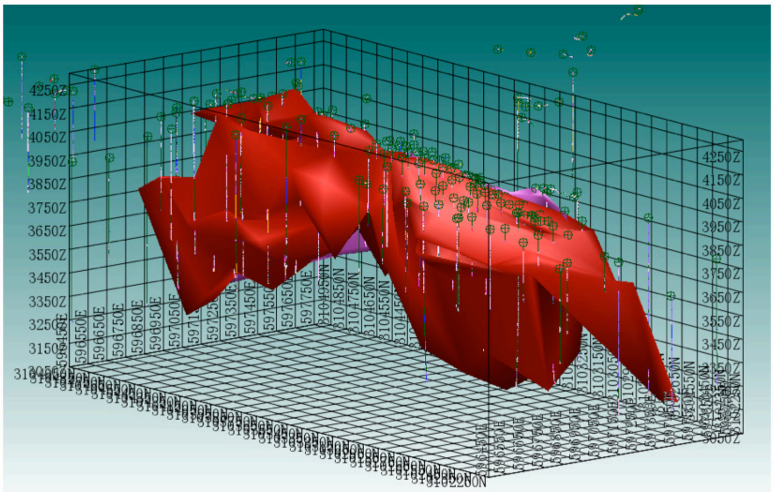


Figure 1 Spatial model of KT1 orebody of Pulang mine

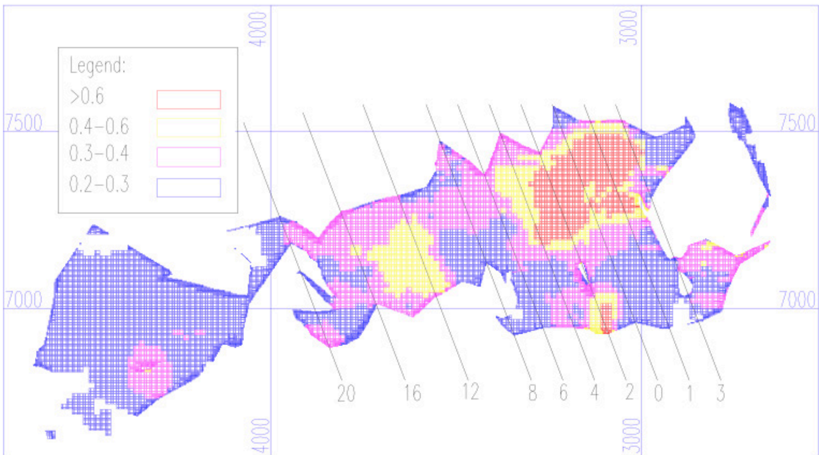


Figure 2 Ore grade distribution at the 3,720 m level of the Pulang mining area

2.2 Mining technical conditions

Research shows that the joints and fractures in the quartz monzonite and quartz diorite porphyry in the deposit are extremely well developed, with an average density of more than 10 fractures per meter. There were three dominant joint groups. The quality parameters of the different rock masses are shown in Table 1.

Table 1 Engineering quality parameters of different lithologies

Rock mass	RQD (%)	RMR	Rock mass quality
Granodiorite porphyry	53	37.81	IV
Quartz monolith porphyry	59	42.03	III
Quartz diorite porphyrite	72	42.92	III
Hornfels	76	42.89	III

