MINE PRODUCTIVITY IN DRILLING AND BLASTING OF VERTICAL CRATER RETREAT STOPES

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A DISSERTATION

Presented to the Department of
Mining Engineering
program at Selinus University

Faculty of Engineering & Technology in fulfillment
of the requirements for the degree of
Doctor of Philosophy in Mining Engineering

2024

ACKNOWLEDGEMENTS

I wish to acknowledge the superior and second to technical and professional guidance and assistance given by my supervisor, **Professor Salvatore Fava.** His wide knowledge, wisdom and experience were my guiding lights at each and every stage during, the study journey. His fatherly patience and drive towards achievement of excellence is highly appreciated.

I would like to express gratitude to the Management team of Mopani Copper Mine (MCM) Plc, for their cooperation, and for affording me the opportunity to use their operations for my research work. Last but not the least, I wish to express my sincere thanks to my family and friends, especially the Nkana, Mindola Subvertical (MSV) shaft and South Ore Body (SOB) team for their help and encouragement and belief that they showed in me which made me want to go on and on in accomplishing academic goals.

I would like to sincerely thank my family more especially my father, **Mr Boniface Jacob Ndhlovu,** for early academic sustenance and my wife for the support, encouragement, help and patience throughout this involving programme.

I wish also to thank **Mr Victor Bwalya** the Head of MSV mine planning for sharing his ideas and been there for me throughout this study. I appreciate his coordination and his help in sharing information during this study.

Finally, sincere thanks go to my bosses, **Mr. Andrew Phiri,** MSV mine manager for being there for me and providing necessary time in ensuring that I complete this thesis despite the tight production schedule and limited time at work.

May the good Lord richly bless all of you.

DEDICATION

To my wife, Eunice Ndhlovu and children (Twachila, Tasila, Twakondwa and Tasheni). The confidence that you have placed in me has always been my drive in pursuit of excellence and greatness through integrity and hard work. The long, hours I spent away from you guys in my effort to put quality time to this thesis will not go unappreciated. This manuscript is therefore a dedication to you all for your patience and supportive aptitude even when things were so unbearable for you.

ABSTRACT

Mine productivity is of high importance in the mining industry and thus, every single effort must be put in place at every mining stage if continuity flow of ore and profitability is to be achieved. Worldwide, mine productivity in drilling and blasting of stopes cause production drawbacks as shown by failure in meeting production targets in the mines. The major mine productivity problem that leads to unsteadiness in viable ore production is stoping, which is the process of extracting the desired ore or other mineral from an underground mine. Mine productivity in drilling and blasting in any mine to run profitably requires clear understanding of management's control in capital investment, labor investment, stoping processes it operates, spending on goods and services, and the way it organizes mining operations.

At Mopani mine, Nkana site in Zambia key hitches in mine productivity leading to variations in sustainable and feasible production of ore are bottlenecks in drilling and blasting operations such as delays and implementation of production strategies and failures of engineering equipment. Stope drilling has a significant impact on productivity, taking into consideration of most importantly the variable nature of ore grades, size, and the depth of the ore body. As stoping of ore deepens, the costs of running operation becomes high and intensive at both two mines of Nkana site, Mindola subvertical-MSV and South ore body-SOB. Alternative significant factor of concern is extensive blasting operations across the mine; this can directly or indirectly affect productivity if not well managed and controlled.

The research dwelled on mine productivity, and it reveals challenges in drilling and blasting of vertical crater retreat stopes -VCR at Mopani mine, Nkana site. Importantly, the research shows that some mining areas have folded ore body that requires proficient contemplating in executing mining operations to turn around productivity performance.

The main objective of this study was mine productivity in stoping evaluation and identification of root causes leading to deficiencies of copper ore delivery at Nkana sites both MSV and SOB and specific objective were to investigate stope drilling and blasting of VCR stopes, determine root causes of poor stoping and productivity; and recommend viable remedial measures to enhance ore output and productivity through improvement performance in VCR stoping operations. The acute hitches of mine productivity in drilling and blasting of VCR stopes at Nkana site leading into decrease in ore production and delivery is due to technical, operation and maintenance issues in stoping. This establishes an interrupted link in the production chain at Nkana mines and adversely affects the whole Mopani mine production process. Hence the need to develop viable drilling and blasting of VCR stopes mine productivity plans at Nkana mines to bridge the gap of ore from the mine sources to match the capacity of Mopani processing plant.

In the study, a conceptual and theoretical framework of mine productivity was established to tackle Nkana stoping productivity. Stoping factors such as technical elements of strategy and maintenance plan are typically tied to production plan and site conditions. Thus, to establish an optimal viable mine productivity model needs thought of technical, operations and maintenance factors. The conceptual framework splits stoping activities into technical, operations and maintenance factors to facilitate the study methodology. Research methodology based on these three factors was established.

The gathering of data was done by visiting mining operation sites, coupled with verbal discussions in the field with technical, maintenance and mining operation personnel as well as a questionnaire. The research reviewed vcr stoping issues at both Nkana sites and the data was set as benchmark for the study. Data gathered provided research data on technical, operations and maintenance factors. In addition, supplementary data also came from: Encyclopedia Britannica, uniselinus library, textbooks, journals, published papers, mining articles and stakeholders. The gathered data relating to the research was then analysed and interpreted through graphs.

The research concluded that the following had the most impact on drilling and blasting of VCR at Nkana site:

1. Under technical factors:

- ❖ Failure by technical department management in timely provision of funds i.e., contractor financial constraints inhibiting full potential on development, the contractors responsible for preparation of vcr chambers require addition of development rigs to meet the target.
- ❖ Delays in providing strategic management plans for development drilling and stoping; and ineffective implementation of plans such completion of capital projects such as mining of access to new production levels, VCR stopes and pump chambers in the deeps to contained water from failure of pumps at 5360 level and 2930 level pump chambers. This has caused frequent flooding of the Banda Ramp from 5814L to 5956L thereby restricting critical ends mining and flooding of the Redpath decline to the shaft bottom affecting and restricting ventilation to the deeps.

2. Under operation factors:

- ❖ Management failure in providing and releasing funds for replacement of old unreliable equipment i.e., lack of recapitalisation of Cubex drilling machines for drilling VCR stopes. (Only two machines are in operation out of required four Cubex at MSV and one machine out of three at SOB)

- ❖ Failure in strategic and tactical effective implementation of productivity and production plans in drilling, blasting and auxiliary operations such as water management systems and adequate supply of ventilation to VCR working areas.
- ❖ Delays in development and production drilling of ends and stopes (mining of accesses to production areas and preparation of VCR stopes).

3. Under maintenance factors:

- ❖ Failure in ensuring adequate machinery maintenance and replacements of spare parts for Cubex machines such as Cubex 18 at MSV.
- ❖ Inadequate maintenance underground workshop facilities impacting negatively on maintenance schedules e.g., small size of workshops, mud and slippery environmental; and
- ❖ Low equipment (Cubex drilling machines) average availability of 75%, unreliability and frequent breakdowns resulting in massive delays of productivity in stope drilling.
- ❖ The average machine ultilisation is 70%. This contributes massive drilling losses as compared to the other two elements in mine productivity. Based on the above, huge capital financial investment in maintenance is needed.

Generally, in all the three elements of mine productivity in drilling and blasting of VCR stopes, management failure is predominantly as it is the key factor in provision of funds to run the operations smoothly and on schedule. The supervisors just ensure that the plans are implemented on time when the funding is adequately in technical, mining operations and engineering such as equipment recapitalisation.

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CHAPTER 1 INTRODUCTION

1.1 Research background

Mine productivity in stoping out of minerals is essential in the mining industry and economic enhancement; and requires comprehensive understanding of all factors affecting drilling and blasting of VCR stopes. These mining factors include technical, operation and maintenance.

The Nkana copper-cobalt operations comprises four open pit and four underground mines, the North Mindola, Mindola, Nkana Central and Nkana SOB (Southern Ore Body). These mines exploit mineralisation, more or less continuously over a strike length of 14 km on the SW margin of the Kafue Anticline, immediately to the east of the town of Kitwe.

Indications of copper mineralisation in the form of a single small outcrop of copper-stained black shale over the Nkana South Ore Body, were first brought to the attention of European explorers and prospectors in 1899. Subsequently two areas of claims were pegged in 1916, one over the outcrop and the other covering small 'ancient' workings, which were initially explored by trenching. Between 1918 and 1922 a 30 m shaft was sunk, and a crosscut encountered 20 m at 3.4% Cu. Further shaft sinking and prospecting was carried out until 1927 when Anglo American began a systematic exploration program. Mining operations commenced in 1927 and by 1932 large scale production had commenced, which has continued to the present, with a number of major ownership changes. Mopani mines, Nkana site - Mindola Subvertical (MSV) and South Ore Body (SOB) have been having challenges in meeting stoping targets due to several reasons, which results in the loss of production.

1.1.1 Mindola subvertical – MSV

The Mindola deposits form the northern section of the operation. Location of Nkana is at - 12° 47' 46"S, 28° 10' 54"E; Mindola - 12° 46' 32"S, 28° 9' 48"E. MSV mine is currently the deepest mine on the Zambian Copperbelt. Production is executed through stoping, which is at present active to 4370 ft (1332 meters) below surface with long-range plans indicating future production up to 5956ft (1815.4 meters) level. The orebody is tabular and dips between 55° to vertical. The thickness varies from 8 m to 14 m.

1.1.2 South Ore body-SOB

South Ore Body deposits form the Southern section of the operation and are located at - 12° 50' 11"; 28° 11' 56'E. The mine has folded orebody of synclines and anticlines with multiple structures or limbs namely, A-fold, B-fold, BC, CD, CI, CA, DA etc. The dip is ranging from -30^0 to 85^0 and the average of VCR dipping is from 65^0 to 85^0, and SLCs dipping from -30^0 to 85^0). The grades range from 1% to 3.5% depending on the structures, Synclines are generally high in grade. The thickness is 3.0metres to 170metres.The stope sizes are:(a) Strike length – 15m for SLC transverse and 30m for SLC Longitudinal, 23m for VCRs, (b) Width (thickness) Length – 170m maximum for SLCs and 30m for VCRs with 10m mid pillars and 10m rib pillars, (c) Stope height – 30m maximum for SLC and 50m maximum for VCRs.

The activities involved at both **MSV** and **SOB** in extracting ore from different production areas include drilling, charging, blasting and as well as auxiliary services such as mining water and ventilation. Vertical crater retreat VCR is the predominant mining method while sublevel open-stopping method is also used. The vertical crater retreat method of mining was first introduced at Nkana, Mindola mine in 1989 following several trials that helped define the design criteria for its application. Inappropriate execution of the mining activities at both MSV and SOB affects the required amount of time and effort and thus the job-site productivity. Serious drilling targets of long hole down -down to hole(LHD-DTH) meters deficits have been experienced at Nkana mines. The mines need to enhance stoping, ore generation and productivity of mining to keep costs per tonne to a minimum and to maximise profits return to shareholders, on long-term basis throughout the life of mine. Hence, the reason why this research work dwelled on identification of root causes of drilling and blasting setbacks at the mines, to improve on stoping productivity and production.

Theoretical and conceptual framework

A conceptual framework of mine productivity in drilling and blasting was determined for Nkana mine site; MSV and SOB mines as shown in Figure 1. The framework outcome will enhance the current DTH drilling rate averaging 4,476.066 meters per month in a period of five years as illustrated in table 1.

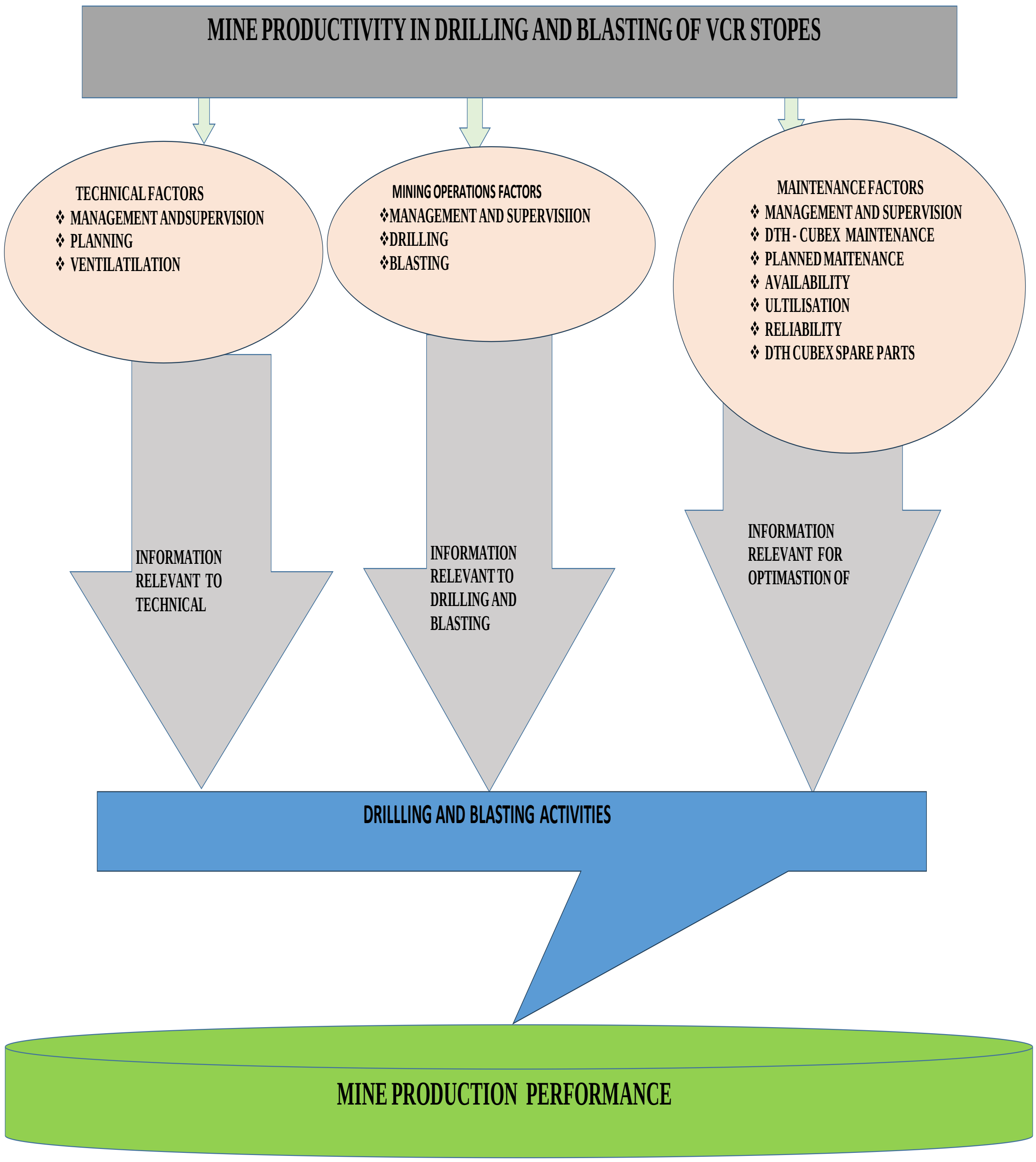

Figure 1:The Conceptual Model of the Dissertation

Figure 1 shows the conceptual model of this dissertation, which illustrates three important elements in mine productivity in drilling and blasting. The framework structure was developed to address problems in the research. The two factors; technical factor and maintenance policy are tied strongly to success of mining operations and stoping areas. In the framework management is listed in the three elements and this visibly displays that it is key in the mine productivity in drilling and blasting of VCR stopes, these elements include:

- ❖ **Technical factors in mine productivity**

Technical factors in mine productivity in drilling and blasting of VCR stopes are key phases in underground mine production. The technical group disciplines play dynamic roles to mining operations and have great impact on mine productivity and production.

