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Studying the Appropriate Underground Mining Methods in Sukari Gold Mine

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Authors' contributions

This work was carried out in collaboration among all authors. Author ABMK designed the study, performed the selection and analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MAG and MAY managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

This paper represents an attempt to study mining methods and development in the area of underground mining in Sukari gold mine. Detailed mining and rock mechanics data had been collected from Sukari gold mine to select the appropriate mining method for underground area. Underground mining methods have been studied to show that the selected mining method in SUKARI gold mine is suitable for the geology of the ore body, and hence proposed mining method could be taken into account. A brief background about Sukari gold mine is given and the used mining method in Sukari gold mine has been approved. Some of the suitable mining methods are discussed according to selection method and the most appropriate one is listed. Mining method selection was done by UBC method and Hartman flow chart.

Keywords: Sukari gold mine; method selection; underground mining; UBC method; Hartman flow chart.

ABBREVIATIONS

D&F : Drift-and-Fill
FW : Footwall
LBS : Longitudinal Bench Stoping
RMR : Rock Mass Rating
RQD : Rock Quality Designation
SHS : Shrinkage stoping

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SLOS : Sub-Level Open Stoping
SQS : Square Set Stoping and Stull Stoping
TBS : Transverse Bench Stoping
UBC : University of British Columbia
UCS : Uniaxial Compression Strength

1. INTRODUCTION

It is important to select mining method suitable for the geometry of the ore body to be used in mine design. Mining method should take ground conditions into account and also technical and economic parameters.

The main object of the present work is to select an appropriate mining method for Sukari gold mine. To achieve this work, geology of Sukari gold ore body has been studied to confirm the selected mining method considering two techniques, Hartman flow chart and UBC method. According to characteristics of SUKARI ore body, flow chart designed by Hartman [1] and the UBC method techniques have been applied to illustrate their applicability to SGM considering safety, suitability, production rate, dilution, recovery and flexibility.

2. THE GEOLOGY OF SUKARI DEPOSIT

The Sukari gold deposit is in late Precambrian basement rocks and is located in the eastern desert of Egypt at intersecting of lat 24°57'N and long 34°43'E. The deposit has a strike length of approximately 2,300 metres and ranges in thickness from 100 metres to approximately 600 metres, and this mine lies in the central part of the eastern desert of Egypt.

The region has old history of exploration and mining carried out through all stages of history, from Pharaonic (3,200 BC), through Ptolemaic, Roman, Arab and British colonial to the present day.The Sukari gold deposit is an example of a significantly larger gold deposit in the Precambrian. Auriferous rocks at Sukari are porphyritic and fine grained felsic rocks, extensively altered and quartz veined. Centamin plc Gold Mining Company divided Sukari granite into four exploration zones from north to south respectively; Pharaoh, Gazelle (behind Raa), Raa and Amun. Drilling indicates that the Sukari Pluton dips toward the east between 50° and 75° where the western and eastern contacts of the pluton are thus regarded as footwall and hanging-wall contacts respectively [2].

3. MINING METHOD IN SGM

Sublevel open stope is the current mining method used in Sukari gold mine. It is also known as sublevel stoping, longhole stoping or blast hole stoping. It is an underground mining method that is classified as a self-supported mining method. As a high-production bulk mining method, it can be used in large steep dipping or regular shaped ore bodies. The ore body needs to have competent rock that does not require extensive support. Sublevel stoping is a method that requires a many steps of pre-development, but this is partly offset by the fact that most of the development is located inside the orebody. Therefore, it can generate an ore feed and revenue. To extract the ore, large open areas are created which are called the ‘stopes’. These stopes are not meant to be accessed by the miners, which means that all drilling and blasting has to be done from the sublevels that are located at regular intervals.

4. MINING METHOD SELECTION

Selection of mining method is very important, since it is one of the most important factors in the success of the project. Although several methods are technically available, they may result in big different economic performance. This is the reason the selection should be done carefully and not just the pick one that seems practical [3,4].

In this section the preliminary mining method selection will be done by using flow chart designed by Hartman [1] and the UBC method [5,6] and their applicability for Sukari gold mine will be discussed, ruling out the unsuitable methods by comparing their safety, suitability, dilution, production rate, recovery and flexibility.