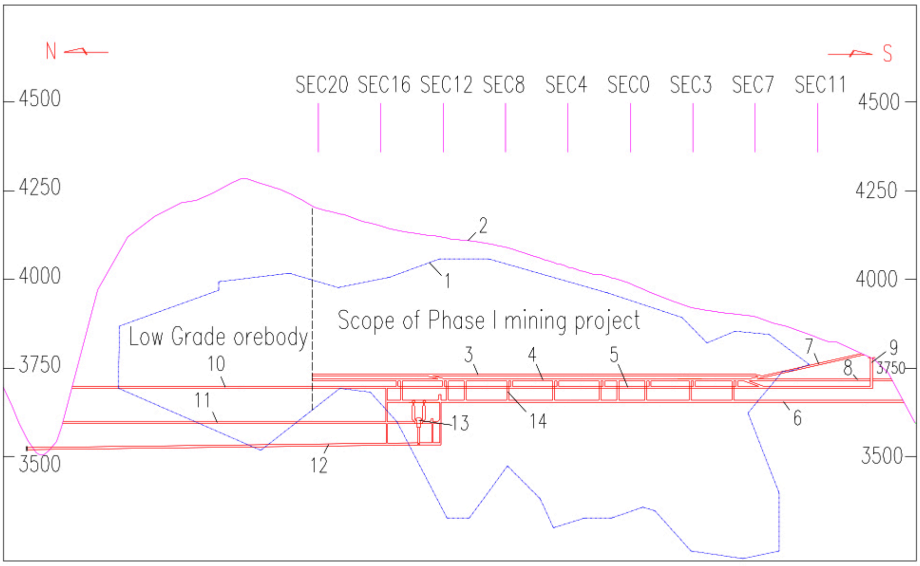
According to Laubscher's caving chart, the hydraulic radius of continuous caving in the Pulang copper mine is 20-22 m and the caveability of the orebody is moderate to easy. Moreover, the orebody above the 3,720 mL is thick, massive and continuous, with evenly distributed ore grades, and is free of pyrophorisity and cohesiveness, permitting surface subsidence. The block caving method is, therefore, quite suitable for exploiting this part of the deposit.

3 Mine engineering design

3.1 Deployment of main levels

The first mining lift of the Pulang copper mine (Phase 1) targets the orebody above the 3,720 mL, which will be extracted as a single lift. The caving column height of the orebody is 85-380 m, with an average column height of around 200 m.

Four main levels are envisaged in the first lift. From bottom to top, they are the 3,660 mL track haulage level, the 3,700 mL return air level, the 3,720 mL production level and the 3,736 mL undercut level. The undercut level is 16 m above the production level, which is 60 m above the track haulage level. The longitudinal projection of the mine development system is shown in Figure 3.



1. Orebody; 2. Surface topography; 3. 3,736 mL undercut level; 4. 720 mL production level; 5. 3,700 mL return air level; 6. 3,660 mL track haulage level; 7. Intake air ramp; 8. 3,720 mL trackless adit; 9. Return air shaft; 10. 3,700 mL return air adit; 11. 3,600 mL intake air adit; 12. 3,540 mL belt adit; 13. Crusher station; 14. Ore pass.

Figure 3 Longitudinal projection of development system of Pulang mine

3.1.1 Production level

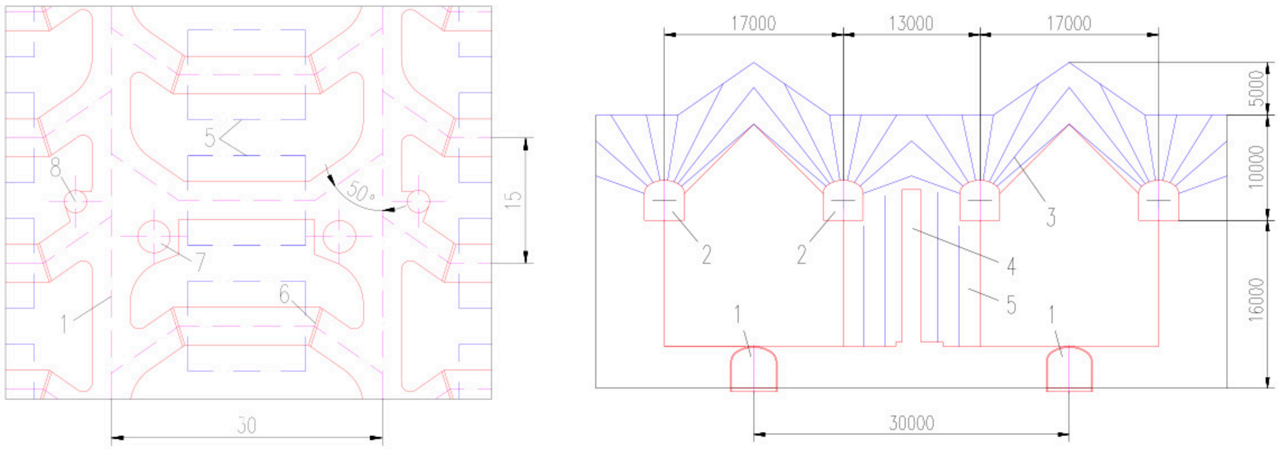
Based on the mining technical conditions of the deposit and considering the stability of the bottom structure and the control of ore loss and dilution, the production drifts are arranged perpendicular to the orebody strike with a spacing of 30 m and the drawpoints are spaced at 15 m, with an offset herringbone layout. The drawpoints intersect with the production drift at an angle of 50° in order to better accommodate the manoeuvring of 14 tonne LHD loaders (Figure 4(a)).