- ❖ **Mining operations factors in productivity**

Mine operations are important in stoping processes, they determine fiscal capability of the whole mine, delivery-focused in ensuring necessary improvements for higher profitability, turns inputs to outputs in mine productivity in drilling and blasting of VCR stopes, tactically vital and the forefront of productivity in stoping and ore production. In the study, drilling is the process of penetrating through the ground and extracting rocks or minerals from various depths beneath the surface for confirming the geology beneath, waste material- ore production and/or providing samples for chemical analysis. The purpose of drilling in mining operations is to create small or large diameter holes in the rock massive for the placement of explosives in order to loosen and fragment the material for subsequent operations while blasting in mining is a chemical and physical process that occurs through the firing of explosives. It breaks mineral-bearing materials. These materials can be coal, ore and mineral stone. The process reduces solid body, such as rock, to fragments and enable easy handling.

Drilling and blasting is practiced most often in underground and surface mining; and works as follows:

- A blast pattern is created.
- A number of holes are drilled into the rock, which are then partially filled with explosives.
- Stemming, inert material, is packed into the holes to direct the explosive force into the surrounding rock.
- Detonating the explosive causes the rock to collapse.
- Rubble is removed and the new tunnel surface is reinforced.
- Repeating these steps until desired excavation is complete.

Resources are used in drilling and blasting of VCR stopes to create an output that is suitable for use. Productivity is the rate of the efficiency of production. Often, a productivity measure is expressed as the ratio of an aggregate output to a single input, or an aggregate input used in a production process, i.e., output per unit of input, normally over a specific period of time. For mining firms, productivity outgrowth is important because providing more ore in the production system and processing plants leads to higher profits. As productivity in drilling and blasting of VCR stopes increases, mining firms can turn resources into revenues, paying stakeholders and retaining cash flows for future growth and expansion (Yenice, 2019).The researcher explains the selected theories and concepts for the study. In the study, particularly, theory of Productivity at the mine face was considered to be the most appropriate.

Theory of Mine Productivity

According to Humphreys (2019), the concept of mining productivity and fourth industrial revolution has specific significance in mining since mining operates in an industry with diminishing assets. This has materialised as a common and extremely considered theory in mine productivity in drilling and blasting of VCR stopes and other mining units processes. Globally and regionally researchers have diligently to demonstrate that the productivity and production growth has first to overcome the effects of all mine productivity in drilling, blasting and other mining operational issues before it can make any tangible progression in production. Though much discussion on depletion focuses on the issue of grade decline in the unresolved available resources, reduction goes a bit wider than this. The theory also takes the form of advanced stripping ratios such as the need to remove more overburden, harder rock, more intricate mineralogy and more impurities in the ore demanding more processing. Furthermore, it indicates the necessity to carefully arrange and pay for accumulative sums of numerous mine unit processes. Globally (Moyo, 2016), during the boom years, Theory of Productivity at the mine face, there were two major contributors to the decline in the mining industry's productivity, for instance high capital spending and high operating expenses.

- **Maintenance factors in mine productivity**

Maintenance factors of mine productivity in drilling and blasting of VCR stopes are an important aspect in ore production. Always the system has to be able to sustain a large amount of targeted long hole drilling- down to hole -(LHD-DTH) meters and production tonnages to be produced while maintaining high machine availability and acceptable performance. Low machine availability, unreliability; and frequent break downs cause massive losses in drilling of VCR stopes at Nkana site.

1.2 PROBLEM STATEMENT

The acute hitches of mine productivity in drilling and blasting of VCR stopes at Nkana site leads into decrease in ore production sequence and adversely affects the whole Mopani mine production process. VCR mining method forms the backbone of Nkana mining operations. The mining technical difficulties at Nkana mines have affected stoping, which also negatively affects the production across Mopani. The key influential issues of productivity in stoping and blasting at

Nkana mines appear to be at initial sight, preparations of development, preparation of critical controls, underground water system, ventilation system in the VCR chambers, long hole drilling, operators' skills, ore blasting, and machine maintenance.

Table 1: Nkana Five-year DTH actual meters vs planned meters

	2018	2019	2020	2021	2022	Total
Annually meters actual (m)	35,532	20,031	25,613	38,944	28,935	149,055
Annually meters planned(m)	53,520	37,342	95,461	42,917	39,780	269,021
Deficit (m)	(17,988)	(17,311)	(69,848)	(3,973)	(10,846)	(119,966)
Achieved percentage (%)	**66%**	**54%**	**27%**	**91%**	**73%**	**62%**

The mining method has posed some challenges, especially with drill deviations resulting in complicated holing ring delineations. Poor drilling control makes blasting a nightmare, because choice of blast holes to blast requires very good appreciation of where the blast holes are holing. The poor state of the drill rigs, lack of appreciation of geometry by most operators and aligning of the rig are problems that need urgent attention to address the situation. Hence the need to develop viable drilling and blasting of VCR stopes mine productivity plans at Nkana mines to bridge the gap of ore from the mine sources to match the capacity of Mopani processing plant. In Table 1, it is clearly illustrated that five-year actual DTH meters were **149,055** meters vs **269,021** planned meters giving a shortfall of **119,966** Meters.

1.3 RESEARCH QUESTIONS

1. What are the major causes of stoping failures at Nkana?

2. What could be done to improve on mine productivity in drilling and blasting at Nkana mines to meet Nkana long hole drilling- down to hole -(LHD-DTH) planned targets?

1.4 MAIN OBJECTIVE

The research objective was to investigate root causes of mine productivity in drilling and blasting setbacks and develop a criterion to achieve productivity improvement in drilling and blasting at Mopani, Nkana mines MSV.

1.4.1 SPECIFIC RESEARCH OBJECTIVES

a) Investigate productivity in drilling and blasting of VCR stopes;

b) Determine root causes of drilling and blasting failures; and

a) Recommend viable remedial measures to improve long hole drilling- down to hole -(LHD-DTH) meters output and productivity.

1.5 GENERAL DESCRIPTION OF NKANA

The Nkana area is located in Kitwe and geographically lies in the centre of the Copperbelt province of Zambia and some 258 kilometers north of the capital, Lusaka. Mopani Copper Mines Nkana Division has four shafts which are:

a) North shaft;
b) Mindola sub-vertical shaft (MSV);
c) Central shaft; and
d) South Orebody (SOB).

The study was undertaken at MSV and SOB which are located in the north and south of the Nkana mining area. Figure 1 illustrates the location of all four ore sources at the Nkana mine site (Chanda, 2000)..

NKANA MINE SITE ORE SOURCES

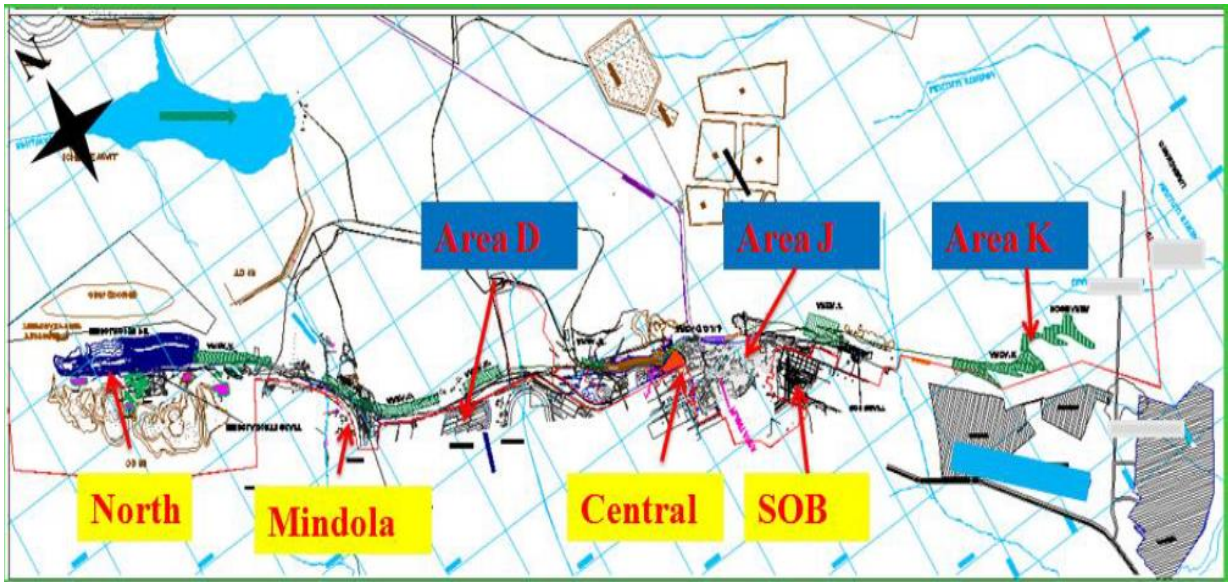

Figure 2: Nkana mine sites (Bwalya, 2013)

1.5.1 Mining methods

Currently there are basically two mining methods that are employed at MSV and SOB. The two are the Sublevel Caving (SLC) and the Vertical Crater Retreat (VCR)

At Nkana, MSV, the mining method is applied in areas where the Orebody is wide, that is, greater than 20 m and therefore the drifts traverse the ore from the footwall. The driving of a series of sublevels commences at the top of the Orebody proceeding downwards, thus making SLC a 'top-down' method. At MSV, this extraction front is in the form of an echelon retreating at 45 degrees.

1.5.1.2 Vertical Crater Retreat -VCR

The VCR method operates using spherical blasting effect and employs large diameter blast holes inter-spaced at predetermined spaces and blasted in such a way that an upside-down crater is formed. This mining method mainly is employed in steep orebodies (+55°) with fairly stable host rock and surrounding rock. During stope blasting, it is cardinal to ensure that the stope is maintained full and only the swell is drawn until the whole stope has been fully blasted. This method reduces dilution due to stope sidewall sloughing, as the stope is kept full during blasting thus providing sidewall support. The machine used in VCR chambers is the Cubex machine which can drill holes up to 50 m or more to the next level known as the holing level (bottom chamber), these holes are slanted as the orebody is inclined. Ore extraction can either be by flow through to the extraction box or mechanized draw on draw point level. Ore extraction may also be mechanized in cases where the orebody thickness is in excess of 20m.

The VCR mining method gives better fragmentation and has reduced development requirements and generally results in improved ground conditions. Post filling of VCR stopes further improves the ore extraction and recovery through increased pillar rate of about 2m per day until all the ore from the stope has been extracted. After every progressive blasting, there are loader machines at the holing level that transport the ore from that point to the tipping point. This VCR mining method is basically done in two ways, that is, either by using the up-dip method or down-dip method. In the up-dip method mining progresses upwards were every stope that is mined out has to be refilled in order to maintain ground stability and room for men and machinery to work on when time comes to extract the next upper level. Down-dip method employs the same system except that in this case mining is from upper to lower levels. Vertical crater retreat (VCR), also known as Vertical retreat mining, is an open stoping, bottom-up mining method that involves vertically drilling large-diameter holes into the orebody from the top, and then blasting horizontal slices of the orebody into an undercut. A system of primary and secondary stopes is often used in VCR mining, where primary stopes are mined in the first stage and then backfilled with cemented fill to provide wall support for the blasting of successive stopes. Similar to Sublevel open stoping and Blasthole stoping methods, VCR mining is used for steeply-dipping (>45º), or both vertically and horizontally large orebodies with competent ore and waste rock strength. It differs from other open stoping methods in that it is a bottom-up method, as opposed to a left-to-right method, and it does not require the excavation of sublevel drifts before blasting and mucking can take place. The thickness of one horizontal slice varies between 2 and 5 meters in height.

1.5.2 VCR HISTORY

The VCR mining method was developed by INCO and CIL Inc. and is based on Mr. C.W. Livingston's crater blasting theories. It was first used in 1974, at the Levack mine located in the Sudbury Basin's North Range , and it provided productivity benefits almost immediately. In fact, mining productivity, measured in pounds of nickel and copper produced per manshift, has improved by approximately 80% at the Sudbury basin between 1980 and 1990, after their conversion to VCR mining. The mining method soon spread worldwide; being adopted for use for the first time in the U.S. in 1977 at the Homestake mine. It is currently the dominant mining method of the Sudbury basin, as both Inco and Falconbridge regard VCR as their mining method of choice. The mining equipment subsidiary company Continuous Mining System (CMS) was developed in 1984, through Inco's push to expand VCR as a mining method. During the early years of VCR mining, CMS machinery, such as in-the-hole drills, was developed by Inco for use in their own VCR mines. This equipment was passed on to CMS, allowing for global market development, and in the past 8 years they have diversified and developed worldwide. In Table 2, shows suitable characteristics for VCR mining method:

Table 2: Suitable characteristics for VCR mining method:

Characteristics	Requirements
Ore and Rock Strength	The strength of the waste rock must be competent in order to blast against it without having excessive amounts of dilution. The ore deposit is to be of medium to competent strength
Grade	VCR is not a selective mining method; therefore, the ore grade should be low to medium, and it should be relatively uniform throughout the entire orebody
Depth	VCR mining can occur at any depth. Work is carried out in reinforced, small drifts; and given the nature of the mining method, no personnel have to work directly within the drift. Therefore, safe execution of VCR mining can be carried out in deep mines
Oxidizing Ores	Given the small, localized stope size in VCR mining, ore can be recovered very soon after blasting occurs. Therefore, oxidizing, and self-cementing ores such as pyrrhotite can be mined using this method

Crater blasting theory (Livingston, 1974)

1.6 Significance of the study

Mindola Subvertical mine began its works in 1933 and has been in existence for more than 90 years and in this period, its operation has gone deeper (5570 ft). South ore body (SOB) shaft was officially opened in 1956. The two mines have both gone deeper, this basically means that productivity in drilling and blasting for maximum opportunities to be realised in deeper extents without compromise on stoping is such a critical strategy in mining which must not be treated as a simple operational function only.

Hence, the outcome of this research would be of great value to Mopani mine and its workforce in general in that it would lead to enhanced productivity in drilling and blasting and generate sustainable ore production at Nkana mines, MSV and SOB shaft.

1.7 Scope

The research was concentrated on mine productivity in drilling and blasting at Mindola subvertical (MSV) and South ore body (SOB), Mopani Copper Mine. The research material was also gathered globally, regionally and at local level. This was to obviously understand the overview of the study, gain various concepts and to appreciate numerous challenges in mining operations globally.

1.8 Ethics

In the study, the aspect of underground field visits and purpose of research investigations was clearly explained in detail to all employees interacted with in all three elements of mine productivity involved in drilling and blasting of VCR. The communication particulars for the researcher were given in case of any queries regarding the study. Furthermore, employees freely participated in responding to the survey questions and that utmost privacy was assured.

1.9 Limitations

The research had some difficulties in getting the required information; most of the workers who participated did not give all the required information easily to the researcher for instance, only 80 percent responded. The questionnaire participants decided to respond at their own time and thus slowing up completion of research required data. Some survey enquiries were not sufficiently attended to by field workers, and this made it difficult for the researcher to acquire all important research data.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter focused on related literatures and studies for globally, regionally and locally researchers, which were gathered from books, journals and term papers including methodology, findings and conclusions, blogs, newspapers, electronic books, articles, https://www.uniselinus.education/it/library and online materials, which were used as references and additional information for the progression of this dissertation. This chapter also included the synthesis of the mining productivity review, Furthermore, the current study filled in the gaps by validating aspects that earlier researchers had overlooked, as well as addressing the gaps in stoping operations which need conformity with innovations and implementations in technical, maintenance and mining operation activities to enhance productivity and maximise returns by mining companies' shareholders. The literature was reviewed through:

- Quantitative technique:

  This is a process that involved collecting numerical data.