4.1 Hartman Flowchart

Hartman developed a flowchart for defining the mining method. This chart is qualitative and it is mainly based on the geometry of the deposit, with some reference to the ground conditions. Tables 1 & 2 are Comparison of Deposit Conditions Favorable to Underground Methods according to Hartman [1].

This method should only be used as an approach to the proper method selection. Chart (Fig. 2) is very quick and easy to use.

Table 1. Comparison of deposit conditions favorable to underground methods according to Hartman

Factor	Unsupported mining methods			
	Room and pillar	**Stope and pillar**	**Shrinkage**	**Sublevel**
Ore strength	Weak to Moderate	Moderate to Strong	Strong (should not pack)	Moderate to Strong
Rock strength	Moderate to Strong	Moderate to Strong	Strong to fairly strong	Fairly strong to strong
Deposit shape	Tabular	Tabular, lenticular	Tabular, Lenticular	Tabular, Lenticular
Deposit dip	Low, preferably flat	Low to moderate	Fairly steep	Fairly steep
Deposit size	Large, thin	Any, preferably large, moderately thick	Thin to moderate	Fairly thick to moderate
Ore grade	Moderate	Low to moderate	Fairly high	Moderate
Ore uniformity	Fairly uniform	Variable	Uniform	Fairly uniform
Depth	Shallow to Moderate	Shallow to moderate	Shallow to Moderate	Moderate

Table 2. Comparison of deposit conditions favorable to underground methods according to hartman

Factor	Supported				Caving	
	Cut and fill	**Stull**	**Square set**	**Longwall**	**Sublevel caving**	**Block caving**
Ore strength	Moderate to Strong	Fairly strong to strong	Weak to fairly weak	Any (should crush, not yield)	Moderate to Fairly Strong	Weak to moderate, Cavable
Rock strength	Weak to Fairly Weak	Moderate	Weak to very weak	Weak to moderate, cavable	Weak to Fairly strong, cavable	Weak to moderate, Cavable
Deposit shape	Tabular to irregular	Tabular to irregular	Any	Tabular	Tabular or massive	Massive or Thick Tabular
Deposit dip	Moderate to Fairly Steep	Moderate to fairly steep	Any, prefer ably steep	Low, prefer ably flat	Fairly steep	Fairly steep
Deposit size	Thin to moderate	Thin	Any, usually small	Thin, large areal extent	Large, thick	Very large, Thick
Ore grade	Fairly high	Fairly high to high	High	Moderate	Moderate	Low
Ore uniformity	Moderate, Variable	Moderate, variable	Variable	Uniform	Moderate	Fairly uniform
Depth	Moderate to Deep	Moderate	Deep	Moderate to Deep	Moderate	Moderate