Given that many production drifts are very long, ore passes are arranged in the production drifts to take advantage of the high operating capacity of the 14-tonne electric LHDs. Depending on the panel width, one to three vertical passes, with a diameter of 3.6 m and a length of around 60 m, are deployed in each production drift. A grizzly with a mesh of 1.2 m by 1.2 m is placed at the opening of each ore pass, allowing ore blocks of less than 1.2 m to pass through.

One return air raise is located near each ore pass in each production drift, connecting the 3,720 mL production drifts with the 3,700 mL return air level.

3.1.2 Undercut level

The undercut level is 16 m above the production level. Simba 1,354 long-hole rigs are used for drilling undercut blast holes. Two parallel undercut drifts are arranged above and between two production drifts. The spacing of the undercut drifts is respectively 13 m or 17 m. The maximum undercut height is 10 m (Figure 4(b)).



(a) (b)

1. Production drift; 2. Undercutting drift; 3. Blast holes; 4. Slot; 5. Drawbell; 6. Brow line; 7. Ore pass; 8. Return air raise.

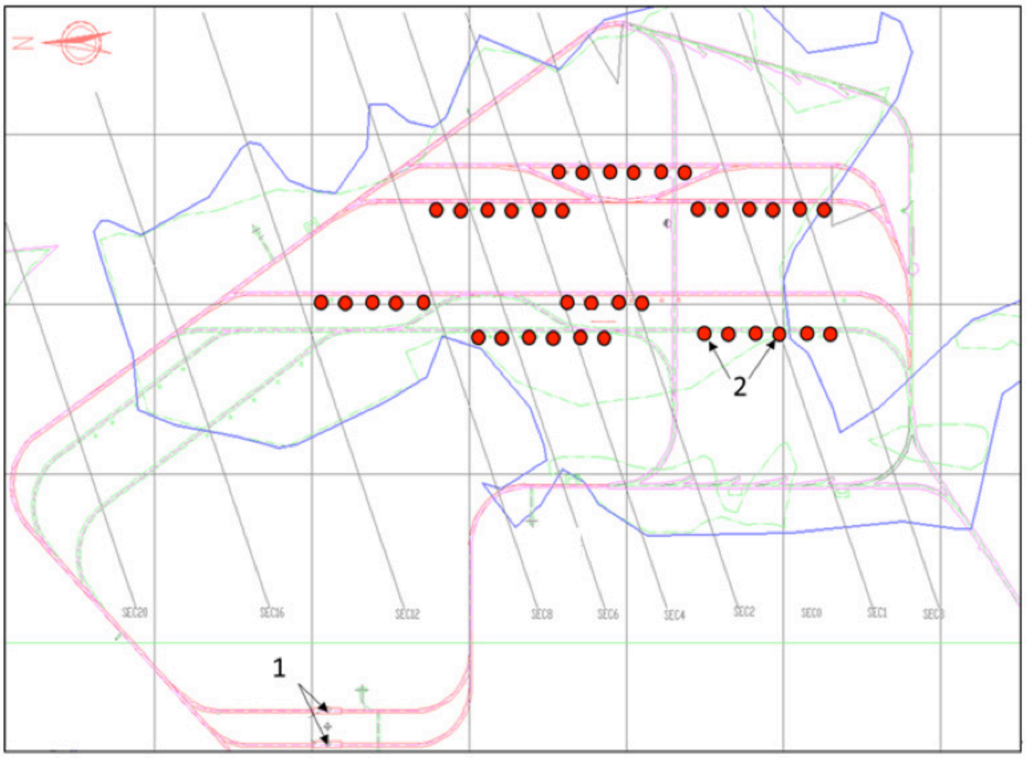
Figure 4 Partial layout of production level, major apex and drawbell

