

Digital Precision Design For a Platinum Gold Mine With Deep Ming in South Africa

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Abstract. A platinum mine in South Africa is a deep mining mine that the mining design involves a series of difficult problems, such as high stress, high temperature and high lifting and so on. Choosing the right mining method and developing system is the key technology to solve these problems, and is also an important plan for mining design. First of all, based on multi index factors, 6 mining methods were quantitatively analyzed and scored, and the sublevel open stoping method was chosen as the best mining method. In order to ensure the safety of this mining method, the hydraulic radius theory is introduced to analyze stope structural parameters stability. Secondly, with the view of global mining technology, we compared the development system of South Africa, China, Australia and other countries, and compared 6 development options in terms of technical, economic and security factors. The final selection of the development system combines the Chinese and Western design concepts, absorbs the advantages of each other and gets the recognition of the owners. Finally, we optimized the mining block, and carry out the 3D dynamic programming for the development system based on the 5Dplaner software, which realizes the digital precise design for the mine.

1. Background introduction

The Lesego Platinum Project is located approximately 300km northeast of Johannesburg in the Limpopo Province of the Republic of South Africa. Access from Johannesburg to the central portion of the project area is via a national highway to the town of Mokopane and then via a tarred road to an intersection with a gravel road, north of the project area.

The Merensky and UG2 seams exhibit a continuous yet gradual dip transformation. The seam dips have been altered due to a localised up-folding structure to the west known as the “Phosiri Dome”. This dome has caused the seams to be folded upwards towards the dome. Dips for the UG2 and Merensky reefs range from 75° down to 7° below 1,800 mbs (Metres below surface), as shown in Fig. 1.



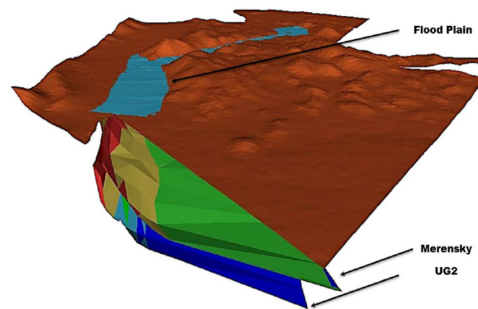


Fig. 1. Lesego Platinum ore body characteristics.

The Merensky mineralised mining width ranges from 1.0 m~1.40 m with an average width of approximately 1.1 m. The Merensky mineralised mining width ranges from 1.12 m~1.44 m with an average width of approximately 1.3 m. Rock Properties are as followed in Table 1.

Table 1. Rock parameter of Merensky & UG2.

Orebody Parameter	Units	MERENSKY	UG2
Strike extent	km	4.8	4.8
Dip extent	km	0.8	0.8
Dip range	Degrees	90° - 30°	90° - 30°
Depth range below surface	m	350 - 1200	350 - 1200
Ore strength	MPa	~140	~120
H/wall strength	MPa	~180	~170
F/wall strength	MPa	~180	~170
Structural conformity		Good (Low Confidence)	Good (Low Confidence)
Grade continuity		Gradational	Gradational
True thickness	m	1.0 – 1.2	1.2 – 1.8
Planes of weakness		No	Yes
Dilution potential		Low	High

2. Research on mining methods

2.1 Mining method selection

The ore body is deep buried and its thickness is relatively thin, so it is not suitable for open pit mining. Based on the consideration of resources/reserves, engineering geology, hydrogeology, technology, economy, environment and others of the mine, this design draws the conclusion that underground mining mode is recommended only, and 6 mining methods (from option 1 to option 6) are listed for comparison and optimization that is shown in Table 2.

Option 1-Alimak mining method

Option 2-Sublevel open stoping mining method

Option 3-Breast mining method

Option 4-Sublevel upwords & downwords holes

Option 5-Shallow hole shrinkage mining method

Option 6-Cut and fill stoping mining method

Table 2. Evaluation value of Each Mining Method in total

Advantages / Disadvantages	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Reef geometry	42	33	30	33	37	36
Rock properties	54	66	66	66	66	60

