Application and research of block caving in Pulang copper mine

Qifa Ge$^{1,2,*}$, Wenlu Fan$^3$, Weigen Zhu$^2$, Xiaowei Chen$^2$

$^1$University of Science & Technology Beijing, China
$^2$China Enfi Engineering Corp., Beijing, China
$^3$Corresponding author e-mail: geqf@enfi.com.cn

Abstract. The application of block caving in mines shows significant advantages in large scale, low cost and high efficiency, thus block caving is worth promoting in the mines that meets the requirement of natural caving. Due to large scale of production and low ore grade in Pulang copper mine in China, comprehensive analysis and research were conducted on rock mechanics, mining sequence, undercutting and stability of bottom structure in terms of raising mine benefit and maximizing the recovery mineral resources. Finally this study summarizes that block caving is completely suitable for Pulang copper mine.

1. Introduction
Block caving has received much intense attention from mining industry since it was applied in America Pewabic iron mine in 1895. It has a long history more than 100 years and accumulates a lot of experience [1, 2]. At first, block caving is only applicable to broken ore body with developed joint crack. With the development of rock mechanics and the wide use of trackless equipment, block caving is also applied in the stiff and stable ore body. As we know, the use of the LHD units for loading ore becomes common in block caving with rare use of ore-drawing system with screening and scraper. The economic benefit of block caving which is the only mining method can be comparable to that of open-pit mining because block caving has a lot of advantages, such as large production capacity, convenience in production organization and management, operation safety and low mining cost. In this case, block caving gets the attention of mining engineers.

At present, block caving has already got application in many mines across the world including America, Chile, South Africa, the Philippines, Canada, Australia, China, etc [3]. Among the 50 mines with block caving, Teniente mine in Chile has the largest production output of 140000t/d.

Block caving began come into China with a test status in the 60s of this century, and was researched in Yimeng copper mine and Laiwu Mazhuang iron mine at the earliest [4, 5]. Then block caving was tested in Jinshandian iron mine, Chengchao iron mine, Tongkuangyu copper mine, Fengshan copper mine, etc. And at present, block caving has been successfully applied in Zhongtiaoshan Non-ferrous Metals company Tongkuangyu copper mine that had an annual output of 400mt in the first phase and 600mt of designed production in the 2nd phase. Now Tongkuangyu copper mine is the largest underground metal mine in China.
2. Overview of Pulang copper mine
Pulang copper mine is located in the east Diqing Tibetan Autonomous Prefecture of northwest Yunnan. The highest elevation of mining area is 4702m and the lowest is 3450m. Mining area is cold and has the yearly average temperature of 4 degrees Celsius. Then the region has a long freeze period and enjoys only 128 frost-free days [6].

The main ore body of KT1 ore is located in the potassic silicification sericitization zone of Pulang No.1 porphyry center between 15 to 48 prospecting lines. The area between 7 to 20 lines is covered by Quaternary glacial till which exposes on the surface between 0 to 4 lines. The length and the vertical depth of the main ore body are 2240m and 2 - 766m respectively. Ore body extends from north to west with a lenticular style. The ore body model is presented in Fig.1. The ore is with copper grade of 0.20% to 3.74% and average copper grade of 0.49%, and is associated with beneficial mental element of gold, silver and molybdenum, etc. The middle part of the ore body is thick and has a high grade, but the ore body emerges the phenomenon of thinning and getting lower of grade to the around.

![Fig.1 KT1 ore body model in Pulang mining area](image)

The first phase of Pulang copper mine is exploitation of ore body above 3720m level and the designed ore production is 12.5 million t/a. Based on conditions of the mining area, drift development scheme was selected. Extraction level, undercutting level and return air level in Pulang copper mine are communicated with assistant ramp.