3.1.3 Return air level

The 3,700 mL return air level is located 20 m below the production level. The secondary return air drifts, which are connected with each production drift through the return air raises, are arranged along the orebody strike and are then connected with the general return air drift. The contaminated air resulting from flushing the undercut and production levels is discharged to the return air level through the return air raises and then returns to the surface through the 3,700 mL return air adit and the south return air shaft.

3.1.4 Haulage level

Ore is transported in the 3,660 mL centralised track haulage level. An unmanned 65-tonne electric locomotive is used to tow the train of 20 m^3 tramcars. Each train has a capacity of 300 tonnes with ten tramcars. The haulage route is a ring route with four parallel strike loading drifts, each of which has one or two ore pass groups comprising five or six ore passes. Accesses are provided between the parallel drifts for communication, permitting easy vehicle scheduling and transportation (Figure 5).



1. Unloading station; 2. Ore pass.

Figure 5 Diagram of 3,660 mL track haulage level

3.2 Mining process

3.2.1 Ore blocks division

The Pulang copper mine features a super massive orebody. In Phase 1 of the project, a total mining area of about 380,000 m^2 in footprint will be exploited in Lift 3,720 m using the block caving method. This part of the orebody is 1,140 m long in north-south strike and 180-500 m thick and Lift 3,720 m will have a service life of some 20 years. If the footprint of the whole lift is subjected to continuous undercut as one block or panel, the front length of the undercut will gradually increase and become so long that it makes it difficult to guarantee the normal undercut speed (Liu & Bian 2016) while an excessively slow undercut speed will cause stress concentration on the bottom structure in front of the undercut advance front (Liu & Zheng 2008). In addition, the larger the mining range, the more difficult it will be to organise and manage production. Lift 3,720 m has, therefore, been divided into three blocks for mining. The middle zone is the first mining block, which is thick and has an area of 330 m by 500 m. The southern and northern blocks will be mined after the first mining block. The relative positions of these blocks are shown in Figure 6.