Total		96	99	96	99	103	96
ADVANTAGES AND DISADVANTAGES	Ground water	1	1	1	1	1	1
	Dilution	3	-3	3	-4	2	4
	Extraction ratio	-2	4	1	4	4	4
	Safety	3	5	1	3	-3	5
	Mining cost	-2	3	-3	3	-2	-5
	Capital investment	-2	-4	3	-4	4	-4
	Flexibility and	2	3	2	1	3	4
	Productivity	4	5	-3	5	-3	-4
	Production rate	3	4	-5	4	-3	-5
	Development rate	5	1	-3	4	0	-5
	Selectivity	2	2	3	1	1	3
	Stability of	-1	-2	1	-2	0	3
	Fragmentation	2	-1	3	-1	3	3
	Degree of	3	4	-4	4	-4	-3
	Ventilation	-4	1	3	1	3	3
	Ore recovery	2	3	4	4	3	5
	Skills required	-3	4	5	-1	-3	-4
	Ramp-up time	2	4	-1	1	-5	-3
	Environmental	0	0	0	0	0	5
	Waste rock dump	1	-2	1	-2	1	3
Total		115	131	108	121	105	106

By comparison and analysis, the SLOS (sublevel open stoping) is considered to be the best option that is a mining method in which ore is blasted from different levels of elevation but is removed from one level at the bottom of the mine. Before mining begins, an ore pass is usually drilled from a lower to a higher elevation. Jumbos selectively drill holes into the roof or floor of the drift and fill them with explosives. When the roof or floor is blasted, loose rocks, or muck, fall through the drilled ore pass. A Load Haul Dump (LHD) vehicle transports the muck to another ore pass where it falls to a hopper that feeds a crusher. The crushed ore is then elevated (raised) to the surface in a skip. As the muck is taken out, more drilling of the now higher roof continues. The roof is blasted till it is so high that it cannot be reached by a jumbo. Then a jumbo working in a higher elevation drift is used to intersect the stope. After blasting, the ore falls down to the lower drift where LHDs can drive in to load the muck and dump it at an ore pass. Drilling and blasting continues until the stope is completely excavated. Once the stope is completely hollowed out, it is backfilled from the bottom, up. The backfill material used can be a mixture of sand and rocks, waste rock with cement, or dewatered mill tailings (rejected low grade ore from processing, usually fine and sandy). The backfill material must have a lot of strength to support the roof of the empty stope.

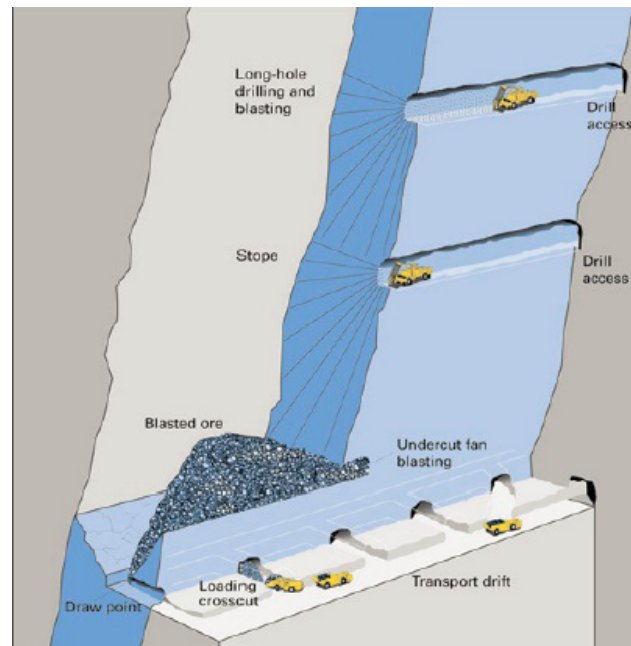


Fig.2 Illustration Showing Typical Sublevel Open Stoping Layout

2.2 SLOS stability index determination theoretical basis

The Hydraulic Radius (HR) is a geometrical measure that more accurately combines the influence of both size and shape of an excavation (Fig.3) [1-2]. When applied with rock mass ratings it provides an empirical estimate of rock mass stability particularly for sub-vertically inclined orebodies planned for bulk or selective mining methods. This concept and empirical design charts developed by Potvin were used exclusively to define the stope geometrical limits for Lesego [3-4].

2.3 SLOS stope geometries

The critical design HR was related to variations in strike spans to determine the optimum vertical spacing between sill pillars. The analysis indicated a maximum vertical span of 65 m between sill pillars when strike spans are 100 m. The strike spans will need to be isolated by continuous rib pillars. For design purposes and considering the position of the ore drives, a vertical spacing of 70m between sill pillars is suggested.