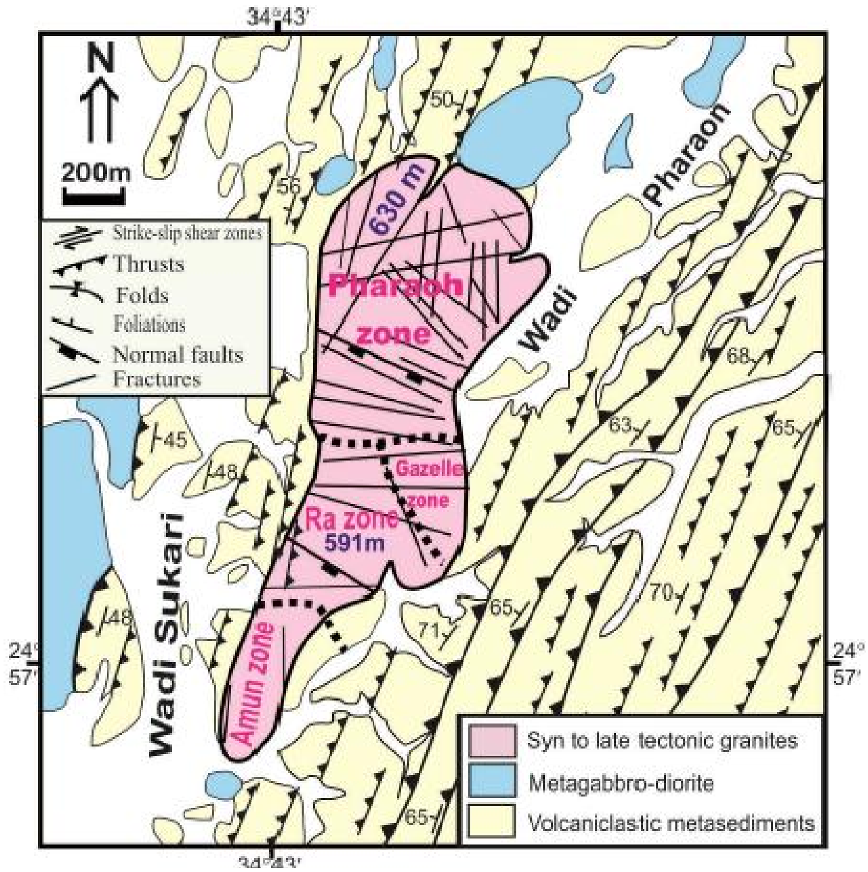

Fig. 1. Detailed geological map of Sukari gold mine area

Table 3. Ore geometry and rock spesifications [11]

Input data	Description	Input data	Description
Geometry/grade distribution		**Hanging wall**	
General shape	Tabular	Rock substance strength	200 MPa
Ore thickness	15 meters	RQD	80 Percent
Ore plunge	65 degrees	Joint spacing	0.5 meters
Grade distribution	Gradational	**Dry conditions**	
Depth	640 meters	Principal insitu stress	40 MPa
Ore zone		RMR	75 percent
Rock substance strength	180 MPa	**UCS**	**10.1**
RQD	60 percent	**Footwall**	
Joint spacing	0.5 meters	Rock substance strength	170 MPa
Dry conditions		RQD	55 percent
Principal insitu stress	40 MPa	Joint spacing	0.4 meters
RMR	75 percent	**Dry conditions**	
UCS	**5.3**	Principal insitu stress	40 MPa
		RMR	60 percent
		UCS	**15.3**

As the open pit has already used for surface mine so only deep deposit options are being investigated. Then, applying the geometrical properties of the deposit: tabular, steep and thin and moderate strength yields the result of shrinkage stoping, cut-and-fill stoping and stull stoping [1].