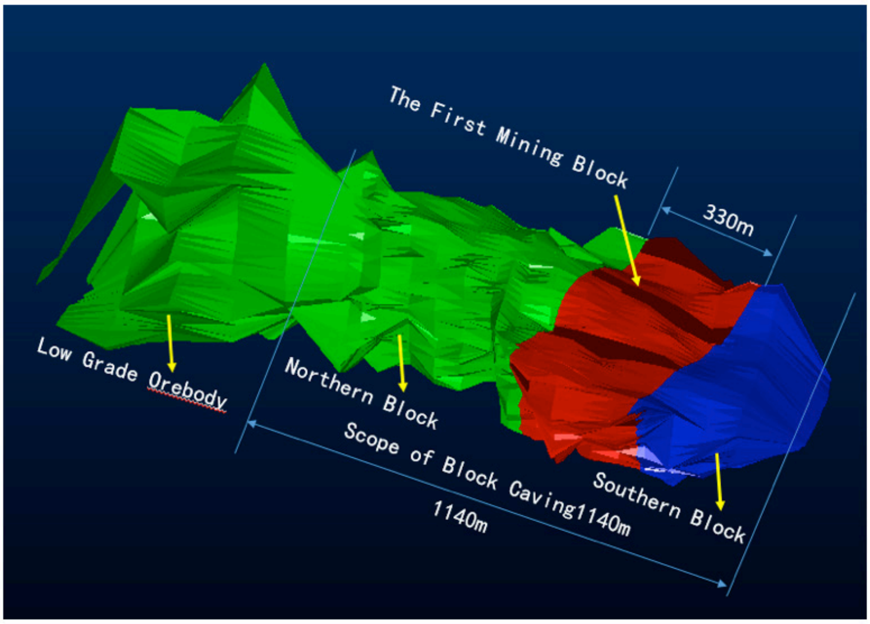


Figure 6 **Block division of Lift 3,720 m**

3.2.2 Mining sequence

Several faults intersect the first mining block (Figure 7). The larger faults are mainly concentrated in the central and southern part of the block. The ore grade is higher in the central area, which was, therefore, chosen for initial undercutting, before advancing backwards to the east and west sides. The high ore grade in the initial undercut area is conducive to a higher ore grade in the early stage of production. Meanwhile, the incompetent rock of this area permits earlier formation of continuous caving.

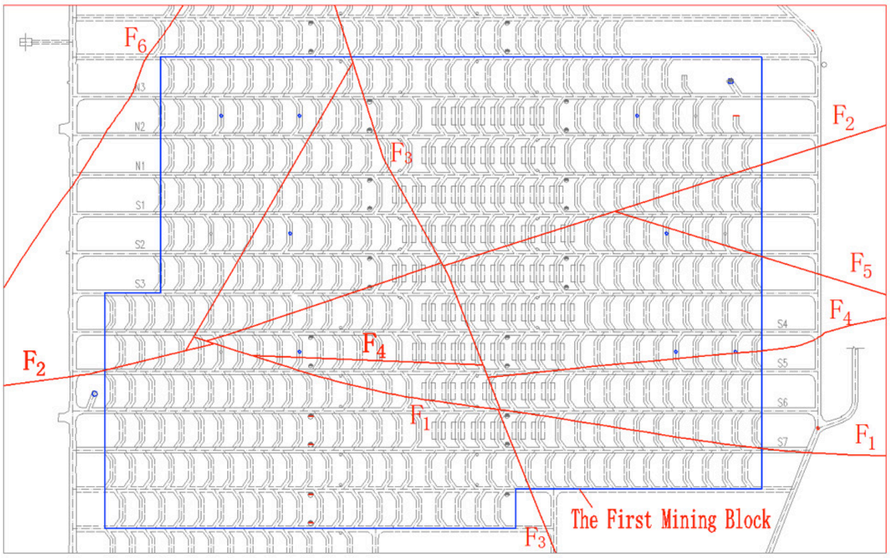


Figure 7 **Fault distribution in first mining block**

After the first mining block is extracted, mining of the northern and southern blocks will begin. Due to the small area of its orebody, the southern block will be undercut all at once before ore extraction starts. For the northern block, continuous undercutting along the diagonal direction of the footprint is recommended.

The progressive undercut schedule for Lift 3,720 m is shown in Figure 8.