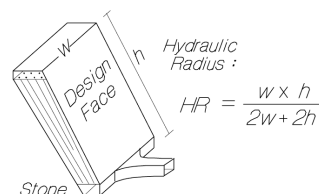


Fig.3 Concept of hydraulic radius (HR)

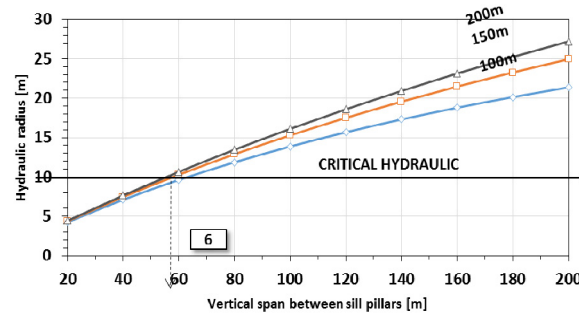


Fig.4 Vertical span between sill pillars

The sill and rib pillar dimensions were determined using the rock property information and the Hedley and Grant strength pillar formula with pillar loading accounting for the dip of the orebody.

$$\text{Average Pillar Stress} = \frac{(\sigma_v \cdot \cos^2 \theta) + (\sigma_h \cdot \sin^2 \theta)}{(1 - e)} \quad (1)$$

The critical HR for Lesego has a range of 8.5-11.5. For design purposes a HR of 10 was selected for SLOS stopes.

3. Optimal design on development system

Lesego Platinum Mine is a greenfields project, hence no primary mining infrastructure currently exists at the site. A vertical shaft system is the most feasible and cost effective primary access method. In addition, there are inclined and ramps can be considered. By comparing the 6 development options (as shown in Table 3) in terms of technical, economic and security factors., the option 6 is considered as an optimal development system option [5], it means that the engineering of primary access the ore body are mainly composed of main shaft, inclined ramp and vent shaft. According to their different advantages and disadvantages as well as the layout of the shaft [6], this research takes into account the characteristics of development system in South Africa, China, Australia and other countries.

The quantitative comparison of different options is shown in Table 4. The primary access to the orebody is a twin vertical shaft system, and the 3D diagrammatic sketch of development system is shown in the Fig.5[7-8]. The vent shaft is a raised hole through sectional construction, ramp and main shaft are simultaneously constructed from the ground surface.

Table 3 Different development system options

Option	Item
Option 1	Combined shaft+Two Return air holes
Option 2	Main shaft+Auxiliary shaft+ Return air shaft
Option 3	Main shaft+Auxiliary shaft+ Return air shaft
Option 4	Main inclined shaft+Auxiliary shaft+Return air shaft
Option 5	Main shaft+Auxiliary Ramp+ Two Return air holes
Option 6	Main shaft+Auxiliary Ramp+ one Return air hole

Table 4 Quantitative comparison of different options

No.	Item	Option	Option	Option	Option	Option	Option
1	Capital construction	160,760	149,231	149,231	178,786	128,294	117,938
2	Productive construction	120,461	115,619	115,619	123,779	33,572	29,041
3	Capital investment of	68,064	58,434	58,434	63,529	50,194	41,231
4	Productive investment of	44,645	40,546	40,546	41,029	15,895	11,974
5	Capital investment of	24,094	27,780	24,800	27,199	25,967	28,937
6	Productive investment of	593	2,893	593	7,693	6,202	6,202
7	Comparable Capital	92,159	86,213	83,234	90,728	76,161	70,169

8	Difference of Capital	-21,990	-16,045	-13,065	-20,559	-5,992	0
9	Capital construction time	60	60	54	72	60	54
10	Comparable operating	6.3	6.8	7.7	5.2	7.1	10.0
11	Net present value	610,248	622,117	662,146	552,032	644,686	673,519
12	Net present value difference	58,217	70,085	110,114	0	92,654	121,488
13	Comprehensive ranking	5	4	2	6	3	1

3.1 Capital development project

(1) Main shaft

It is arranged inside the skip and cage for lifting ore and personnel with its diameter 7.5 m. In order to reduce initial construction investment, the main shaft is divided into two stages, the depth of main shaft is 841m in the first stage, and the service time is 1~6 years. After the fifth years of production period, the shaft will extend to the 1,229m depth. It can be used as air intake by dividing main internal space.