3. Application of block caving in Pulang copper mine

3.1. Analysis of rock mechanics and ore body characteristics
According to the report of Pulang engineering geology, quartz monzonite porphyry and quartz diorite porphyrite generate many joints and fissure that have the joint density more than 10 per m and have 3 main sets of joints. The RQD value and RMR value of quartz monzonite porphyry are 53% and 61.7 respectively and the rock quality classification of this rock mass is belong to class II. The RQD value and RMR value of quartz diorite porphyrite are 47% and 53.94 respectively and the rock quality classification of this rock mass is belong to class III. Through the prediction of Laubscher caving chart, the cavability of ore body is medium caving [7, 8].

In the consideration of ore body characteristics, Pulang copper ore body has a uniform distribution in ore-rock and ore grade which is low. Ore body is thick and vertical, and is provided with sufficient caving area, besides, developed joints exist in ore body. At the same time, the ore of Pulang copper mine has no spontaneous and bonding properties, and ground surface is allowed to collapse.
From the current design scope, the planning mining ore is basically thick and well continuous, therefore block caving is applicable for Pulang copper mine in technology.

3.2. Main components of block caving
Taking into account of related factors about the dip and thickness, occurrence and mechanical properties of ore body, ore body above 3720m extraction level is selected as the first-mining scope and adopts block caving scheme of sublevel. The maximum caving height is 370m and the average is 200m. Caving height of world block caving mine is shown in table 1. Based on the engineering of relevant experience, caving height of Pulang copper mine is rational.

| Mines                                | Caving height |
|--------------------------------------|---------------|
| Teniente mine                        | 120~180m      |
| Tongkuangyu copper mine              | 120m          |
| Henderson mine                       | 121.9~243.8m  |
| EESS Deposit, P.T. Freeport Indonesia| 200m, 300m    |
| Northpakes mine                      | 350m          |
| Palabora mine                        | 460m          |

According to engineering practice experience and test results of world mines, the parameters of block caving are determined. From bottom to top on the exploitation system of Pulang copper mine are track transportation level, ventilation level, extraction level and undercut level and the differences in level are 30m, 20m and 16m respectively. The height difference between extraction level and track transportation level is 50m, and the height difference between extraction level and undercut level is 16m. Block caving layout is presented in figure 2.

3.2.1. Extraction level. According to the physical mechanics properties of ore-rock in Pulang copper mine and experience of LHD units for loading ore in abroad block caving mines, spacing of drawpoints is 15m, and spacing of extraction drifts which is perpendicular to ore body trend is 30m. The drawpoint drifts of production level are staggered as offset herringbone layout, and spacing of the drifts is 15m. Ore removal route and ore-drawing roadway meet at 50° angles.

3.2.2. Undercut level. Inclined undercutting is applied in Pulang copper mine, and undercut roadway positions between ore-drawing roadways, which are similar to those of Palabora mine in South Africa. The height of undercutting is 5m. At the same time, both sides of upper part of ore-drawing roadway
have undercut roadways that is perpendicular to ore body trend, and spacings between undercut roadways are 13m and 17m respectively.

3.2.3. Ventilation level. Ventilation level in 3700m is below 20m of extraction level. The main return layout in the ore body along the trend of ore body, and connects each ore-drawing roadway through the air raises. Fresh airflow flows into the mine work faces of undercut level and extraction level, while polluted air through air raise to the main return roadway, and from main wind-returning roadway to the ground surface.

4. Research of mining technology

In order to improve the economic benefit of mine, exploitation of rich ore body becomes a priority based on the ore body occurrence conditions, especially the rich ore body between 1~4 lines. Due to the requirements of local environmental protection, only whole underground mining is practical, while open pit mining is not allowed.

4.1. Division of ore blocks

The mining area of 3720m middle part is large and reaches 0.38 million square meters. Exploitation of 3720m middle part has a long mine service life. Considering bottom structure stability, mining sequence, mining production organization management, 3720m middle part is divided into three ore blocks, the first mining block is located in the central area of high grade ore. After finishing the first mining block, starting to mine ore blocks in the southern and northern independently.