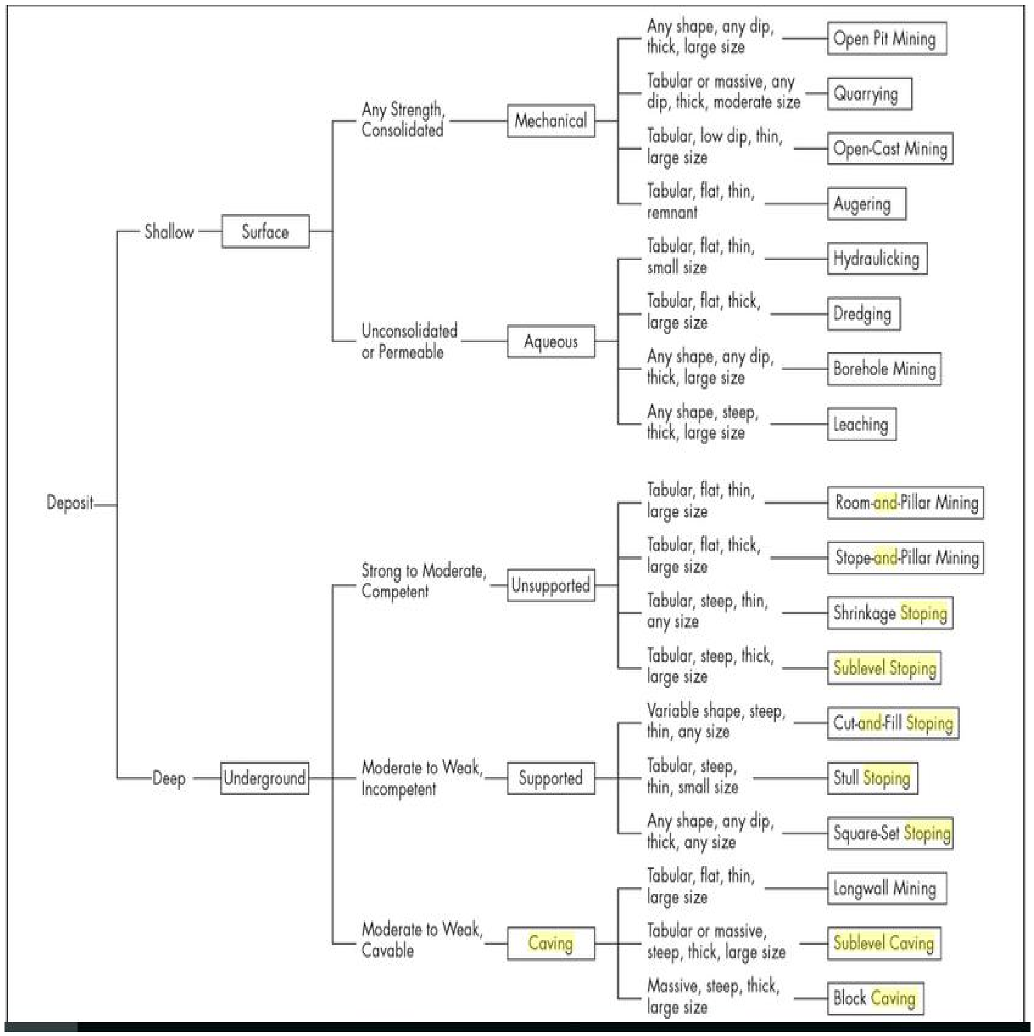

Fig. 2. Hartman flowchart

4.2 UBC Method

The UBC method [6,7] is based on Nicholas method [5], difference being the use of RMR for ground conditions instead of RQD used in Nicholas method and the depth of the deposit in the geometry section [8]. UBC is quantitative method, meaning it gives different methods points and then ranks them according how many points they received. The points come from two categories: the deposit geometry and the ground conditions, which are further divided into the strength of hanging wall (HW), ore and footwall (FW). The points given go from one to five and if the condition does not fit a method, it receives -49 points [9,10].

From SUKARI gold mine Table 3 describes the ore geometry and rock specifications.

Using this data, the Table 4 describes ore and rock specifications.

Using this input data the UBC method selection process will be calculated as follows.

4.3 Discussion the Results from UBC Method

4.3.1 Sub-level open stoping (SST&S\C)

SLOS received the highest score in the UBC method, it is the best method according to UBC method and according to Hartman flowchart also it is available method for mining the ore. It gets a score of 36 points. Sub-Level open stoping is the same method that is currently in use at Sukari mine, it is suitable for intermediate depth and deep part. However, the Hartman flowchart does not consider SLOS as an option for narrow ore.

SLOS is sort of common methodology employed in underground mining, because of high production and being simply mechanized. Drilling is finished in rings from sublevels permitting usage of enormous mass blasts and mucking is finished at the bottom of the stopes. As the name implies, stopes are left open after they are mined out. Naturally, this causes stability problems, which is why pillars need to be left between the stopes. This leads to low initial recovery, which is not desired, since the ore in Sukari mine is highly valuable. Using of remote controlled LHDs machines allows the stopes to be small zones, so SLOS can be considered a safe method [1,12].

4.3.2 Cut-and-Fill Stoping (C&F)

Cut-and-fill stoping became the 2nd method or option according the UBC method and the Hartman flowchart also say it is available method. It takes rank of 34points .Cut and fill stoping is nearly the same method that is currently in use at Sukari mine. The drilling is done from overcuts and mucking from undercuts. In terms of safety and mechanization this method is very similar to Sub-Level Open Stoping. However, when all the stopes are backfilled there is no need for pillars and so that initial recovery is high. Stoping operations use mass blast which leads to moderate dilution at best, depending on the stope size. Cut and fill stoping is very flexible and is suitable to orebodies of almost all shapes.

There are two mainly classes for Cut and fill stoping, longitudinal bench stoping and transverse bench stoping.

- **Transverse Bench Stoping(TBS)**

In Transverse Bench Stoping the production drifts are driven perpendicular to the strike of the ore. The stopes are opened by doing a slot raise, usually near the back end of the stope and the production then proceeds by ring blasting.