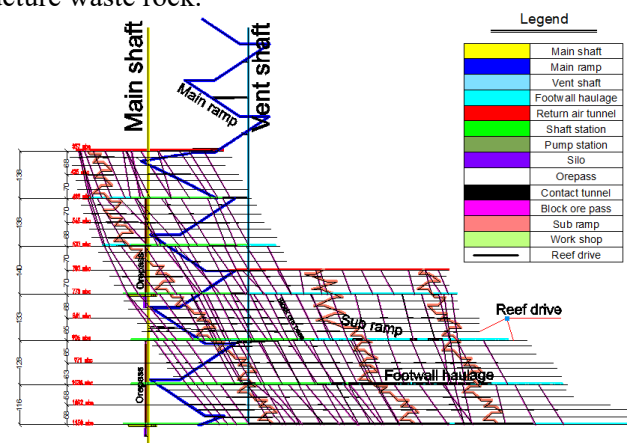
At the end of the fourth year of production, the main ramp is excavated to 1229 mbs, that is, the bottom of the main shaft. Then, the upward reverse construction technique is adopted to extend the main shaft. During construction, the 50 m high shaft project is reserved at the bottom of the main shaft of Phase 1, and it shall be constructed until the two sections of the upper and lower shaft pass through.

(2) Vent shaft

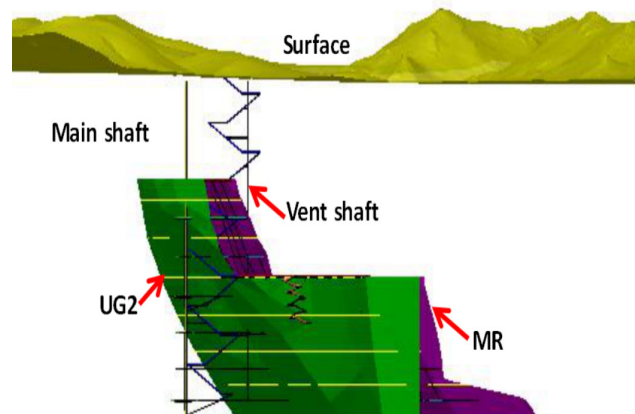
The ventilation shaft's primary purpose is to provide an exhaust route for return air from the underground workings. It is used as a return air shaft and is divided into two stages, the first stage is up to 773 m, and the service time is 1~6 years. After the fifth years of production period, the shaft will extend to the 1,150 m depth. When the main ramp is excavated to 1150 mbs, that is, the bottom of the vent shaft. Then, the upward reverse construction technique is adopted to extend the vent shaft. During construction, the 50 m high shaft project is reserved at the bottom of the vent shaft Phase 1, and it shall be constructed until the two sections of the upper and lower shaft pass through.

(3) Ramp

It is from the underground to the surface, and is responsible for the transportation of materials, equipment and infrastructure waste rock.



(a) Development system



(b) Development system and ore body

Fig.5 3D diagrammatic sketch of development system

The ratio of different development projects is shown in Fig.6.

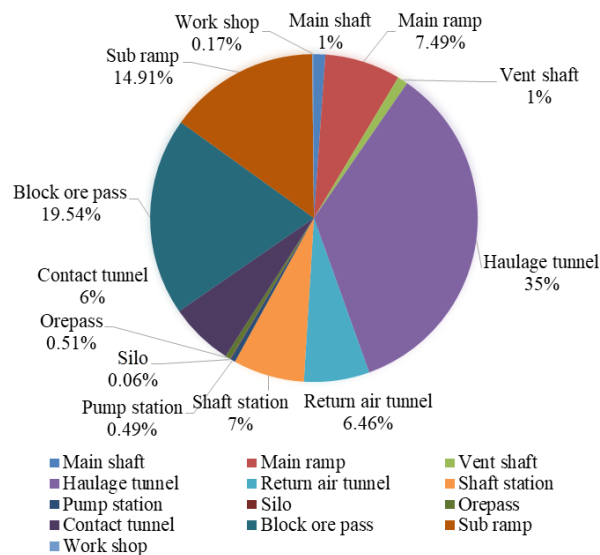


Fig.6 Proportional distribution of different development projects

3.2 Development and transport system

The ore is transported by trackless equipment. After the stope blasting, the ore is extracted from the stope and transported to the block pass by the LHD (as shown in Fig.7 and Fig.8). Then it will be transferred to the truck through a vibrating miner that is installed at the bottom of the block orepass (as shown in Fig.9) [9-10].