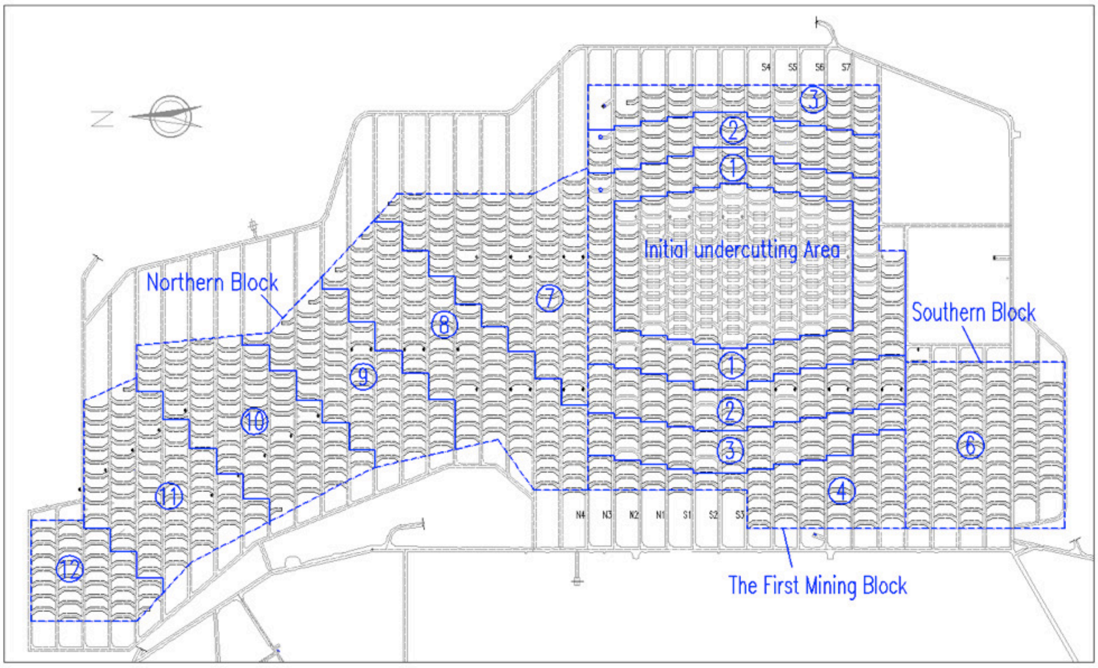


Figure 8 **Year-by-year undercut sequence diagram of Lift 3,720 m**

3.2.3 Undercut strategy

To effectively control the influence of stress concentration on the bottom structure, continuous undercut in advance, that is, an advance strategy, is recommended (Liang et al. 2017). In other words, the advanced distance of undercutting may be adjusted in a timely manner according to changes in bottom structure stress, which is monitored during the construction and production undercutting process. However, excavation of drawbells and formation of the bottom structure will always occur in the stress-relieved area so as to dramatically reduce stress concentration on bottom structures and significantly improve their ground stress environment.

4 Status quo of mine production

4.1 Ore output and grade

PC-BC software is used to simulate the mining footprint (Chen et al. 2015), the extractable ore tonnage and the production schedule of this lift. This shows that the three blocks have a total extractable ore tonnage of 220 million tonnes, with an average copper grade of 0.42%.

The mine began trial production in March 2017 and total ore output in 2018 was 5.82 million tonnes. Since 2019, the mine's production capacity has maintained steady growth. Output in the first half of this year reached 4.1 million tonnes and, in July alone, 1.1 million tonnes were produced, taking the mine to its design production capacity.

4.2 Ground surface subsidence

By July 2019, 115 drawbells and 250 drawpoints had taken shape, a footprint area of around 80,000 m^2 had been undercut and a ground surface subsidence area of some 93,000 m^2 had been formed. This demonstrates that continuous caving of the orebody and normal ground subsidence had been established and the risk of air blast caused by the sudden collapse of the cave back had been eliminated.

Maptek I-Site 8820 XR-CT 3D laser scanning monitoring technology from Australia has been introduced at the Pulang mine to effectively monitor surface subsidence. With the adoption of a non-contact high-speed laser measurement method, rapid scanning and measurement can be conducted in the mine's subsidence area to obtain point cloud data. The mass point cloud data is then used to reproduce the mining status quo through a 3D reconstruction, thus facilitating monitoring and analysis of mine surface subsidence.

Figure 9 shows the range of undercutting and surface subsidence as of July 2019. Figure 10 shows the status quo of surface subsidence.