Table 4. Description of ore and rock according to UBC method tables

Geometry/Grade distribution	
general shape	Tabular
ore thickness	narrow
Ore plunge	Steep
grade distribution	Gradational
depth	Deep
Rock mechanics/rock mass rating	
Ore zone	Strong
Hanging wall	Strong
Footwall	Medium
Rock mechanics/rock substance strength	
Ore zone	Week
hanging wall	Medium
Footwall	Strong

Table 5. The scores of different mining methods according to UBC

Geo	O\P	B\C	SST	S\C	LWM	R&P	SHS	C&F	T\S	SQS
1-	2	2	4	4	4	4	4	4	2	1
2-	3	0	3	0	0	1	0	4	0	2
3-	1	4	4	4	-49	-49	4	4	0	2
4-	3	2	4	2	1	2	2	3	1	1
5-	-49	3	2	2	3	2	2	4	1	2
Rock mass rating										
6-	3	0	4	1	2	5	3	3	1	0
7-	4	2	4	2	3	5	4	3	3	0
8-	4	3	2	3	-	-	2	2	1	0
Rock substance strength										
9-	3	2	2	3	5	0	1	1	2	3
10-	4	2	4	2	2	2	3	4	2	1
11-	4	1	3	2	-	-	3	2	1	0
Total	**-18**	**21**	**36**	**25**	**-29**	**-28**	**28**	**34**	**14**	**12**