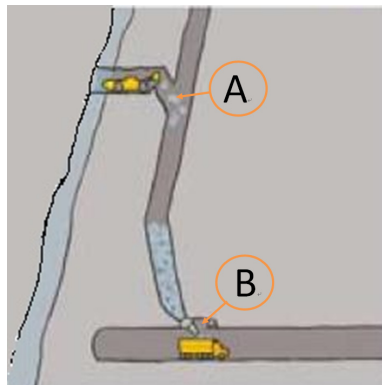


Fig.7 Ore unloading and loading system



Fig.8 Sketch of a LHD dumping ore into a block orepass

The ore is transported by the truck from the ore block to the ore unloading chamber that near the shaft station. Crushing chamber is equipped with secondary a crushing equipment and a screen of size 300mm×300mm. Ore block of less than 300mm will be transferred directly to the pass through the screen, small amount of ore larger than 300mm is broken through secondary crushing equipment which is installed at the top of main orepass (as shown in Fig.10). And then unloaded to the loading level through the main orepass, finally it will be lifted to the surface through the main shaft.

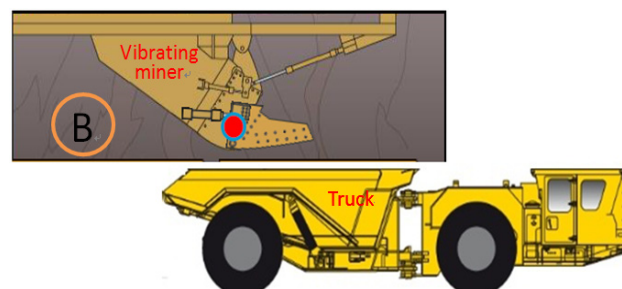


Fig.9 Sketch of ore loading into a truck

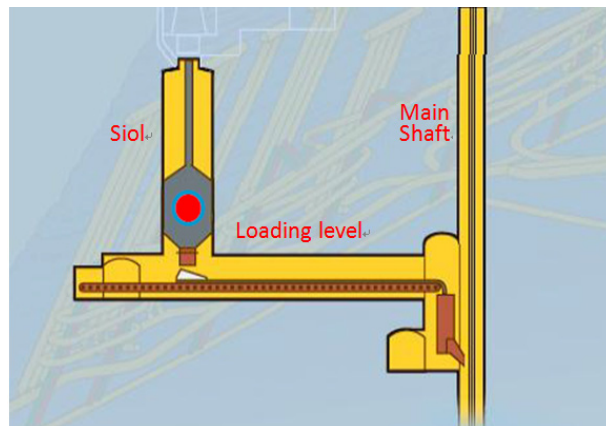


Fig.10 Sketch of skip loading level

4.Application of digital precision design technology

Based on SLOS, we used 5D Planer software to do mineable shape optimization (MSO) [11-12], and the result of MSO was showed in Fig.10.

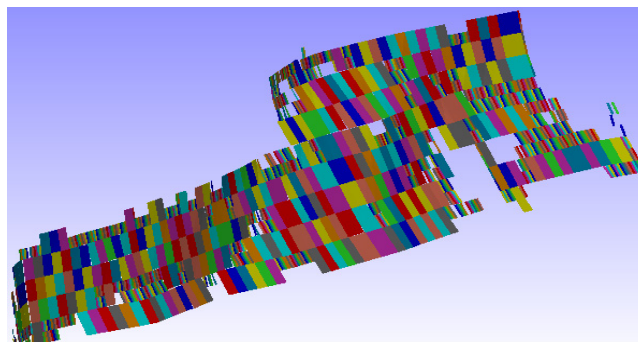


Fig.11 Mineable shape optimization result

The determination of mine productivity depends on the factors such as the mine geological reserves, the demand for products and the degree of difficulty of mining technical conditions [13-14]. The 5Dplaner software is used to construct the production path of the stope model and the matching of the mining and cutting engineering model [15]. Based on the digital simulation and simulation mining and database technology, the mine 3D visualization efficient planning is realized. It can also generate 3D animation of mine simulation mining, which can be used to simulate the whole process of production, run through the whole design life cycle of the mine, and output the production plan with the Gantt chart (as shown in Fig.11).