- Qualitative technique:

This involved collecting non numerical data such as text in order to comprehend the concept of mine productivity study. This aided in gathering in-depth insights into the study problems.

2.1.1Global search for relevant literature

The study of global literature is a powerful tool for mine productivity research because it encompasses so many themes that are important to understanding mining activities.

2.1.1.1 Background of Vertical Crater Retreat (VCR)

Vertical Retreat Mining (VRM), however it is also known as 'Vertical Crater Retreat' or 'VCR' or sometimes simply called 'Inverted Crater Blasting'. In 1983, it was called 'an achievement of the last decade' and is practiced in mines in Canada, Australia, Europe, Central America, and the U.S. It was advertised as 'a unique and revolutionary new application of spherical charge technology, when applied to primary stopes and pillar recovery,' and 'eliminated or reduced raise - boring, slot - cutting and the dilution of ore by backfill.'

The concept of VRM (as it is commonly referred), is simple. On a specific pattern layout, large diameter vertical holes are drilled from a cut (top sill) into the ore to breakthrough at the undercut (bottom sill) anywhere from 33 m to 122 m below. Spherical charges (explosive charges having a length to diameter ratio - L/D - equal to about 6/1 or slightly larger), are positioned accurately in the boreholes (at an optimized distance from the back of the undercut to the charge center) and are then detonated - cratering out a volume of rock into the undercut. The objective is to take thin slices anywhere from 3 m - 4 m off the back to fill the draw point. Drill patterns are laid out according to rock properties. In most underground mines using this method, holes are laid out usually as a 3m x 3m. (burden /spacing) pattern, to provide the required, for 165 mm boreholes and about 3.7m x 13.7 m for 200 mm boreholes.

The word 'Retreat' in 'Vertical Retreat Mining' refers to the blasting progression. As each charge is loaded and detonated with this process repeated, the remaining ore to be blasted is "in retreat" upwards until a section of about 7 m to 17 m is left at the top of the stope. The remaining zone is known as the crown, which is left intact for loading and, for safety reasons, is detonated all at once.

2.1.1.2Theoretical Literature on mine productivity in stoping

In the study, the mine productivity theories were looked at to grasp underground concepts in mine production. This enabled clear understanding of the mine productivity research.

2.1.1.2.1 Mr. C.W. Livingston's crater blasting theory

The theory expresses that when an explosive configured as a cratering charge and is detonated in rock, a compressive wave travels out from the explosive. The magnitude of the stress wave produced by the compressive wave front or strain wave depends on the dynamic compressive strength of the rock and the impulse generated by the explosive at a specific velocity and density. The wave hits the rock/air boundary (free face) and is reflected as a dynamic tensile wave back into the rock. Since tensile strength of rock is much smaller than the compressive strength, by a factor ranging from 10-25% of the compressive strength, the rock fails in tension. At the free face the rock begins to scab off back to the explosive charge. The extent of the scabbing process depends on the type of rock, the type of explosive, the shape of the explosive charge and the distance from the boundary or "free face". The free surface velocity of the scabbing rock is twice the body wave particle velocity. Some of the important factors associated with VCR blasting operations are;

- Ore characteristics;
- Explosive energy;
- Charge shape (must be spherical);
- Explosive charge position; and
- Optimized volume broken.

When an explosive charge of constant weight and shape is positioned at different distances from a free face and then detonated, the amount of material excavated by shock and gas pressures changes with the depth of burial of the charge. For the cratering process to work efficiently in mining, an optimized volume of ore broken with a minimized charge weight producing a specific level is desired. Theory further stated that at increased depths of burial, most of the energy goes to the production of local crushing in the borehole along with seismic waves. As the depth of burial is reduced, surface scabbing begins to occur. Just at the point of tensile failure, large slab shaped fragments are formed along with a shallow crater. Further decreasing the crushing in the borehole along with seismic waves. As the depth of burial is reduced, surface scabbing begins to occur. Just at the point of tensile failure, large slab shaped fragments are formed along with a shallow crater. Further decreasing the depth of the charge results in changes in the crater shape and depth. Radial cracks now begin to form propagating out from the borehole. Some concentric circular cracks will radiate outward from the center of the borehole. Noise and flyrock will begin to occur. The quantity of broken material will pass through a maximum specified screen and at this point the would be considered to be fine. The maximum volume produced by a charge at a specific depth of burial can be determined by varying the depth of burial in a sequence of testing. (Mr. C.W. Livingston, 2014)

2.1.1.2.2 Theory of mining productivity and the fourth industrial revolution

The concept of productivity has specific significance in mining since mining operates in an industry with diminishing assets. Productivity growth has first to overcome the effects of this before it can make any real headway. Though much discussion on depletion focuses on the issue of grade decline in the outstanding available resources, depletion goes a bit wider than this. It can also take the form of advanced stripping ratios (the need to remove more overburden), harder rock, more intricate mineralogy and more impurities in the ore (demanding more processing). Moreover, it implies the need to safely dispose of and pay for increasing amounts of solid and liquid wastes. In the absence of a capacity for the positive contributors to productivity to outweigh the negative effects of depletion, then costs of mineral production must rise and so, eventually, must prices. Furthermore, the nature of the commodity business hitherto, with its homogenised products, is such that producers can do little by way of branding or product variation to help increase the value of their output. It all comes down in the end to costs and, to a substantial degree, this means productivity. In recent years, there have been some worrying developments in industry productivity. Since around the year 2000, productivity in mining across the global seems to have declined, and declined considerably (Humphreys, 2020).

2.1.1.2.3 Theory of mining industry and sustainable development

Some mining firms moved from developed countries to other regions due side effect of environmental legislation development and increased costs of waste management. Today, international companies often mine for oil, coal, gas, uranium, rare earth elements, and fine metals in regions far from the big consumer markets and final users. Mining regions are now often located in remote areas of north of Canada and Australia, and in developing countries in South America, Asia, and Africa, often with less stringent mining laws and weaker environmental regulations. Mining impacts, comprising waste streams and social impacts, were, therefore, generally transferred from developed and densely inhabited regions to other regions. In underground mine productivity, mining ores are usually aggregated in sectors such as base metals, fossil fuels, and precious metals. Metals such as iron have been mined for long time, while others such as aluminum were recently mined. Total amounts of metals extracted already from the Earth crust and contained in applications (infrastructures, machinery, and tools) are very large. Today, to maintained good sustainability in the mining industry, some mining companies have started reprocessing the metals from accumulated scrap and waste in landfills and this may be in some cases more cost-effective than to mine ore deposits. For example, in 2008, the world steel industry produced over 1.3 billion tonnes of steel. It used 1.48 billion tonnes of raw materials or 470 million tonnes less than, would have been desired to make the same volume of steel in the 1970s. Concerning aluminum, it is estimated that since 1880 900 million tonnes of aluminum were produced of which nearly 75% is still in use today. The demand for aluminum continues to skyrocket and recycling aluminum saves more than 90% of the energy required to producing new metal, thus rendering recycling very attractive (Carvalho, 2017).

2.1.1.2.4 Theory of Productivity at the mine face

Globally, during the boom years, there were two major contributors to the decline in the mining industry's productivity: In the boom years (200 to 2002) the mining industry was doing well with low capital spending and low operating expenses. High capital spending and high operating expenses, in the post boom years (2003 up to 2012), capital spending continues to bedevil many companies in the industry, the analysis suggests. Mining capital spending applied poorly seems as a key causer to decreasing productivity at most of the mines where performance fell. In the period from 2003 up to 2012, the mining industry capital spending in production surprisingly increased (Moyo, 2016). Mining firms, the substantial sums have not transformed yet to the extent of additional output essential to expand their scores in productivity and production. For instance, Americas iron-ore miner and Africa producer miner both greatly financed their mines and did raise output. However, the output growth was not sufficient to compensate the huge increase in capital spending. These mines scored a down fall of 35% and 25%, respectively (Moyo, 2016) in production.

2.1.2 Global perspective on mine productivity

Flesher **(**2018**)** carried out a study and published a paper on mine productivity. The study proved that the mining industry's production efficiency performance is possibly the main element of its long-term capability to convert greater product prices into improved incomes. The research was specifically intended to track true underlying productivity: how much total material (ore and waste) is being shifted by using what amount of resources. It thus not only disregards the influence of grades, strip ratios, and mining commodity prices but also takes into account the rising cost of mine supplies, such as diesel fuel. The research showed that over the past year, several indicators of different aspects of the global mining sector's performance established that mine productivity turned around after the dark days of 2014, 2015, and early 2016.

Darmstarder (2014) did a study on global mining development and environmental. He stated that unquestionably, an important source of mining industry success has been its productivity record and technological and other factor underlying that record production and productivity performance. When all activities in production areas are well understood by all stakeholders, then the coordination is impressive.

Simpson (2018) carried out research on mine productivity and natural resource industries improvement through innovation. The researcher clearly stated that high productivity is essential ingredient of prosperity. It improves the competitiveness and lessens the impact of resource depletion.

Smith (2012) did research on productivity and its impact on employment and labour relations. Smith stated that a range of factors have driven productivity and influenced the need for increases which included some or all of the following; the level of mechanisation, geological conditions and competition factors. In many mines all over the world, in many countries improving productivity is the only way to survive. The key to increase productivity lies in the careful integration of employment and industrial relations policies.

Matysek and Fisher **(**2016**)** carried out a study on mine productivity. Success in mine productivity innovations needs a number of other mining aspects such as:

- Taking new ideas;
- Converting ideals into useful processes;
- Interacting with groups undertaking similar mining activities.
- Government policy must take a long-term view and not be hostile to product and process risk taking. For example, corporate or personal tax rates and other taxation arrangements that are internationally uncompetitive will ultimately lead to development of innovative ideas being undertaken elsewhere; and
- Making advances in an industry where the country already has comparative advantage will generally be more straightforward and successful than starting a new enterprise in a new sector. To this end building on the comparative advantage and global scale that Australia already has in mining provides a strong foundation for new innovation.
- To tackle the question of mine productivity manageably this study, it was decided to divide the subject into technical, operations and maintenance factors which are discussed below. These factors encompass work by Darmstarder (2014) who defined technology, Simpson (2018) who mentioned innovation and Smith (2012) who identified level of mechanisation geology conditions and competition factors.

2.1.2.1 Mine Productivity Technical Factors

Worldwide, the sector units perform vital role in making mining firms production viability (Whittle, 2018).

2.1.2.1.1Management and supervision

Productivity matters happen due to unsteady supervisory decisions made in various sectors of mine activities. The technical factor primarily supervisory role is to offer knowledge; and other amenities required by mining operation team. Worldwide, all mining industries, management and supervisory are anticipated to make swift plans that enables mining companies operate economically (MacEwan, 2020). In mine productivity in drilling and blasting, the key to revival productivity lies in the careful incorporation of employment and industrial relations policies (Smith, 2012).

2.1.2.1.2Mine planning

Planning section in the mining industry gives guidance as to how the underground mining activities will be executed i.e. issuing of layouts for development of accesses to stoping areas. It provides comprehensive formulations of optimum strategies to attain shaft production targets; and these consist of:

- Target attainment categorisation;
- Strategically designs;
- Tactical formulations;
- Mining resources required creation; and
- Application of appropriate implementations, leadings, and guidance in mining actives

2.1.2.2 Mine Productivity Operations Factors

Underground mine operations factors are important in mining unit processes; and they are tactically in the lead of underground productivity and production. The unit processes in mine operations determine financial viability of the entire mine operation.

2.1.2.2.1 Supervision and Management

Supervision and management of operations factors are primarily concerned with planning, organizing leading coordination and controlling in the contexts of productivity and production.

It is delivery-focused; making sure essential enhancements for higher profitability and that mines effectively turn inputs to outputs in an efficient manner. The inputs might signify anything from materials, equipment and technology to human resources such as mining staff or employees. The alterations in the everyday operations have to provide sustenance to the company's strategic goals. There are five main groups of undertakings performed by operations management and supervision, arising from its planning, organising leading coordination and controlling role. These activities involve considering assets, costs and human resources (Cleverism, 2018).

2.1.2.2.2 Mine Drilling

The study looked at the current Cubex 15 and 16 drilling rate and operational issues at Nkana mines based on drilling achievement. The process involved enquiry of use Cubexes equipment in vertical crater retreat -VCR-chambers in production areas and skills used in drilling rig operation that nurture general mine productivity of stoping outcomes. The research also evaluated the reasons why long hole drilling- down to hole -(LHD-DTH) plan targets of drill rigs are not met and how proficient and effective these drilling and blasting setbacks can be improved as regards to where the company is headed in the future.

2.1.2.2.3 Stoping

Worldwide, mining is a preferred removal of ore on the surface or underneath the earth. It is used when the rock is adequately resilient and cannot fall down in the chamber and requires provision of more support to keep the stoping area stable. After stoping out the ore, the waste rock materials are often backfilled into stope to fill up the void and stabilise the mining area. There are several types of ore extraction. Cut-and-fill mining method is used by Caylloma Mine in Peru, where the orebody is appropriate, that is dipping steeply in steady rock masses. VCR is applicable in ore bodies that are competent, steeply dipping such as for mining firm (INCO) in Canada (Goel, 1986).

2.1.2.2.3.1 VCR stope development

The amount of tonnage in a stope will depend on the size of the stoping chamber. Stopes that are big in size will need more support work to make the areas safe and stable for men from the chambers. However, bigger stopes have huge tonnages that provide sustenance of high rates of mucking for longer production period.

In South Dakota, North America, a mining company called Homestake is a VCR mining setup. The mine recently changed its mining method from cut and fill to vertical crater retreat and enhanced productivity. The subsequent optimum method engaged by Homestake mine is mechanised cut-and-fill (MCF), which has 48% cost disadvantage compared to VCR, in relations to direct mining costs (Goel, 1986).

2.1.3 Mine Productivity Maintenance Factors

The research looked at the engineering issues and evaluated gaps concerning maintenance and mining operatives.

2.1.3.1Management and supervision

Mine productivity and production depend on availability, utilisation, and reliability of equipment. The maintenance of equipment needs full commitment by supervisors and managers. Maintenance schedules ought to be adhered to by both mining operation and engineering maintenance crews. In all mines globally maintenance has huge impact on mines financial aspect and influence on productivity and production. The team working on the machine needs to have a performance drive for work and time improvement on attending to machines break downs.

Globally, mines have introduced policies on maintenance of equipment, program on effective assets management, human capital management plan to action improvement on incentive of staff, decreasing worker turnover. This enables mining companies to increase production output and reduction on waste of mine resources (Punkkinen, (2016)).

2.1.3.2 Maintenance of equipment

Achievement in production can only be done when machines are properly maintained. For a mine to have mining operations efficiencies improved, certain significant factors need to be well looked into by management and supervisors (Granseberg, 2015):

- Operators skills;
- Experience;
- Training;
- Schedules;
- Maintenance skills; and
- Availability of spares.

Factors accomplishment is done by good administration services. Mobile equipment and other fixed machinery must have a planned schedule to enable improved of productivity with less time on breakdowns. Underground mine productivity globally, hinge repairs of equipment on the following factors:

- Machine care;
- Overheads;
- Labour;
- Equipment replacements failure;
- Replacement of ropes, batteries, tyres, lubricants, hydraulics, tracks; and all of which should be well scheduled; and

- Condition and age of machinery.