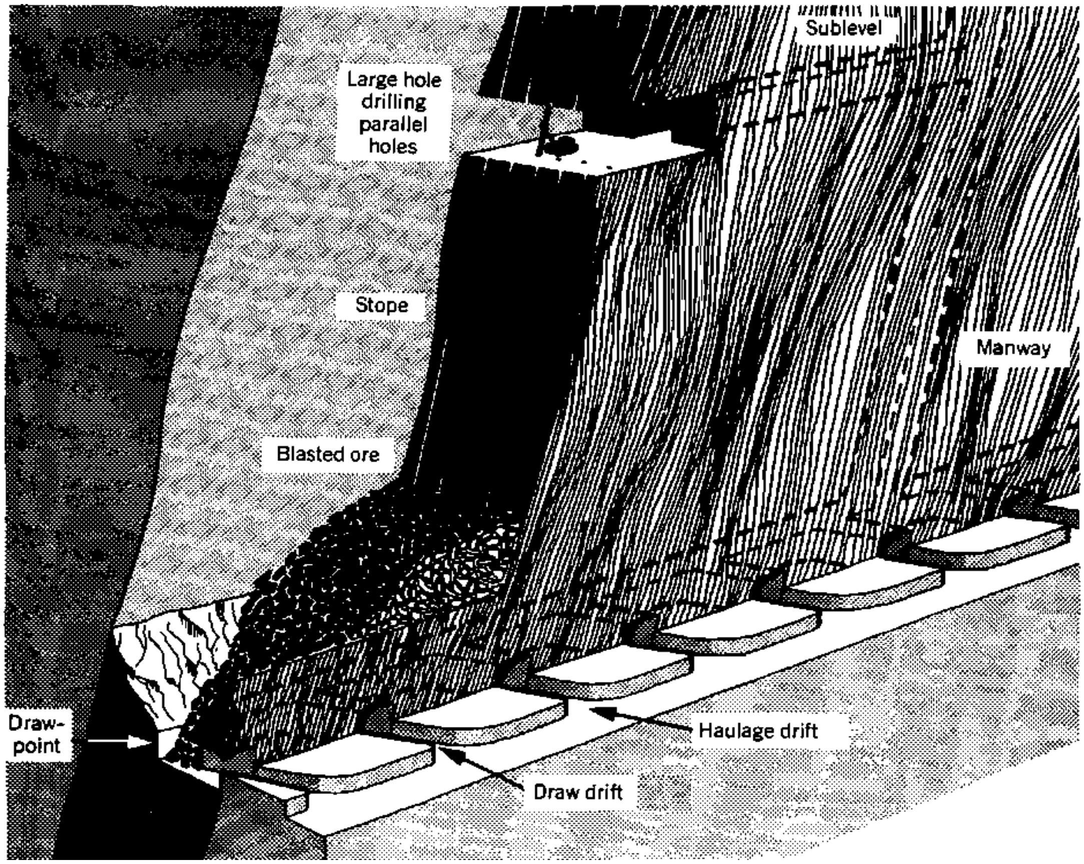

Fig. 3. Sublevel stoping using parallel drilling and blasting into a slot

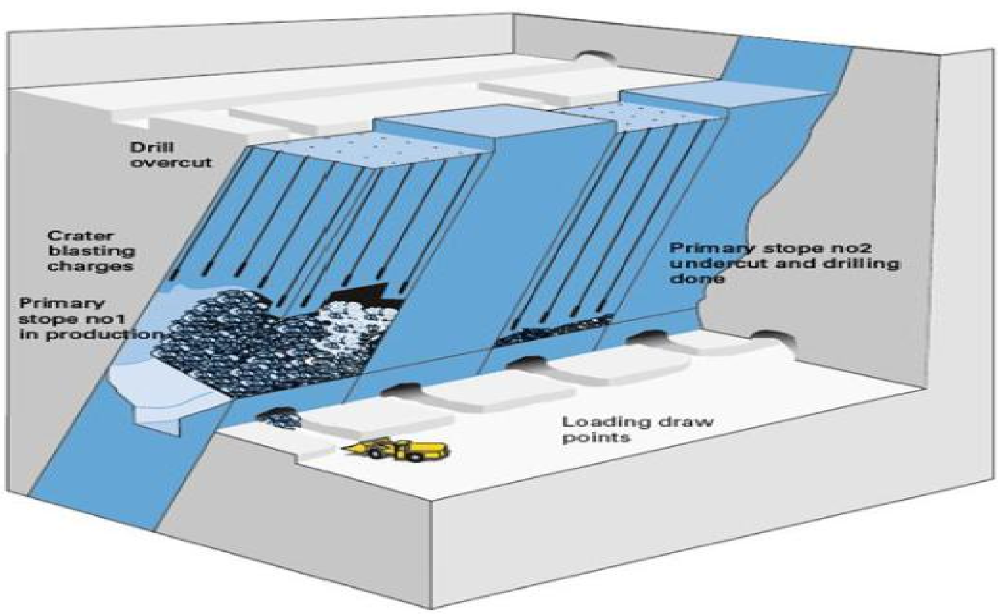

Fig. 4. Vertical crater retreat

The big disadvantage of TBS is the fact that every stope needs its own draw points, thus requiring lots of development.

- **Longitudinal bench stoping**

Longitudinal bench stoping is similar to Transverse Bench Stoping but the production drifts are driven parallel to the strike of the ore. This means that more of the assembly drifts are driven within the ore itself, thus reducing the event within the waste. The production of the stope is done like as in Transverse Bench Stoping, doing a slot raise and then blasting rings. It is very well for narrow veins, since the lengths of the stopes are not limited by the thickness of the ore. This means possibly fewer slot raises, and less development in the waste per ton of ore than in Transverse Bench Stoping depending on the maximum stable stope length [13].

4.3.3 Vertical crater retreat (SHS)

Shrinkage stoping was placed 3rd in the UBC method arrangement and get a score of 28 points. It was also included in the Hartman flowchart. Vertical Crater Retreat is a modernized version of shrinkage stoping. The main difference between the two is that in Vertical Crater Retreat drilling and charging is done from the overcut making it much safer than shrinkage stoping, where this is done from inside the unsupported stope. This also makes mechanization easier, thus making Vertical Crater Retreat more productive. The mine design of Vertical Crater Retreat is very similar to Transverse Bench Stoping, therefore they have mostly the same strengths and weaknesses. The main difference is that Vertical Crater Retreat is not good for narrow ore due to utilization of large diameters for drilling [14].

4.3.4 Square set stoping and stull stoping (SQS)

Square Set Stoping proved to be the last best option for the deep parts in the UBC method, while Stull stoping appeared in the Hartman flowchart. Both of these methods are artificially supported methods, usually with timber. Both are very labor intensive and have low degree of mechanization, resulting in low production rates. The advantages of these methods are that they can follow the orebody closely allowing high selectivity and low dilution. Building timbered support requires workers to enter the unsupported stopes making them unsafe methods.

4.3.5 Drift and fill (D&F)

Drift and fill isn't mentioned in neither of the used mining method selection tools, but its one possible method for this type of ore. Drift and fill may be a mining method that was frequently used before the longhole drills came popular. This method is suitable for steeply dipping narrow veins hosting high grade ore. The production is completed from drifts driven into the ore instead of stopes. This minimizes the development in the waste since there is no need for the footwall drifts.