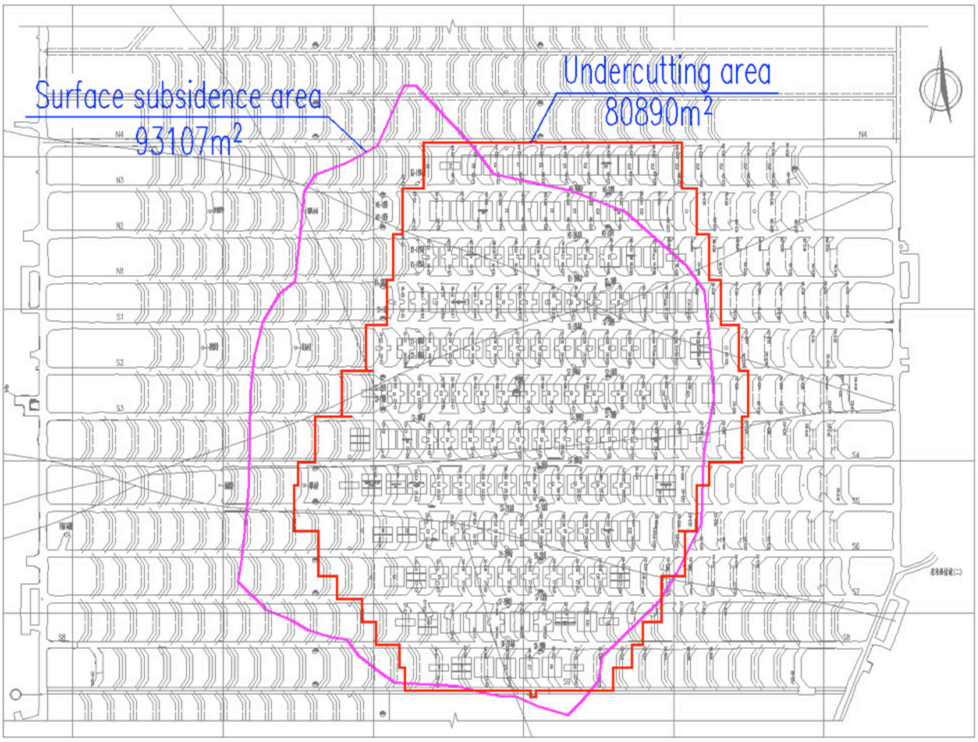


Figure 9 Ranges of undercutting and surface subsidence as of July 2019

Figure 10 Photograph of surface subsidence as of July 2019

4.3 Stability of bottom structure

The bottom structure, that is, the major apex, is the key access for ore production and its stability directly determines the success of block caving (Fan et al. 2017). Robust support and reinforcement are provided in the main locations - for example, production drifts, draw points, drawpoint brow lines and undercut drifts - mainly by using long bolts, cables, net spraying and shotcretting.

Since the mine began operation, there has been no major deformation of drifts such as undercut drifts, production drifts and haulage drifts, all of which are relatively stable. Given that faults are relatively well developed and the wall rock of the drifts is fairly fragmented, advanced pipe-roof support and steel arch reinforcements have been used for the S4 and S5 production drifts, partly to maintain their stability.

Figure 11 shows the support section of production drifts. Figure 12 shows the supporting effect of drifts.

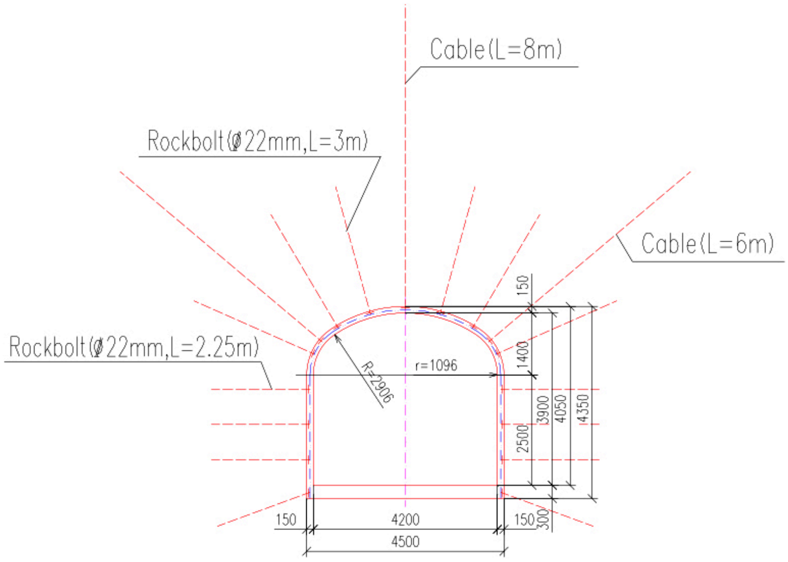


Figure 11 Support section diagram of production drifts

(a) Production Drift

(b) Drawpoint brow line

Figure 12 Supporting effect of production drifts

4.4 Routine ore drawing control

A routine ore drawing management system has been developed and is used at the Pulang mine (Li et al. 2017), permitting dynamic adjustment of the ore drawing plan. Based on the monthly ore production plan, the engineers calculate the planned ore drawpoint and corresponding ore grade and assign the result to the extracted ore tonnage of each single drawpoint. The software can display the daily production schedule, including the name of drawpoints in the ore drawing, the planned daily extracted ore tonnage, the expected ore grade, the ore deposit amount, the tonnage of ore that has been drawn, and the current ore-drawing height and other information (Figures 13 and 14).