  Although the main restraint in engineering maintenance is absence replacements, workforce coaching in equipment maintenance would help and improve on the availability and reliability of machines, hence providing a steady mine production.

2.1.3.2.1 Machine availability

Availability of machine is defined as machine available percentage when in use against the determined time the machine will be available without break down or disturbance to fix or replace spares. It is the tangible period the equipment is able to be used in mining operations as a ratio of entire planned production time (Fiix software, 2020). See example below (Equation 1).

Availability$=\frac{\boldsymbol{run\ time}}{\boldsymbol{Planned\ productin\ time}}\ x\ 100$ **..Equation 1**

Where;

Run time = The actual amount time the production was happening

Planned production time = The total expected machine time to operate in production.

2.1.3.2.2 Machine utilisation

Utilisation of machine is a rate on how machines are intensively practically used in areas of productions. The run time is interlinked to time that the machine is available and actual time planned for machine to be used (Demand solutions, 2020).

Utilisation $\frac{\boldsymbol{actual\ machine\ used\ hours}}{\boldsymbol{available\ machine\ time}}\ x\ 100$ **……Equation 2**

2.1.3.2.3 Machine reliability

Reliability of machine in production is defined as the likelihood that equipment can operate for a specific period of time without failure and at usual conditions of working and it is the time off of unplanned interruption. (Fiix software, 2020).

Reliability= $\frac{\boldsymbol{machine\ availabe\ \ hours\ without\ failures}}{\boldsymbol{specific\ period\ of\ time\ (shift\ production\ hours)}}\ \boldsymbol{x\ 100}$ **......Equation 3**

2.1.3.2.4 Planned maintenance

This is any activity on machine repairs that planned and recorded in the maintenance system. This helps in machine interruption reduction; all required spares and other resources are put in place before the maintenance time. Scheduled maintenance is classified into two types (Fiix software, 2019).

- **Preventive maintenance**

  This is planned work on the equipment before breaking down. It helps to prevent fault failure and enable the good sustenance on machine availability. For example, doing the repairs on Cubex 16 every 130 hours after drilling in VCR stope.

- **Unscheduled maintenance**

  The maintenance encompasses putting up a strategic plan in place to have an asset repaired as swiftly as possible when there is failure. Adequate spare parts need to be available at all times to handle break downs and make machine ready for production.

2.1.3.3 Spare parts

In the study, the retained compatible parts of equipment such as spares needs to be available to reduce on breakdown time. These must be in an inventory and used for replacements of failed machine parts. Spare parts are a significant piece of logistics in engineering maintenance of equipment to be used for production. There is need for effective supervision and management of spare to have acceptable results in LDH-DTH drilling. This should include stock specification of goods required by end users in production areas. The maintenance team needs to work hand in hand with inventory management to ensure purchasing and keeping of spare parts, ordering, shipping, handling, and related costs are closely monitored. The inventory processes and systems should involve detecting items requirements, targets, techniques of replenishment, actual report, inventory estimated status, and other functions linked to material tracking (Salunkhe, 2019) ;(Chileshe,2016).

2.1.3.4 Auxiliary services in mining

The auxiliary services include productivity and production issues such mine air, ventilation, and mine water. These matters are significantly influential in drilling VCR chambers and enhance productivity in LDH-DTH drilling.

2.3 Regional perspective on mine productivity

Mine productivity issues research was carried out by Zhuwara (2018) in South Africa. Zhuwara clearly stated that progression in information, energy and mechanisation technology promises to transform the mining industry into a resilient sector. Zhuwara further stated that focus on new technology in the mining industry centres on developing new business solutions that counter cost and risk. Particularly, the vast opportunities presented by such technology, it is imperative for developing countries, especially in Africa, to create enabling environments in which innovation can take root and participants of the mining sector can fully explore new strategies that enhance mining returns..

Niengo **(2016)** carried out a research on mine productivity in South Africa. Niengo stated that it requires mining companies to develop innovative extraction strategies to ensure the long-term competitiveness and viability of the sector. Mining companies need to move away from traditional mine planning practices and start to incorporate optimization techniques into their mine plans. This includes shifting from the deterministic way of mine planning to probabilistic mine planning techniques

Sizwa **(2018)** carried out a research on mine production, safety and teamwork in deep-level mining workplace. Sizwa stated that mining sector continues to play a significant role in the development of the southern Africa economy both direct and indirectly despite regional social economic challenges that have constrained its competitiveness and performance.

2.2 Regional search for relevant literature

In the research, regional literature review was carried out to appreciate mine productivity in selected southern Africa countries. Thus, the search was steered through both frequently used web research engines and academic interdisciplinary databases including Google Scholar, Encyclopedia Britannica and uniselinus online library. Mining industry is of strategically and tactical importance in Southern Africa region. Roughly half of the world's copper, vanadium, platinum, and diamonds originate in Southern African Development Community (SADC the region, along with 36% of gold and 20% of cobalt; and greatly contribute gross national product and employment (Robbins, 2019). The goal in talking about other mines is to clasp a broader understanding of mine productivity research at Nkana mines. Region prospective, the study looked at the two mines to appreciate their operations as regard to mining. These included:

2.2.1 TauTona mine

TauTona mine, situated on the West Wits line, south of Carletonville, in South Africa's Northwest province, about 70 km south-west of Johannesburg run by AngloGold Ashanti. The mine includes Savuka, is a mature deep-level underground gold mine with a limited life-of-mine. Mining is undertaken predominantly on the Carbon Leader reef (CLR) horizon, with TauTona mining towards the boundary of Sibanye Gold's Driefontein gold mine.Sinking operations began at TauTona in 1957 and stoping operations on the Ventersdorp Contact reef (VCR) horizon in 1961. The mine has a three-shaft system, comprising a main, subvertical and tertiary vertical shaft. Mining at this operation is undertaken at depths ranging from 2 900 m to 3 480 m. Savuka was included in the TauTona operations in 2013 and produced Gold and by-products of uranium. Geology/Mineralisation, The CLR is the principal economic horizon at TauTona and the VCR is the secondary economic horizon. The CLR is located near the base of the Johannesburg subgroup, which forms part of the Central Rand group. The Central Rand group sediments are unconformably overlain by the Klipriviersberg lavas and the VCR is developed at the interface between the Central Rand group sediment and the overlying lavas. The CLR and the VCR at TauTona are vertically separated by about 900 m of shales and quartzites. (5th August 2016 By: Sheila Barradas - Creamer Media Research Coordinator & Senior Deputy Editor)

2.2.2Minas Moatize Mine, Mozambique

Minas Moatize is a coal mine located near Tete Province, in Mozambique. The mine has proven reserves of 25.45 million tonnes (Mt) and probable reserves of 17.2 Mt. The estimated mineable reserves are 42.65 Mt and marketable reserves are 23.45 Mt. The mining area of Minas Moatize lies in the Chipanga Seam at the centre of the Moatize coking coal basin. Mining operations have been historically done with a pillar mining system using a scraper winch.

Production is targeted to ramp up to four-million tonnes a year run-of-mine production, producing about 2.2-million tonnes of saleable coking. The management has launched drill rigs mobilisation and a drilling programme aimed at identifying and improving drilling activities. The Mozambique government has developed a robust mining code, following a period of communication with mining companies to ensure that projects are developed for the benefit of all stakeholders (Minas Moatize Mine, 2019).

2.3 Local perspective on mine productivity

The study looked at various article done by other scholars, these included:

Chileshe (2016) did an article on mine production and productivity constraints. He stated that human resources skills was the big issue, where by contractor labour being seen as a cause of poor performance across a range of activities from exploration and to development and long hole drilling. Chileshe (2016**)** carried research on mine production and productivity constraints. He stated that production and maintenance managers and supervisors struggled with balancing planning, organization, leadership and control as well as prioritization of strategies and setting of goals in the mines.

Ndhlovu and Chileshe (2020) stated that mine productivity factors identification is critical in underground mines. The key in mine productivity factors can be grouped into technical, mining operations and maintenance.

Lwindi and Chileshe (2015) carried out a research on quality management tools in derivation of productivity constraints in Zambia open pit mine. Lwindi and Chileshe stated that increasing cost of production and low productivity have been the biggest challenge since the privatisation of the mines and further stated that management decided to outsource some operations in a bid to improve overall output, without success.

Sikamo (2016) carried out a research on copper mining. Sikamo stated that mines performed badly during the period of nationalisation, since they lost focus on their core business. Continuous re-investment in machinery and new technology is very important for increasing productivity. Investing in human capital is another area that is very important and new mine owners will do well not to neglect this aspect.

Munyindei (2016) did a study on social economic impacts of mine productivity. The researcher clearly stated that mine productivity has been the economic and social back bone of Zambia since the commissioning of the first large scale exploration on copper and cobalt deposits in the Copperbelt.

Sinkala (2018) carried out a research on titled "an overview of copper mining in Zambia's Copperbelt province". Sinkala stated that the copper production plays a vital role as one of the major driving forces in Zambia's economy.

2.3.2 Drilling and blasting designs

Locally, the study looked at mine productivity in drilling at Kansanshi mine in the northwestern of Zambia. According to the collected data at mine, before designing any drill pattern, the geology and geotechnical information of the area must well be understood. This is due to the fact that each pattern thus designed is largely dependent on these two aspects. The geology of the area is important in that the pattern to be designed must be known whether the material is highly weathered or fresh rock and as to whether it is ore or waste. If the material is highly weathered the main purpose is just to shake it hence the drill pattern should be well spaced out, while if the rock is fresh the main purpose is to break it into small fragments which will lead to the burden and spacing being reduced. On the other hand, when the material being blasted is ore the drill patterns must be designed such that fragmentation is effective after blasting for easy digging and crushing. The major drill and blast pattern currently in use at Kansanshi is staggered. The staggered pattern has been adopted due its good ultilisation of blast energy resulting in good fragmentation. The other advantage is that it requires fewer holes for the same area as the other types of drilling pattern, hence, making it cheaper. The burden is normally considered to be the distance between rows of holes in a direction that is perpendicular to the main free face, and the spacing is considered to be the distance between rows of holes in a direction that is parallel to the main free face. While the effective burden is burden that is measured from a hole to the closest interim face (Mining technology, 2020).

2.3.2.1Effects of drilling on fragmentation

For good quality constant fragmentation and productivity throughout a blast, there has to be a drill pattern that is accurately laid out and drilled (Mining technology, 2020).

Where holes are drilled too close together, the following problems occur:

- ❖ Rock fragmentation will tend to be over-fine. The product may be unsuitable for sales of resulting in lost income.
- ❖ Explosive in nearby unfired holes may become damaged and not detonate properly or it may detonate sympathetically. In either case poor fragmentation results can be expected, especially in the toe region of a blast.

Where holes are drilled too far apart, the following problems occur:

- ❖ The explosive energy will be below design levels and coarser fragmentation will result. This can slow downloading operations and decrease loading rates and increase costs dramatically.
- ❖ Harder rock is less tolerant of holes drilled too far apart, and fragmentation will be severely affected (Mining technology, 2020).

Overall rock fragmentation has great influence and impact on productivity. Where there is over size, it may not suit the requirement for the sales of the product and therefore result in lost revenue. There is also a loss in income because of the higher drill and blast cost associated with holes that are drilled closer together than the design calls for.

2.3.3 VCR Stope Preparation at Nkana, Mindola Mine (MSV)

The Vertical Crater Retreat (VCR) mining layout comprises of sublevels spaced at 50m vertical intervals. A mining sequence of development, production drilling and ore extraction operations are conducted at each of the sublevels. All the development ends are accessed from the main decline. After mining the access from the ramp, the footwall drive is collared and mined along strike of the ore body. At this point the footwall drive is only advanced one side for 15.0m. The T-junction is then adequately supported and after that both faces are advanced simultaneously in opposite directions. For safety reasons, no mining is allowed unsupported beyond 5.0m. The position of the footwall drive will be not less than 45.0m from the AFW Contact. This position is outside the stress zone related to stoping. When the footwall drive advances beyond the breakaway point for the crosscut by 15.0m, the crosscut is collared and mined as the second end. The T-junction is adequately supported as per rock mechanics recommendations before advancing the crosscut further.

The two-stope access cross cuts are opened at seven (7) meters each away from either side of the stope pillar line (Figure 2).

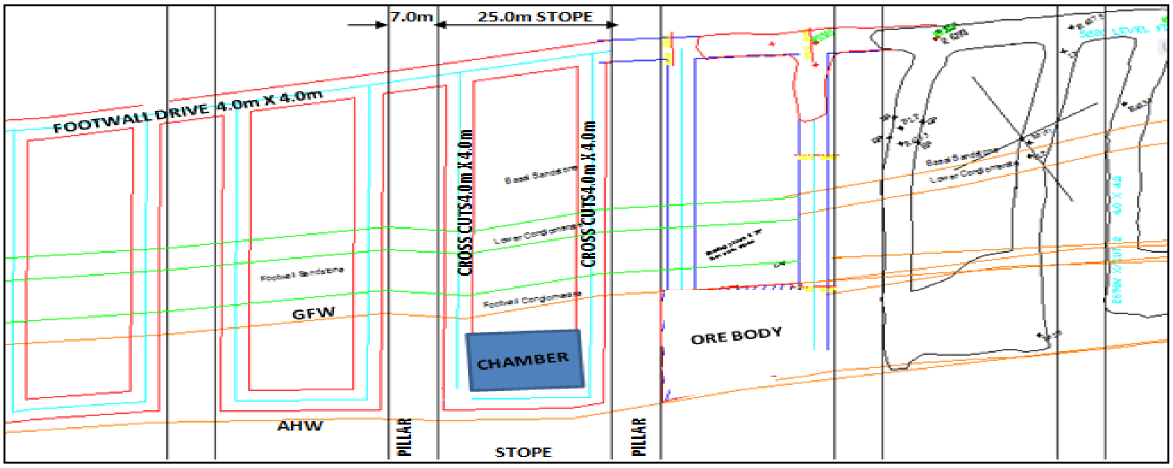

Figure 3: Typical Plan of the VCR Developments layout

Stope size is 25.0m and the rib pillars are 7.0m in width. Access cross cuts to the ore body are mined up to two (2) meters short of the AHW to avoid breaking into the weak Hanging Wall Argillite. At the end of the stope access cross cuts, a drive is mined parallel to and two meters below the hanging wall contact. When the drive is supported with rock studs, the hanging wall is further re-enforced with cable bolt support (Figure 32) in accordance with geotechnical recommendations. At this point, VCR chamber slyping is advanced from the hanging wall towards the footwall contact. This mining approach is intended to keep employees always working in the supported span. The complete chamber is fully supported with wire mesh, rock studs, and cable bolts. In an ideal situation on any drilling level the whole stope area should be filled out or alternatively left with very narrow pillars in order that all the drill holes may be drilled parallel to each other. The poor ground condition at Mindola Mine does not allow this ideal situation to be adopted and instead the footwall side is only slyped close to Schistose ore. Refer to figure 3 showing typical VCR Ore Body and developments Section.