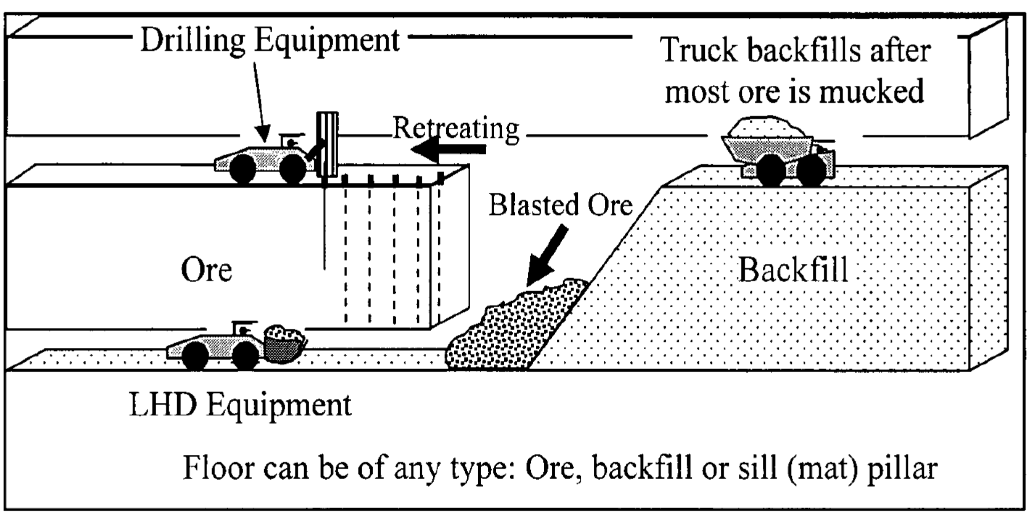

Fig. 5. Avoca mining method sketch

Table 6. The comparison of mining methods

Parameters	Mining method					
	SST	SHS	C&F	D&F	SQS	Avoca
Safety					×	
production rate				×	×	
Suitability		×	×	×		
Dilution	×	×				
Recovery	×					
Flexibility				×		×

4.3.6 Avoca

It is one of underground longhole mining methods, Avoca, or longitudinal retreat open stoping, with delayed backfill. Longhole open stoping is a method employed at Sukari gold mine. Because of its safety, productivity and economic characteristics.

Where the ore is between 4 meters and 12 meters in width, Avoca is used. This method employs conventional longhole benching where the stopes are backfilled with waste rock composed of development waste and crushed material from open pit stripping. Stopes are mined upwards, where the ore is mucked on top of the previously backfilled stopes below.

The broken ore is usually remotely mucked on the lower sill. Rockfill material is dumped, using either scoops or trucks, from the top sill, filling the stope to just short of where the hanging wall exposure would exceed its predicted maximum stable span [15].

5. COMPARISON OF MINING METHODS

The comparison of mining methods was done in terms of suitability, safety, production rate, dilution & recovery and flexibility. Suitability means if the method can be effectively applied to this kind of ore. The method was considered unsafe if the workers have to work in areas of unsupported rock. Production rate can be defined by how labour intensive the method is. Dilution refers to planned and unplanned dilution that will end up in the mill feed while recovery means how much of the ore cannot be mined or mucked, including possible pillars.

6. CONCLUSION

Mining method selection is the fundamental decision made in a mine project, and a proper choice is critical as it affects almost all other major decisions. The selection of a suitable mining method for an ore deposit involves consideration of a diverse set of criteria. . Several methods such as Nicolas, modified Nicolas and the UBC method have been developed to evaluate suitable mining methods for an ore deposit.

Preliminary mining method selection was done to find possible methods. The following methods were suggested by traditional mining method selection tools:

First is sublevel open stoping which get 36 points.

Second is Cut-and-Fill stoping which get 34 points.

Third is SHS or Vertical crater retreat with 28 points.

Sublevel caving became the fourth.

- Stull stoping/square set stoping.
- Drift-and-Fill and avoca mining methods is suitable for mining the ore in Sukari according the properties of the ore.

The most suitable mining method for Sukari gold mine was determined to be sublevel open stoping, which get the highest rank in UBC method and it is currently mining method in use. The result of comparing the methods proved that Sublevel open stoping was seen as the most suitable method for Sukari gold mine.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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