4.2. Mining sequence

According to the characteristics of ore grade distribution, middle ore body grade is high and around ore body has a low grade. In addition, there are many faults in the middle of the ore body, hence the condition of ore body is poor. In this case, the faults are conducive to the caving of cave back. Considering the ore rock condition and the ore grade distribution, The first mining is the ore body between 1~4 lines, and then to the boundary of the first mining block along east west direction. With the reduction of first mining block production, starting the development and undercutting of ore blocks in the southern and northern.

As the first mining area and initiating caving area, it can improve economic efficiency of enterprise, at the same time, it is conducive to the realization of the initiating caving and propagating caving. Figure 3 shows the mining sequence of the various programs, and Figure 4 shows the ore mining grade distribution at the first stage of production under the various mining sequences. As can be seen from Figure 4, the economic result of program 3 is the best. So, we select the program 3 in the designing, Figure 5 shows the whole undercut design.
Fig. 4 Mining ore grade of Cu per year by various programs

Fig. 5 The whole undercut design
4.3. Undercutting and bottom structure stability

Undercutting strategy is an important part of block caving research in recent years. At present, three different undercutting strategies may be used - post-undercutting, pre-undercutting and advance undercutting [1~3, 9, 10].

4.3.1. Advanced undercutting strategies. The undercut takes place above a partially developed extraction level. The partial development on the extraction level can consist of either extraction drifts only or extraction drifts and drawpoint drifts. Then drawbells are formed in the de-stressed area behind the undercut. Thus advance undercutting strategy is very good for maintaining stability of the extraction level.

In this case, advance undercutting strategy was designed for Pulang copper mine to reduce the stress of the extraction level. Drawbells are always prepared in the de-stressed zone which locates 20m behind the undercut front, usually adhering to the 45 degree rule. The production zone is located some 45 to 60m behind the undercut front.

4.3.2. Analysis of bottom structure. Due to the complexity of block caving mining technology and easy failure of bottom structure, numerical simulation method is used to study stability of Pulang copper mine bottom structure in the advance undercutting process with block caving mining.

Based on the bottom structure parameters, FLAC3D 5.0 software is used to establish the numerical model. The numerical model is 450m long×300m wide ×200m high. The sizes of drifts of the model are based on the actual engineering parameters. Figure 6 shows the overall model and the bottom structure model.

![Fig.6 Overall model and bottom structure model](image)

Based on the characteristics of advance undercutting, advanced undercutting process has been simulated. In the simulation, Mohr-Coulomb model is selected as the constitutive model [11, 12]. Figure 7 shows the maximum principal stress contour result in the undercut process, we can see that the bright blue zone within 20m around advancing line is in the state of stress concentration, where the maximum principal stress is about 33MPa. The red zone where the drawbells have been excavated is about 45 to 50m behind advancing line of undercutting, and these areas are in the stress-release state, where the maximum principal stress is about 3 to 20MPa and stress concentration disappears. Thus, the drawbells are constructed in a good stress condition and can maintain self-stability in a long time.
5. Conclusion

Through comprehensive analysis and research on rock mechanics, mining plan, stoping sequence, mining technology and stability of bottom structure in terms of Pulang copper mine, in this study come to the following conclusions:

(1) Based on the geological conditions of Pulang copper mine, low-grade orebody is thick and has a uniform distribution in ore-rock and grade, which needs to adopt a low-cost and efficient mining method. In this way, block caving is just suitable for Pulang copper mine.

(2) Analysis of rock mechanics indicates that ore body generates many joints and fissure that form 3 main sets of joints, and rock quality classification of this rock mass is belong to class II and class III which shows the cavability of ore body is medium based on the prediction of Laubscher caving chart, therefore, rock mass conditions of Pulang copper mine is helpful for using block caving.

(3) By comparing the advantages and disadvantages of three undercut strategies, advance undercut is better for Pulang copper mine, and the numerical simulation indicates advance undercutting strategy is beneficial to maintain stability of bottom structure.

(4) In advance undercutting process, the ares where the drawbells have been excavated is about 45 to 50m behind advancing line of undercutting is in the stress-release state, thus, the drawbells are constructed in the low stress area and are able to maintain self-stability in a long time.

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