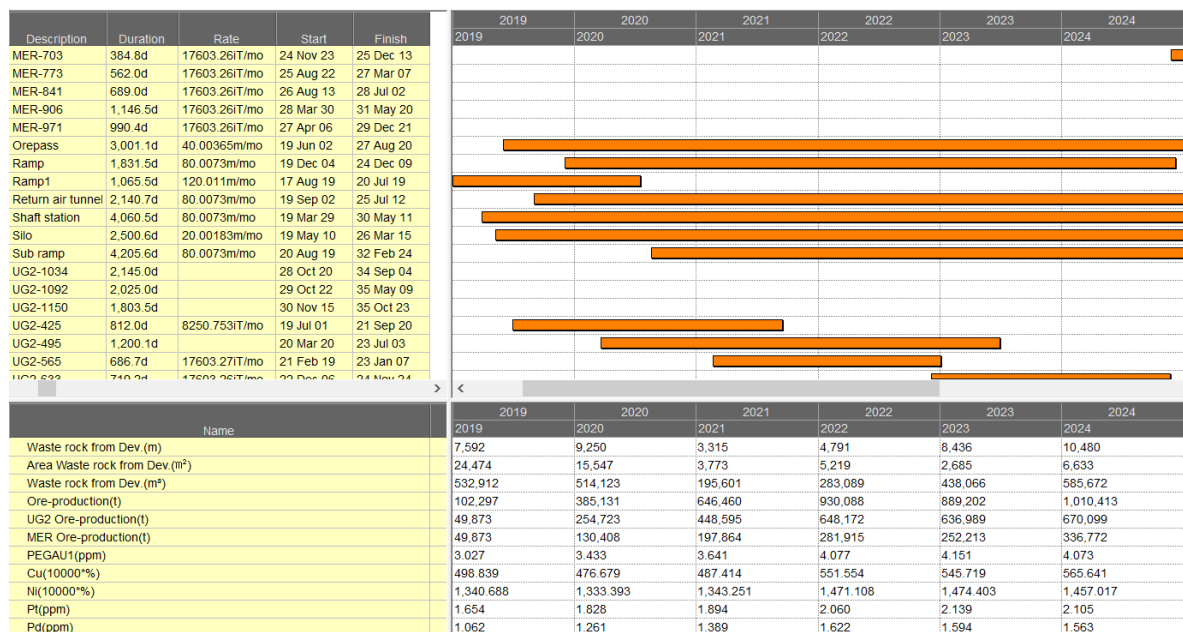


Fig.12 Production plan with the Gantt chart

On the basis of the mining technical conditions, geological ore quantity and the mining method, the mining production scale were calculated by using the digital precision, and the indicators such as mining year decline rate, new level development preparation conditions and reasonable life of mine have been verified according to the mine production scale. Therefore, it is recommended that the scale of mine production be 1,650 kt/a (5,000t/d). The Mining production plan is shown in the Fig.12.

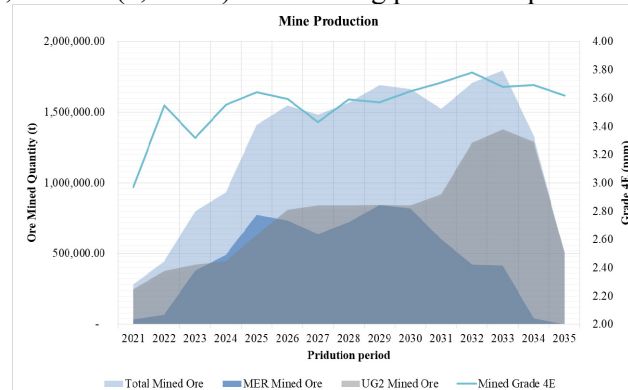


Fig.13 Mining production plan curve

5. Conclusions

(1) Based on multi index factors of Ground water management, Safety, Mining cost, Flexibility and complexity, Productivity, Ore recovery, Skills required etc, the 6 mining methods were quantitatively analyzed and scored, finally, the sublevel open stope method was chosen as the best mining method. In order to ensure the safety of this mining method, the hydraulic radius theory is introduced to analyze stope structural parameters stability.

(2) With the view of global mining technology, we compared the 6 development system options from South Africa, China, Australia and other countries in terms of technical, economic and security factors. The final selection of the development system combines the Chinese and Western design concepts, absorbs the advantages of each other and gets the recognition of the owners.

(3) In this paper, Studio 5D Planner, a famous mine production schedule software which is famous by international mining industry, is used to establish a digital model of 3D visualization development system. By dynamically adjusting the section size, driving speed and construction order of the shaft

and roadway, the whole life cycle of the mine is calculated accurately, and the dynamic programming of the three-dimensional simulation of the development system is completed accurately.

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