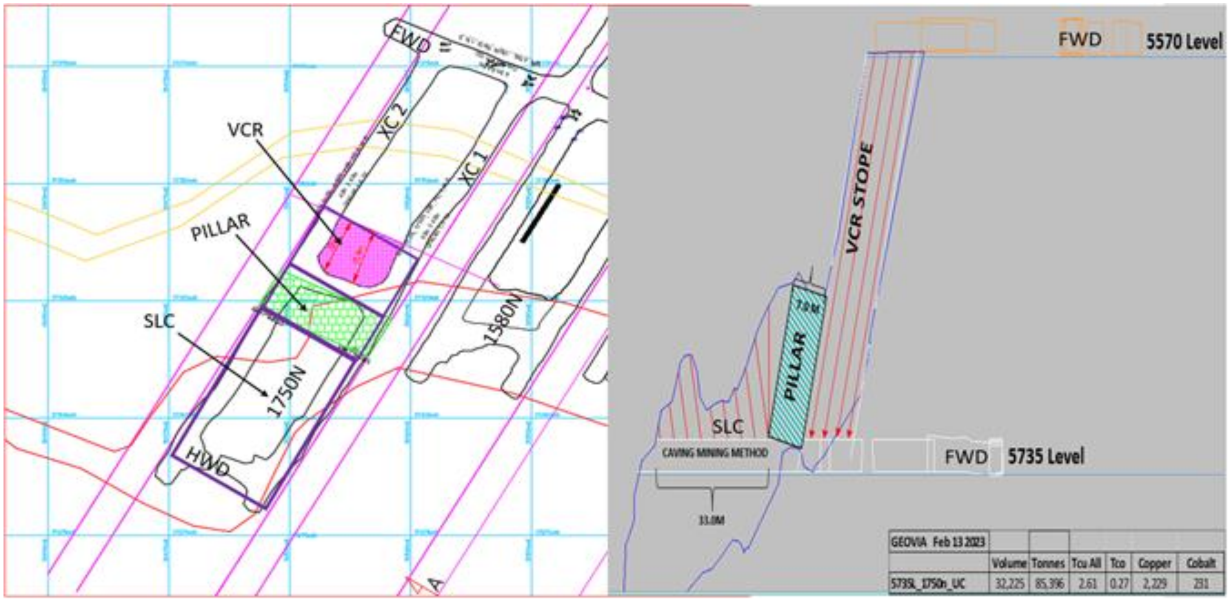

Figure 4: Typical VCR Ore Body and Developments Section

The footwall drive for the stope is 32.0m in length. The footwall drive layout includes ventilation and tip cross cuts of size 4.0m x 4.0m spaced at 100.0m horizontal intervals. At the end of these crosscuts a raise bore chamber for drilling the raise is excavated accordingly. A raise borer machine is used to first drill a pilot hole to the next level below and then ream the hole upwards to the required size.

The main haulage level is established four levels below the current production block. All the other development are the same as that in the sublevels. Ventilation to these levels is facilitated through the ventilation raises at 100m intervals. Refer to table 3 a summary of Nkana Mindola end specifications. Currently the development and support drilling at MSV and SOB Mine is carried electrohydraulic rigs (Jumbo). The contractor electrohydraulic rigs of fleet comprise of a variety of face rigs from major equipment suppliers including Atlas Copco Ltd (Boomer H281, S1D), Sandvik Mining and Construction Ltd (Axera D05). Table 3 is illustrating a summary of Nkana, Mindola development end specifications.

Table 3: Nkana, Mindola development end specifications.

END DESCRIPTION	END SIZE (MTRS)	GRADIENT
DECLINE OR INCLINE	5.0 X 5.0	+/-1:10
ACCESS FROM DECLINE	5.0 X 5.0	1:20
FOOTWALL DRIVE	4.0 X 4.0	1:100
ACCESS CROSS CUT TO THE OREBODY	4.0 X 4.0	1:50
VCR CHAMBER SLYPING	15.0 X 12.0 X 4.0	FLAT
TIP/VENT CROSS CUTS	4.0X 4.0	1:20
HAULAGES	4.0X 4.0	1:200
SHAFT CROSS CUT	8.0X 4.0	1:200

2.3.3.1VCR Layout

When the VCR chamber is completed with all the required support in place, the excavations, cross cuts, drives and the slyped chambers are picked and plotted by the Survey section. The information is passed on to the planning office were a drilling lay out is generated in the best way the Cubex drilling machine will be positioned to drill the holes. At this stage all the geological and geotechnical information is complete and ready for use. When the layout is finally approved, the information is given to the surveyor who transfers the information from the layouts and paints in the roof of the drilling VCR chamber underground. The painting will carry lines for the ring bearing and crosses for the rigging positions for the holes. Figure 4 illustrates MSV VCR drilling design pattern, figure 5 shows SOB VCR drilling design pattern and figure 6 illustrates Nkana south ore body depicting folded orebody of synclines and anticlines and limbs.

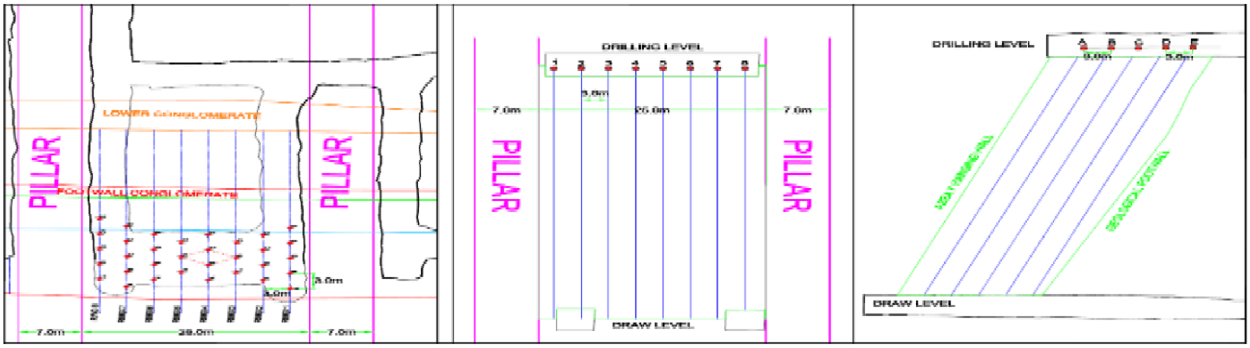

Figure 5: Typical VCR Ore Body and Developments Section

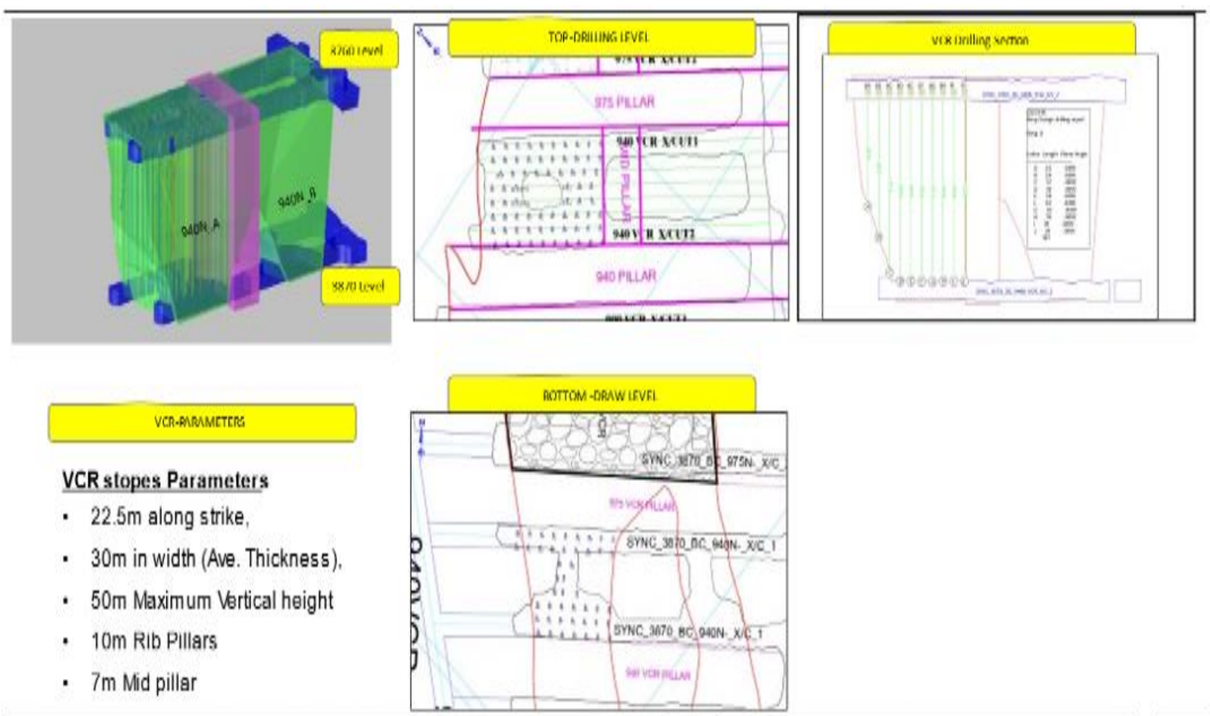

Figure 6 : SOB VCR drilling design pattern

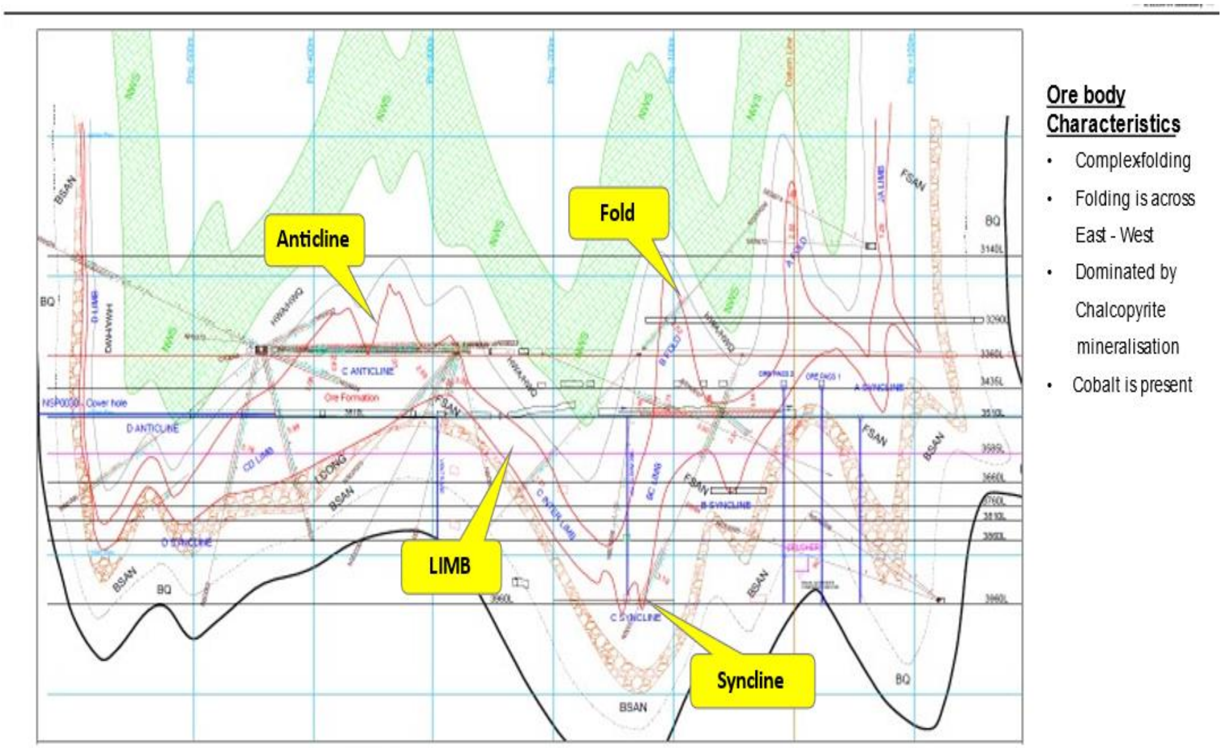

Figure 7: Nkana south ore body showing folded orebody of synclines and anticlines and limbs.

2.3.4 Folded ore body

In the research, it was observed that previous stopes, like 3470N and 3250N at 5220level had a folded shallow- dipping wide ore body formation in which a cut and fill mining method was practiced during the extraction. There was increased development requirements and ore losses during extraction resulting into increased lead-time between stope development and commencement of stope exploitation. This was costly considering the small tonnage that was recovered from the folded shallow dipping wide orebody. Recoveries ranged from 60-65% which is far below the standard extraction factor of 80% tenable of VCR mining method. In some active production areas, the ore orebody is folded, shallow and very thick with a large vertical extent. This requires critical attention in extraction to achieve maximum ore recovery at low cost. See figure 7 depicting the general concept shape of 3D folded orebody and figure 8 illustrates a plan view of folded ore body.

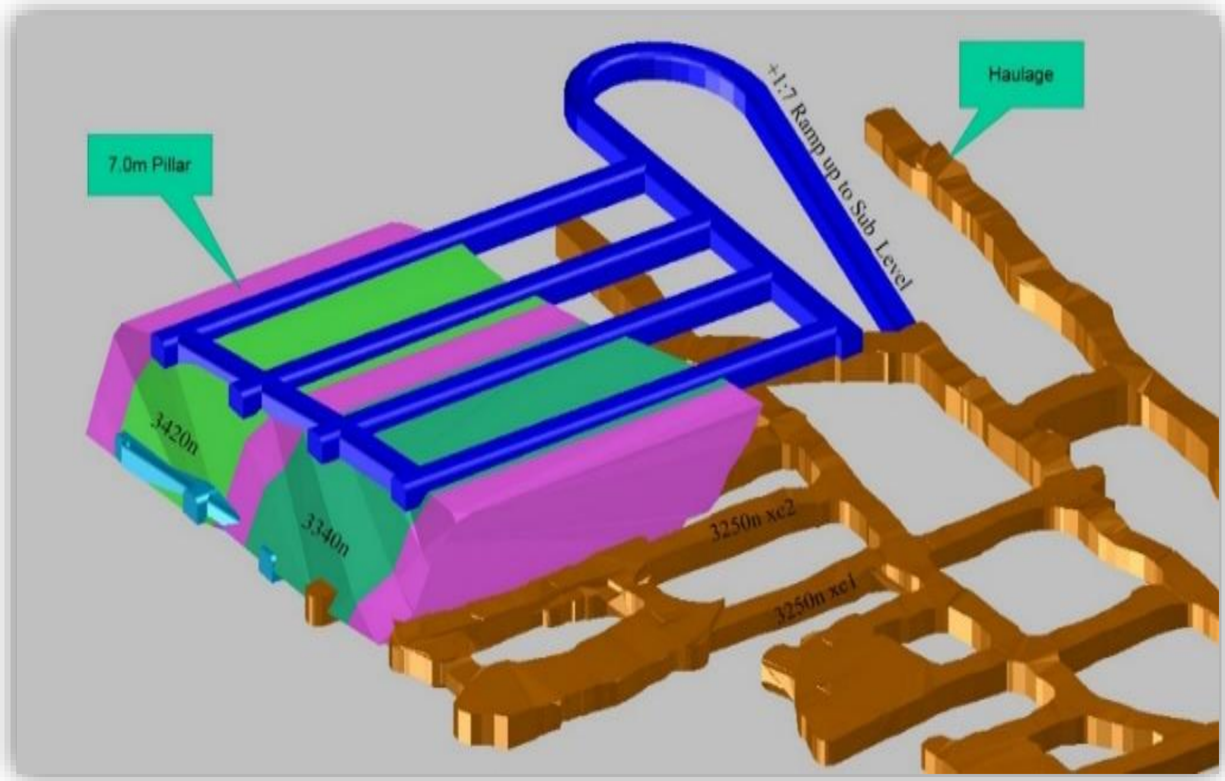

Figure 8: 3D view of the general concept

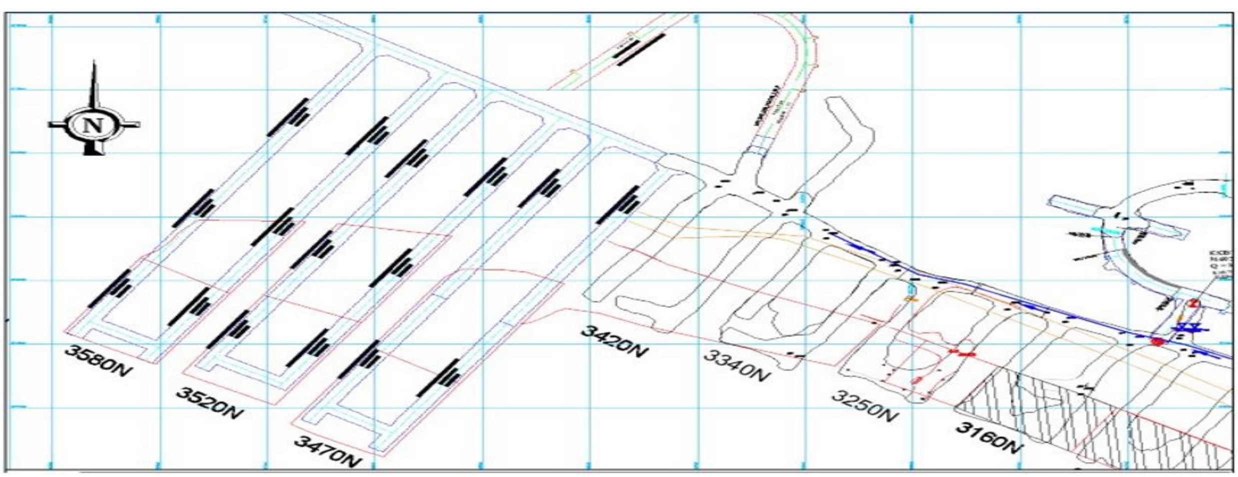

Figure 9: Plan view of folded ore body

2.3.4. 1 Layout and mining

The folded ore body in some production levels such 5220 Level 3340N-3420N and 5735 level position 1750N extracted in three stages. All the stages will involve extraction of the orebody via Sub level Caving up dip (mechanized, with waste rock as backfill using development ground and remote loaders).