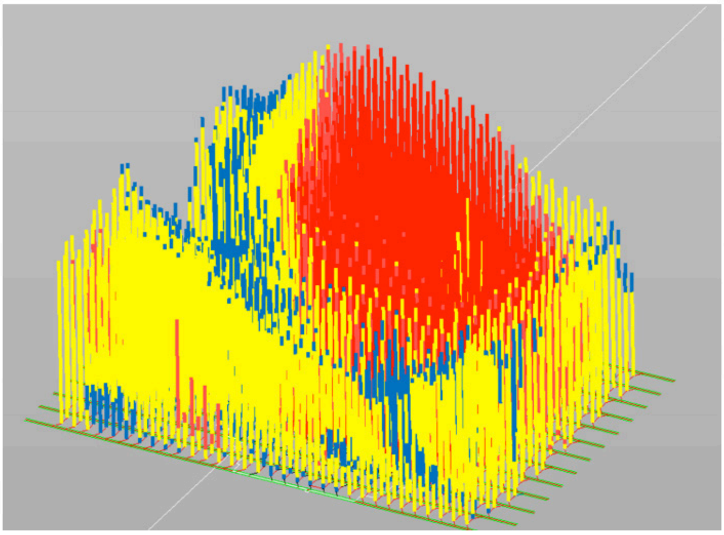


Figure 13 Information about ore drawing column at drawpoints

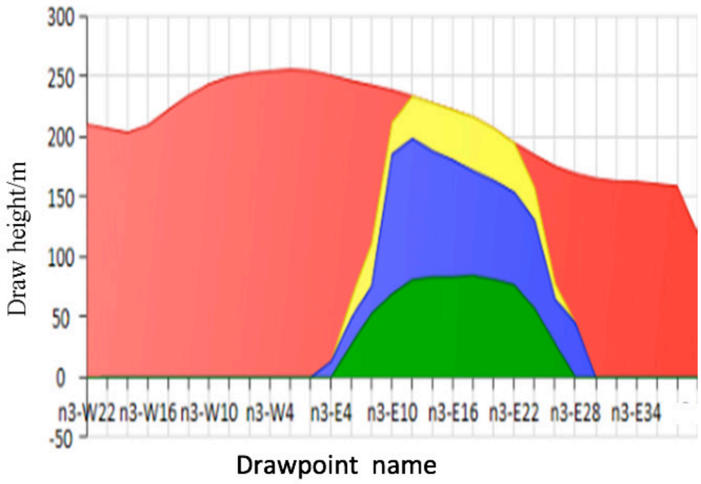


Figure 14 Propagation of caving roof with ore drawing (green area)

5 Conclusion

The Pulang copper mine, which is China's second largest block caving mine, has been successfully constructed and put into operation. It is expected to reach its design capacity of 12.5 million tonnes per year by 2020. So far, all mine systems operate steadily, indicating that their design is basically correct and reasonable. In the future, more attention should be paid to ground pressure management, mud rush control and wet ore drawing management.

- In the southern part of the first mining block, the crisscross faults and poor rock mass near the S4 and S5 production drifts, as well as possible stress concentration formed in the process of undercutting, will result in large deformation and even the collapse of production drifts and drawpoints. It is, therefore, suggested that the monitoring of ground pressure in the production process be strengthened and support of the bottom structure be intensified to ensure the safety of production.

- In the southern part of the first mining block, both caved ore fragmentation and the height of the ore drawing column are small. The fine-grained surface material has become mixed into the ore and entered the drawpoints. In the rainy season, special attention should, therefore, be paid to mud rush monitoring and ore drawing management. It is important to control the ore drawing rate in order to prevent accidents (Samosir et al. 2008).

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