2.3.4.2 Development

It was observed in most areas that washable white-water paint was used for marking the ends. Grade and direction lined were not found to be common practice. It was observed that as the drill rig commences drilling, the pattern was marked off the face leaving the drill rig operator to approximate the burdens and spacing for the washed parts of the face. Red oxide was also noted to have been used by come contractors for face marking which was holding fine for the drilling duration. The end marking was not consistent with the drilling and blast design of a 9 holes cylinder cut and 3 reamed holes. Drilling of unmarked ends is a substandard that results in poor spacing and burden on the face as the operator positions the holes by guesstimating. The downstream impacts are; Poor blast advance, increased mining time of VCR chambers and blasting costs, poor fragmentation, and cost of remediation. The mining sequence of VCR development is as below:

- ❖ Sublevel production drives and the two draw point crosscuts per level will are mined with dimensions of 4.0m width x 4.0m height to ensure good draw coverage.
- ❖ The cross cuts are mined from foot wall drives to hanging wall position and spaced at 17m from each other and 7.0m thickness adjacent to the rib pillar. The rib pillar is the space left between the VCR stopes and aids in stabilizing environment and prevents ore dilution from the previous blasted stope.

Figure 9 illustrates development end in preparation of VCR chambers at MSV.

Figure 10: Development end

The correct face preparation in some development end was not thoroughly executed, site-specific blast designs are not given to the operatives, and not placed at all refuge chambers and waiting places. The correct type of underground paint is not used for face preparations in some areas hence having marked faces being washed off at time of drilling. In the research it was observed that in some instances the drilling pattern was not adhered, for instance a 46-hole design was in use for 4.0m x 4.0m ends with a variant 3 reamed diagonal holes reamed cut design as opposed to the drill and blast pattern recommendations of a 9 holes cylinder cut with 3 reamed holes. Further it was discovered that extreme spacings and burdens of 1.2 meters and 0.4 meters were noticed on two faces as opposed to the standard uniform 0.7m to 0.8m spacings and burdens. The drilled holes were not in straight lines or parallel as per pattern signifying poor face preparation practices. Frequent blocked and missing holes were observed. The impact of poor drilling from missed and/or blocked holes results in loss of designed energy release resulting in poor blast results.

Poor spacing and burden on the face results in many downstream impacts as; poor advanced, poor post blast profile, increased mining and blasting costs, poor fragmentation, and cost of remediation. Figure 10 illustrates mined out crosscut access to VCR chambers at MSV

Figure 11: Depicting crosscut access to VCR chamber.

2.3.4.2.1Ground Support in VCR chamber access

In the study it was observed that the accesses to VCR chambers are supported with the following support regime

- **2.4m Split Sets (Black Split sets)**

  Split Sets per ring= 9

  Bolt spacing within ring = 1.0m

  Ring spacing = 1.0m

  Maximum allowable unsupported span (during drilling and charging) = 0.5m from the face.

- **25Ton x 6.0m long Cable bolts** (swivel barrel & wedge or 500mm thread end.

  Cable bolts per ring = 5

  Bolt collar spacing within ring = 1.5m

  Ring spacing = 2.0m

Split sets and cable bolts are installed before drilling and blasting of VCR stopes. Figure 11 illustrates Side view of support in the access crosscuts and Figure 13: Section view A-A" of support in the crosscut.

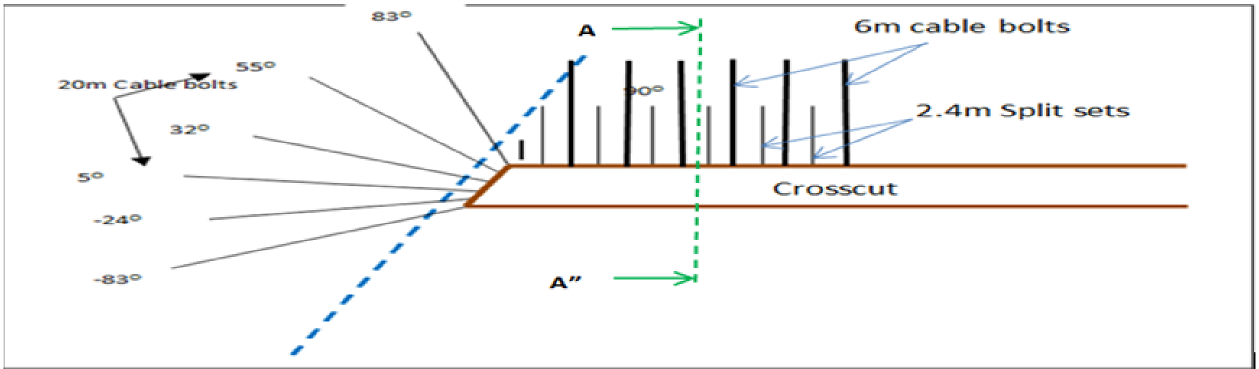

Figure 12: Side view of support in the access crosscut

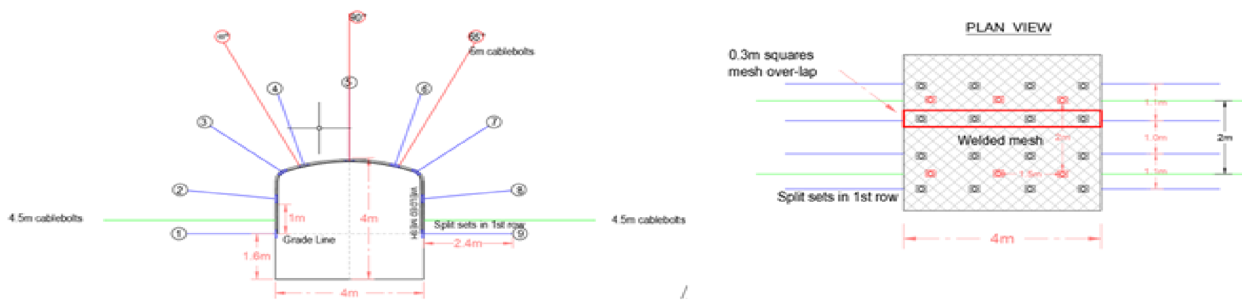

Figure 13: Section view A-A" of support in the crosscut

2.3.4.3 VCR backfilling

In the research it was observed that VCR stope backfill typically contains waste materials mined from development ends and vcr chamber preparations. Backfilling is one of the requirements in the critical controls of stoping. When the VCR stope is blasted a void is created and if not backfilled it can lead to instability problems for further underground mining activities and underground structures. Waste rocks are used to fill the created voids, provide safe working environment for advancement of mining activities. The advantages of backfilling in the VCR stopes are; It helps to support the mine structurally, making it safer, it makes it possible to extract minerals safely, it reduces the risk of spontaneous rock bursts, it improves ventilation in the mine, it prevents roof falls when blasting adjacent VCR stopes and it prevents mine pillars from collapsing after extracting minerals. Furthermore, it reduces dilution as the back-fill material in the previous vcr stope stabilize ground condition and minimizes hanging wall sloughing.

2.3.5 Long hole drilling -LHD-DTH

Production drilling is carried out from the top level in the VCR chamber using the DTH Machine (Cubex). The crawler multi-function drilling rigs are being used to drill the holes at MSV and SOB. The characteristics of the machine were that they are using hydraulics to drill down the hole at a drilling diameter of 165mm and depth of 45m to 54m between the drilling and receiving chambers. The drills are energy source and prime mover which converts energy from its original form (fluid) into mechanical energy to actuate the system. The rod transmits the energy from the drill to the bit. The bit then attacks the rock mechanically to achieve penetration. Compressed air is the flushing medium in the DTH system. For downward drilling, gravity tends to pull the cuttings towards the bottom of the hole. This is why it is necessary to provide annular velocity greater than the slip velocity, to be able to remove cuttings.

The drilling chambers in which these machines are being operated tend to be quite hot as drilling progresses; this is due to the drilled holes that act as an access for hot air from the extraction level below that is not ventilated. Therefore, it is necessary to cover the holes after drilling.

The greatest fear is the premature failure of the roof in the drilling chamber which can be caused by poor drilling of support or the size of the excavation. This could cause damage to the machine and fatality to the men working in the area. Proper handling of drill rods should be emphasized as this could potentially lead to injury as the men struggle to lift the rods as drilling progresses. Some of the hazards associated with working with the DTH machine was the compressed air pipe, which if not handled with care during oil checks could cause harm.

2.3.5.1 Causes of drilling deviations in vcr chambers

The research established the most common causes of drilling deviations in VCR chambers, and these are as listed below: -

- **Geological Formations**

  This problem is most prevalent when the blast hole crosses other rock strata which are at very shallow angle to the direction of the blast holes, with different structural and mechanical properties. Knowledge of the rock formations could be of help when the operator is experienced and applies himself.

- **Guide Rails/Mast Deviations**

  Wear and tear of the guide rails is the biggest cause of deviation. Unfortunately, though, this could result into deviations exceeding 5° which can result in more than 5m deviation from the holing point as a result of loss of intended direction at collaring. (This deviation exceeds burden and/or spacing)

- **State of The Drill String.**

  If the drill string does not provide the required coupling between drill rods, chances of loss of direction are increased and it is therefore important to have the newest drill rods next to the hammer while the older drill rods can be employed towards the end of the blast hole drill cycle. A program of rotating the drill rods needs to be employed to ensure that the older and worn drill rods are only used after the hole has advanced greatly. Use of twine in place of "anti-seize paste" could also have some negative effects on the drilling string.

❖ **Rigging of The Drill Mast.**

Drilling excavations are sometimes undermined or overmined, resulting in the stabilizing stingers requiring extensions. The operators for some reasons do not use the stingers. Use of protractor does not seem to be well appreciated by operators and most often the mast is found out of angle in all three directions.

❖ **State of Equipment**

The control panel is often defective making controls difficult. This makes the operators so challenging to apply correct rig parameters such as bit thrust pressure.

2.3.6 Stope charging and blasting.

In the study, time was spent in the field to grasp the concept of vertical crater retreat charging practice at Nkana, MSV and SOB, the blasting was seen as a combination of cratering and inverse benching. The blasting progression involves application of break raise at the centre of the stope or at an appropriate position where the concentration of blast holes is suitable for increased blasting. The VCR blast has the following characteristics. Figure 13 illustrated positioning of the plug in drilled holes and figure 14 depicts VCR charge column.

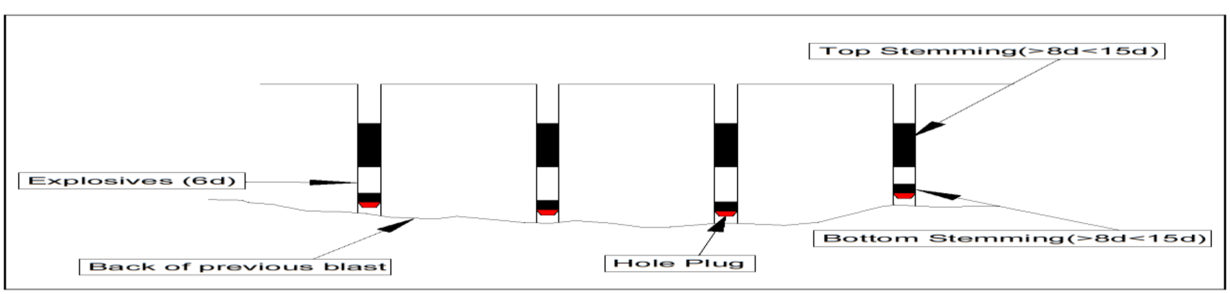

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Figure 13 illustrated positioning of the plug in drilled holes

Figure 14: Plug Positioning in drilled holes

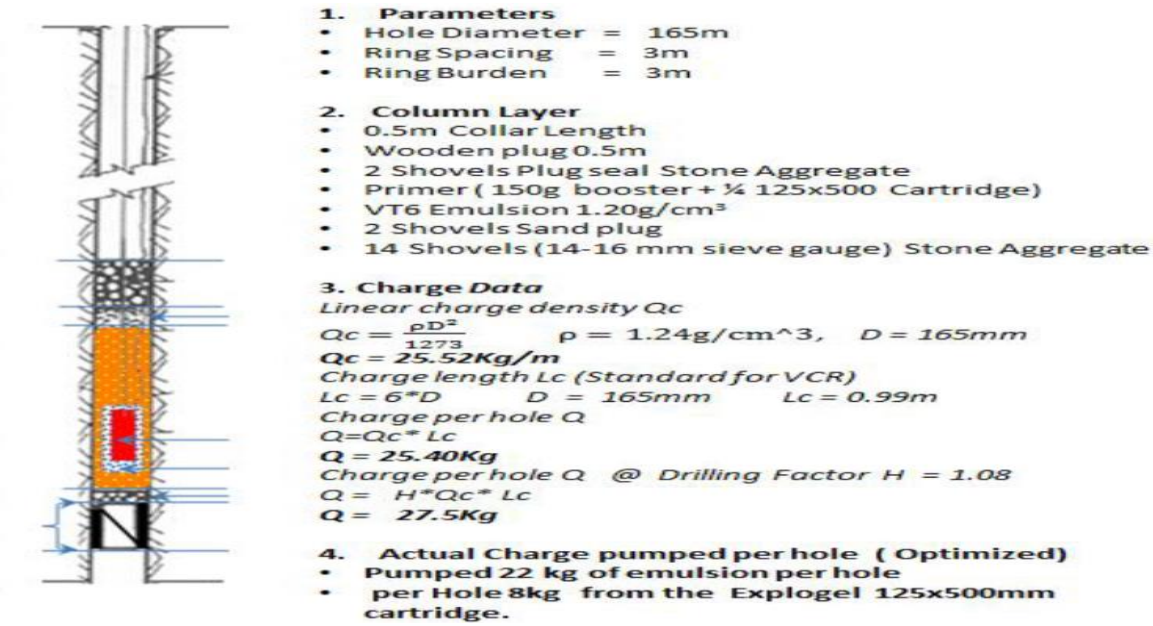


Figure 15: VCR charge column

Charging practiced in VCR stopes at both Mindola and SOB involve the following activities: -

- **Positioning the plug**

  The plug is lowered down the drilled hole, taking into consideration that the plug is well above area of back damage or previous crater, to prevent possible plug migration, which could result from back failure. The mine currently assumes back damage to extend up to about 0.8m above the back of the previous blast.

- **Bottom stemming**

  The mine employs a 4-blast hole diameter stemming length with drill chippings. This may be inadequate resulting in the plug and stemming acting like a missile, with very little resistance. Table 4 shows steaming guide for VCR charging and table 5 illustrates a summary Of VCR Charging Deviations.

Table 4: Stemming guide for VCR.

Stemming guide for VCR charging			
No. Diameter (cm)	Length (m)	Vol (dm)3	Shovels
1.0	0.17	3.7	1
2.1	0.34	7.3	2
3.1	0.51	11.0	3
4.1	0.68	14.6	4
5.2	0.85	18.3	5
6.2	1.03	21.9	6
7.3	1.20	25.6	7

- **Explosive charge**

The study looked at the procedure employed for the charging process; these include: -

- Safety inspection of VCR chamber such as stability in terms of support status.
- Barring down and washing down of the VCR chamber to clear fumes and dust
- Exposing of blocked blast holes.
- Measuring to establishing depth and openness of the blast holes.
- Establishing the relationship between all open blast holes
- Determining which blastholes can be blasted.
- Charging: Under this step the following procedure is applied

  1. Lowering and securing the bottom plug 2. Filling with 4 shovelful of drill chippings 3. Placing a bottom (cushion) cartridge (110X560 - 6.25Kg) 4. Placing the Primer cartridge (110X560 - 6.5Kg + 175g Booster) 5. Emulsion Charging (25Kg) and 6. Top stemming (12 - 14 Shovels of 10 - 15mm Stone aggregate)

Table 5: Summary of VCR Charging Deviations

Attribute	Theoretical Requirement	Current Practice	Remarks
Bottom Plug	Establish suitable Position outside back damage	0.8m above blast back	The Plug can be placed 0.8-1.0m above blast back and then the amount of stemming can be varied according to the required depth recovery to allow explosive charge to attain almost same elevation centre of gravity. It will however be easier to establish same plugging elevation and thereby giving equal stemming resistance at detonation.
Bottom Stemming	8 blast hole diameters to 15 blast hole diameters	4 Blast hole diameters	The total effect of the bottom plug could be smaller than required causing the plug to behave like a missile at detonation. Mindful of danger of upward thrust.
Explosive Charge	6 blast hole diameters	9 blast hole diameters	The charge could no longer be spherical; it probably is oval which could be considered cylindrical. The additional charge could also assist (compensate) to improve blasting effect considering the short bottom stemming length.
Top Stemming	8 blast hole diameters to 15 blast hole diameters	14 blast hole diameters	Mindful of stemming material freezing. Stemming backflush has been noted, but this could be a result of under stemming.

2.3.7 Literature review summary

In mining, stoping is predominantly about two areas of interest; drilling and blasting and in many instances the technical, maintenance and mining operation factors are dominant parameters in mine productivity in drilling and blasting of VCR stopes. These factors thus become critical in making strategic and tactical decisions at both supervisory and management levels. Generally, given the reservations that exist within the mining industry, there always prevails a likelihood that mining operations may not perform as projected, and in the worst case can result in loss of mine productivity in stoping and ore production as whole if the three fundamentals are not well administered and managed. Generally, all the three elements of the mine require a substantial fiscal investment in personnel training, latest mining equipment and technology by the mine owners and other stake holders to keep the operation thriving. Mine productivity in drilling and blasting of VCR stopes in underground mine has three parts:

- **Technical factors:** Core management and supervision as well as the design of development and vertical crater retreat chambers; and issuance of drilling plans and blasting patterns. Its key in inputting of technical services, such as geology, ventilation, survey and geotechnical in all VCR chambers.
- **Maintenance factors:** The management and supervision as well as management of the Cubex machinery in order to effectively attain the overall productivity in drilling, blasting and production goals.
- **Mining operations factors:** Implementation, supervision, and management of drilling and blasting operations in VCR stopes and auxiliary services.

In the research, reviewing of the three elements in mine productivity in drilling and blasting of VCR stopes is determination at improving the supervision and management unit processes and consequences in terms of both mine productivity in drilling and blasting; and entire ore production.

2.3.7.1 Gaps and emerging themes

The gap is relatively huge between theory and reality. The emerging themes and gaps in the study were identified:

Emerging themes

a) Technical elements

Technical factors in mine productivity at Nkana both at MSV and SOB are key phases in underground stoping. Strategically, the technical personnel make layouts and plans of the mining firms and give directions to operative crews on excavation of the VCR chambers. Technical group disciplines play vital role to mining operations and have great influence on mining activities. For instance, planning section in the mining industry gives direction as to how the drilling and blasting activities will be carried out and geology section helps in prospecting ore body, estimating and establishing defined mine mineral resources.

b) Maintenance factors in mine productivity

Maintenance factors in mine productivity in drilling and blasting of VCR stopes are an important aspect in ore production at Mindola Sub Vertical (MSV) mine and South Ore Body (SOB) shaft. The system is incapable to sustain a large quantity of targeted long hole drilling- down to hole -(LHD-DTH) meters to be drilled whereas sustaining high Cubex machine availability and acceptable performance. Low availability, unreliability; and frequent break downs on Cubex machinery trigger substantial long hole drilling- down to hole -(lhd-dth) meters losses as compared to the other two elements in mine productivity in drilling and blasting of VCR stopes.

c) Operation factors in mine productivity

Strategically and tactically, operational unit processes control economic viability of mining firms at global, regional and local levels. The operation unit processes determine economic viability of the whole mine and operations turn inputs to outputs in mine productivity in drilling and blasting of VCR stopes. Operations tactically are vital and are the forefront of productivity and production.

Gaps

The gap is relatively huge between theory and reality or planned vs actual. The literature may as much place more emphasis on mine productivity in drilling and blasting of VCR stopes but tactically implementation of all planned mine tasks lies on the labour force doing actual works on the ground.

The literature identifies lack of optimisation of supervision of operations and maintenance in the mining firms and delays in implementation of management plans of mine productivity in drilling and blasting of VCR stopes of both men and machinery in the mines, however it does not pinpoint on how to improve on the work force moral toward work. Many mines have advanced in technology innovations, enhancement but relaxed on the extensive training for use of latest long hole drilling- down to hole -(LHD-DTH) mining equipment in stoping VCR chambers. Efficient implementations of strategic and tactical plans are not highlighted by all by mining firms. Thus, there is need of seriously usage enforcement of new technology innovations in mine productivity in drilling and blasting for good output delivery. Refer to figure 6 (literature review map).

2.3.8 Literature review map

The mining industry is big and requires wide understanding knowledge in both drilling and blasting. But in some ways, you could say that the mining is more like an onion than a ball because it has three levels. Local mining activities come together to form regional levels, which collectively form global level. The smallest activities at local and regional level are interconnected with the global ones. Figure 15 shows the study literature map, which attempts to reflect this.

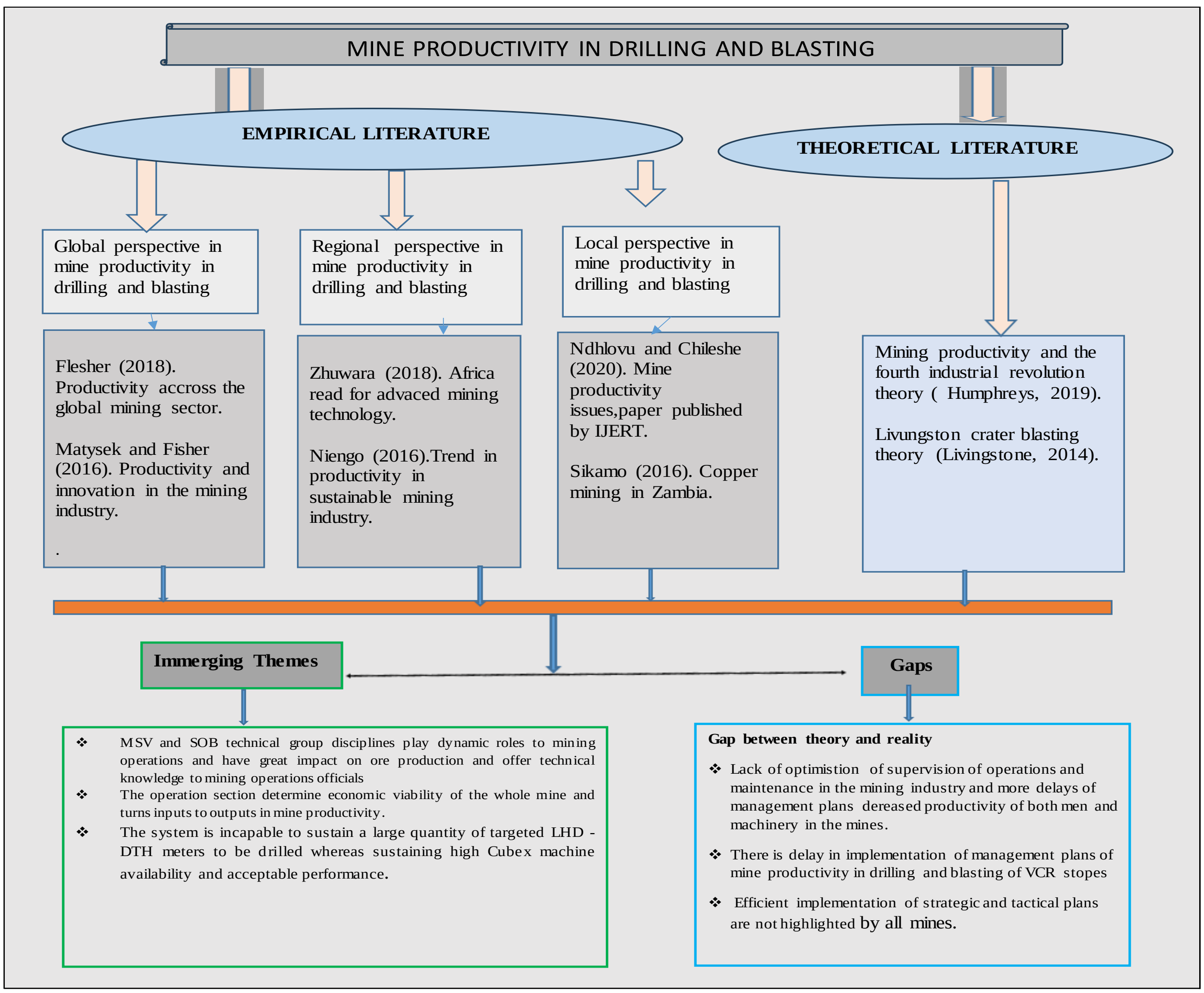


Figure 16: Literature review map

Figure 15 demonstrates the literature map highlighting empirical literature and theoretical literature. The gaps in the box are align with research objectives in the sense that lack of optimisation of supervision of operations and maintenance in the mining industry and more delays in implementation of management plans of mine productivity in drilling and blasting of VCR stopes declined productivity of both men and machinery in the mines. Limited technology innovations, enhancement; and extensive training is required for use of drilling lay outs and latest mining equipment DTH -Cubex in stoping VCR chambers are cardinal as the mines will have skilled labour force and hence, enhancing mine productivity in stoping.

CHAPTER 3 METHODOLOGY

This chapter outlines how the data was collected for the study. Primarily, the research reviewed mine productivity in drilling and blasting of VCR stopes and the data was set as benchmark for the research. It further looked at the review and evaluation of issues pertaining to stoping at Nkana site, both at MSV and SOB. Various techniques were used to gather information for the study.

3.1 Research Design

The research was carried out using quantitative and qualitative methods to attain the research objectives defined in the first chapter. A qualitative and quantitative approach were used in the research to grasp clear understanding of the study, and gain objectives and all gaps associated with the study.

3.2 Research population target

The study focused on the work force in drilling and blasting processes involved in the mine productivity elements at MSV and SOB shaft.

3.3 Sampling and sample size

In the study, the sample was carried out on 80 employees; this was done to have a wider collection of ideas from respondents operating at strategically and tactical levels. The participants were drawn from MCM and different contracting companies doing development and mine services at MSV and SOB shaft. The sampling was done evidently to identify mine issues causing delays in drilling and blasting of VCR stopes.

3.4 Information Sources

Data collection methods or techniques formed an important part of this research. In any research, use of more than one data collection instrument strengthens and gives credibility to the study. The use of more than one data collection instrument portrays a better picture of the case under study. In this regard, the required data from two different sources were collected. (Patton, 2002). The study made use of primary and secondary data sources in order to gather relevant information for the study. Journal articles with up-to-date information offered relatively concise, up-to-date information for research. Various textbooks were useful in literature review as they are intended for teaching and offered a good starting point to the project study because of more detailed explanations and illustration. Meeting proceedings such as pre-planning and morning meetings in the main board room were useful in providing the latest information on VCR drilling and blasting and other information pertaining to ore generation and mine production. The research information sources included detailed literature review and field data collection from MSV and SOB. The data was collected from mining unit processes such as development drilling, VCR drilling, charging, blasting, and Cubex-mobile section, uniselinus online library, Britannica encyclopaedia, magazines, mining journals, and from mining textbooks. Structured interviews were also used to obtain specialised data from various sections of the mine.

3.5 Research questionnaire

The research questionnaire was established to gather detailed data and offer solutions to the main objective of the study, for reference see Table A1 in the appendices. This was done by having field visits in areas where stoping is active and asking miners questions regarding to mine productivity in drilling and blasting. The enquiries were focused on the practical events underground and classified in five categorizes (1 to 5) and rating evaluated accordingly to the miners answers. Different of scaling and rating research questionnaires vary from significant to insignificant. See a sample of questionnaire design (Appendix 1) in the appendices.

3.6 Structure of methodology

Methodology was divided into three phases, namely phase one was data collection, phase two which was data analysis; and phase three which was data interpretation. Refer to Figure 17.

3.6.1 Methodology of data collection (phase one)

This included both primary and secondary data. The data was further classified into qualitative and quantitative through tables and graphs. The research reviewed mine productivity issues at MSV and SOB. The research also looked at theories relating to the study and these included Theory of Livingston crater retreat blasting, Theory of mining productivity and the fourth industrial revolution, Theory of mining industry and sustainable development and Theory of Productivity at the mine face. Data collected was achieved by visiting mining operation sites, coupled with verbal discussions with technical, mining operation and maintenance personnel in the field as well as a questionnaire and supplementary data also came from: Internet, textbooks, journals, underground mining magazines and stakeholders. The focus of data collection was on technical, operations and maintenance factors.

3.6.2 Methodology of data analysis (phase two)

In phase two, the collected data in the study was scrutinised. The analysis was mainly done through statistics, observation analysis, discourse analysis and content analysis.

3.6.3 Methodology of data interpretation (phase three)

In phase three, the analysed data collected in the research was interpreted. This also included additional consideration of corporate cost analysis for mining folded orebody. The data collected was classified into three mining factors: (a)Technical factors (b); Mining operations; and(c) Maintenance factors.

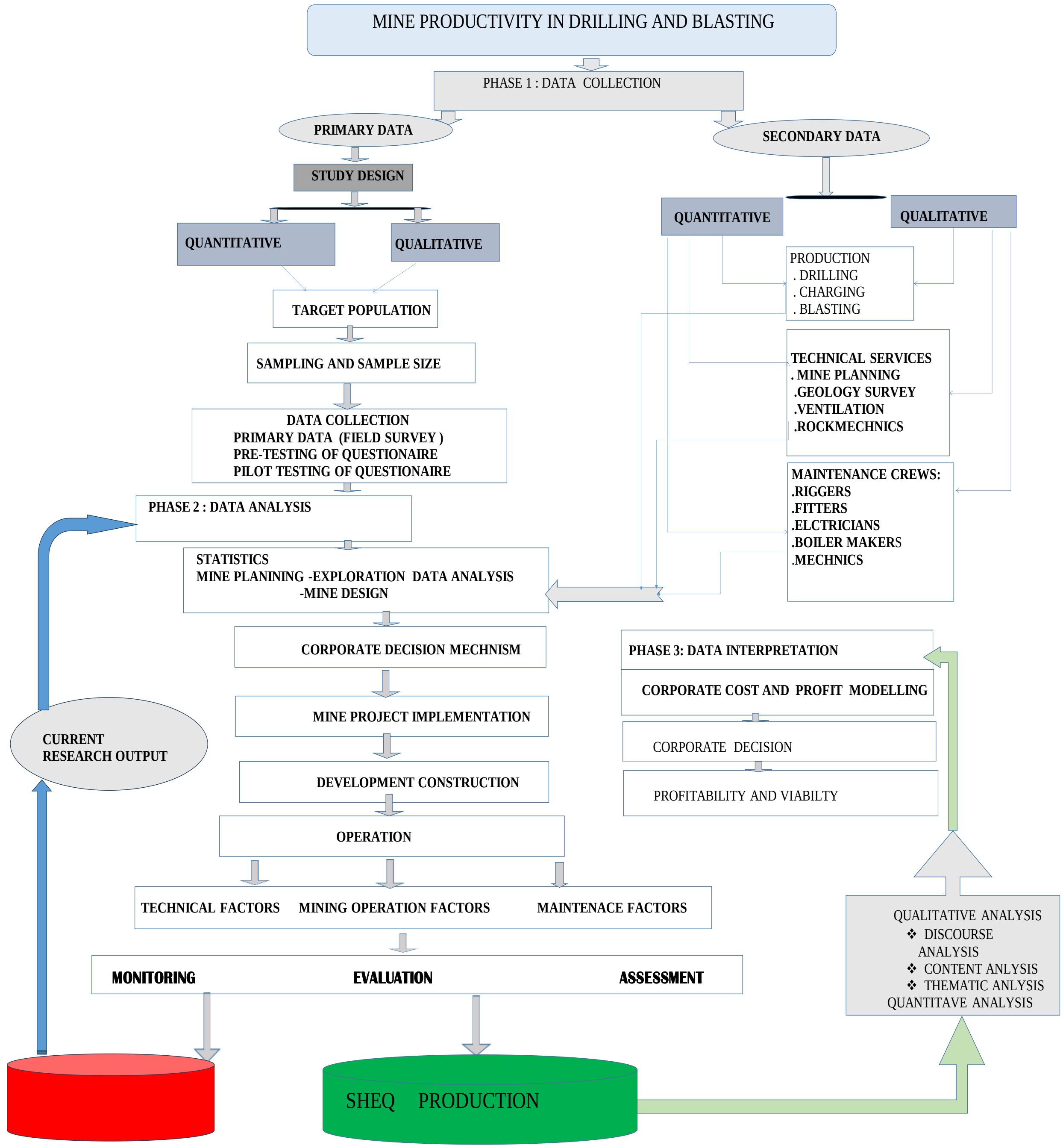


Figure 18: Methodology chart for productivity in drilling and blasting of VCR stope analysis.

CHAPTER 4

PRESENTATION, ANALYSIS AND INTERPRETATION OF DATA

The data presentation, data analysis, and interpretations, as well as the evaluation of this dissertation, are covered in this chapter. The data was collected, reviewed, processed, and interpreted to solve the problems indicated in Chapter 1 of this dissertation. Charts, graphs, and tables were utilized to illustrate the outcomes of the observations, survey, and modeling testing results.

4.1 Data Presentation

In the study, interviews both directed and by questionnaire were conducted in the field with personnel from technical, maintenance and mining operation as regards to productivity in drilling and blasting of VCR stopes. These were officials that frequently work underground in stoping areas like the person in charge (PICs), section bosses, mine captains, foremen and section engineers. The interviews were aimed at obtaining preliminary data that gave insight to the challenges of drilling and blasting of VCR stopes being experienced at Mindola Sub Vertical shaft-MSV and South Ore Body-SOB. Subsections below are the results of these interviews.

4.1.1 VCR stope development

The stope development for VCR mining consists of two primary levels, the top drilling level and the draw point level. Where the stope drilling heights exceed 50 meters an intermediate level is also established in between the drilling and the draw level. Stope size is typically 25 m in strike with a 7 m thick rib pillar and a 50 m vertical stope height. The width averages 16.0 m. The Rib Pillars are not mined but left in-situ without mining. To manage and control stress build up, the stoping sequence is a systematic retreat from the centre-out and then upwards. The lowest panel mined out progresses out to almost the distance of the stope height and creates a 45 degrees angle between the top and bottom lift panels in a pyramid echelon. Strike length of the stopes are 25m along, 50m high and ranges in thickness depending on the orebody thickness from approximately 7m to 15m. Between VCR stopes are 7m thick rib pillars, the purpose of the pillars is to enable sequential stoping, i.e. containing the waste material used to backfill the previously mined stope whilst the following stope is extracted.

4.1.2 VCR stope drilling

A good time was spent in the VCR chambers to observe production DTH machines (Cubex machines), the drilling of holes, the drilling pattern provided, operator target per shift, associated mining risks when the machine is in usage as well as, observing the hazards and conditions of the areas the machines being operated.

Drilling takes place between 4716 feet level and 5956feet level. The drilling of VCR chambers is scheduled as shown in table A2 in the appendices: Cubex drilling is tracked on daily basis.

Three factors of high importance when drilling VCR stopes DTH blast holes include:

(a) Hole drill length;

(b) Drilling angle; and

(c) Direction of drilling holes.

The drilling of all marked holes in the VCR chamber in the correct direction is significant as this will aid the cratering of the ore and ensures effective blast advance; it will also prevent damage to the hanging wall and footwall. VCR drilling is tracked through schedules such as in Table A1 (LDH performance plan) in the appendices. In the study, the following were just some of the factors leading to poor advance prior to drilling.

4.1.2.1 Drilling deviation of holes

It was observed that some VCR chambers were poorly drilled.

- It is extremely significant that all holes be drilled to the correct direction and planned depth as per layout to ensure an even blast and leaving no craters in the stope. Drilling all the holes to the correct depth and direction will also minimise the damage to the hanging wall and to the installed support.
- Proper drilling aid consistently ore cratering.

4.1.2.2 Drill Rig operator

- The operator does not usually drill holes correctly as per layout direction. This is as a result of the rods being uneven especially when the operator struggles to retrieve the stuck rod by positioning the mast in all angles.
- In some instances, the operator had no dope(s) for the VCR drilling pattern.

4.1.2.3 Missing Holes

After establishing the cause of this, it was noted:

- Drilling of some down to hole -DHT holes were not to standard;
- At times, the holes were left out deliberately as a result of the operators inability to position the Cubex machine, obviously this was due to wrong height profile of VCR chambers.

4.1.3 Down To Hole Rig DTH - Cubex

VCR long stoping equipment used is DTH- Cubex. Proper handling of rods should be emphasized as this could potentially lead to injury as the men struggle to lift the rods as drilling progresses. The Cubex machine being used is particularly old and is not self-lubricating. The lubricant has to be placed directly into the drill rods. This could lead to wear and tear due to human error.The maintenance team runs over 3 shifts under the supervision of a foreman, as getting to breakdowns is both tedious and inefficient as travelling sometimes is on foot. The foreman controls the maintenance scheduling and purchase of components. Very few spares are kept for the rigs and once a breakdown occurs the machine normally stands whilst parts are procured. Figure 18 shows the Cubex driller operating 16 at 5570/280 VCR.

Figure 19: Cubex 16 drilling at 5570/280 VCR .

4.1.3.1 Cubex Machine setup in VCR chamber

When the Cubex machine is driven into the VCR drilling chamber, the following procedures are followed:

- The entire body is first aligned straight to and parallel below the survey painted line for bearing. At the painted cross in the roof, the Cubex machine body is jacked and levelled, the mast is dumped and the drive head lowered level to the actuator centre. A bob tied from the roof rigging position will intersect with the drive head making the floating rigging position for the hole.

- During drilling a standpipe is fitted on the collar of the hole to avoid debris dropping back in the hole.

- Upon holing each hole is checked for accuracy in dip, length and expected holing point.

- When drilling is completed, all breakthrough holes are surveyed and plotted to ascertain the burdens are within tolerance. Figure 20 is a typical composite plan of the top and bottom of VCR Chamber while figures 21 is a typical drilling profile of VCR stope. Figure 22 is showing drilling section and figure 23 illustrates a pictorial view of a VCR stope.

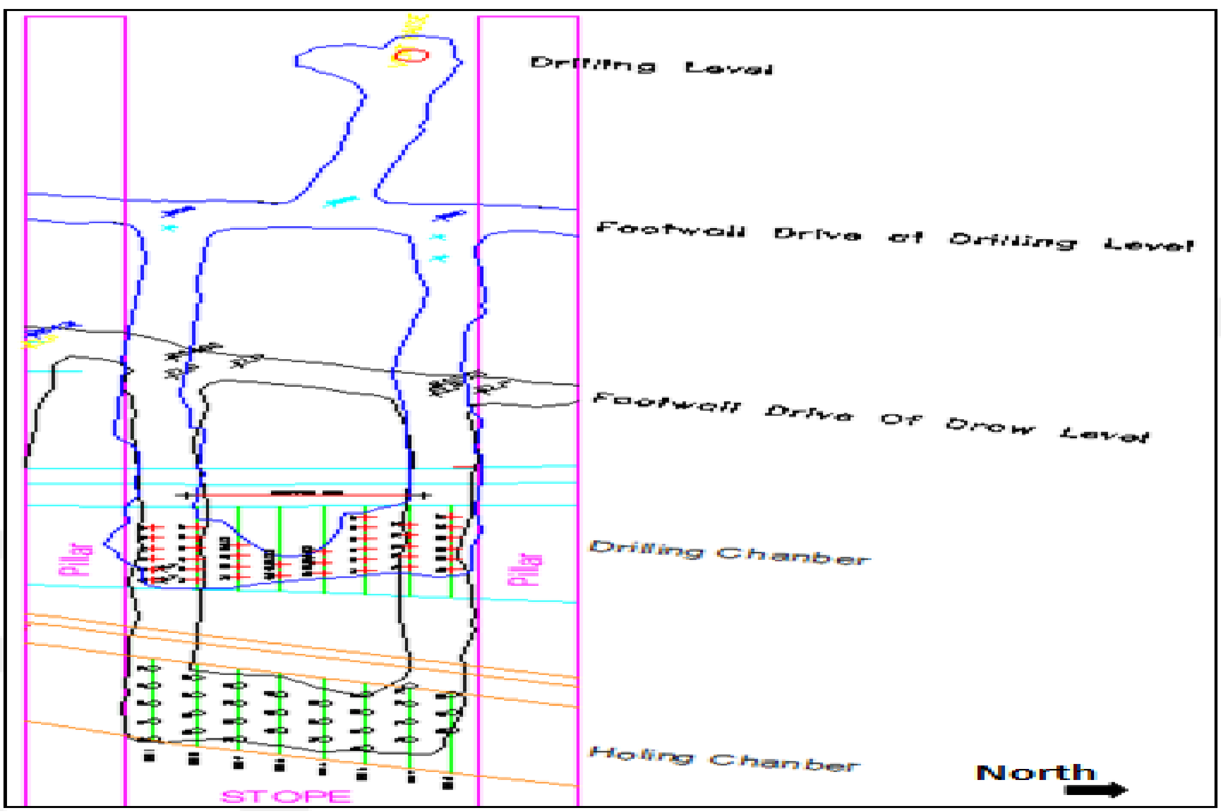


Figure 20: VCR Composite Plan

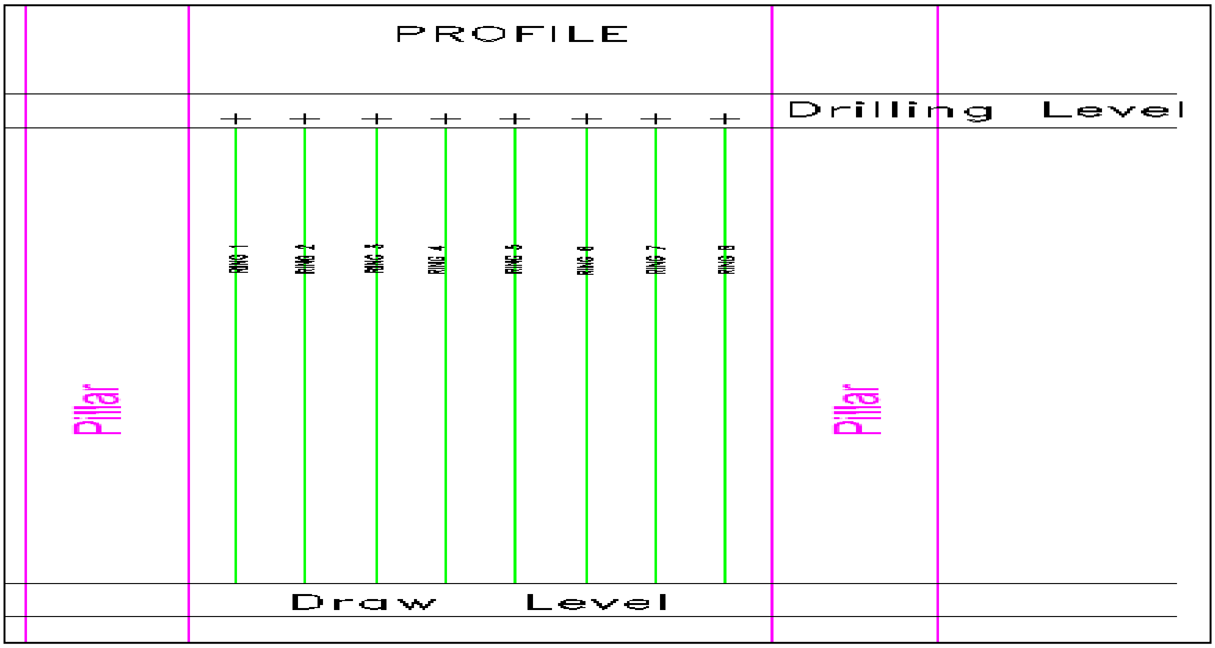


Figure 21: Typical Drilling Profile

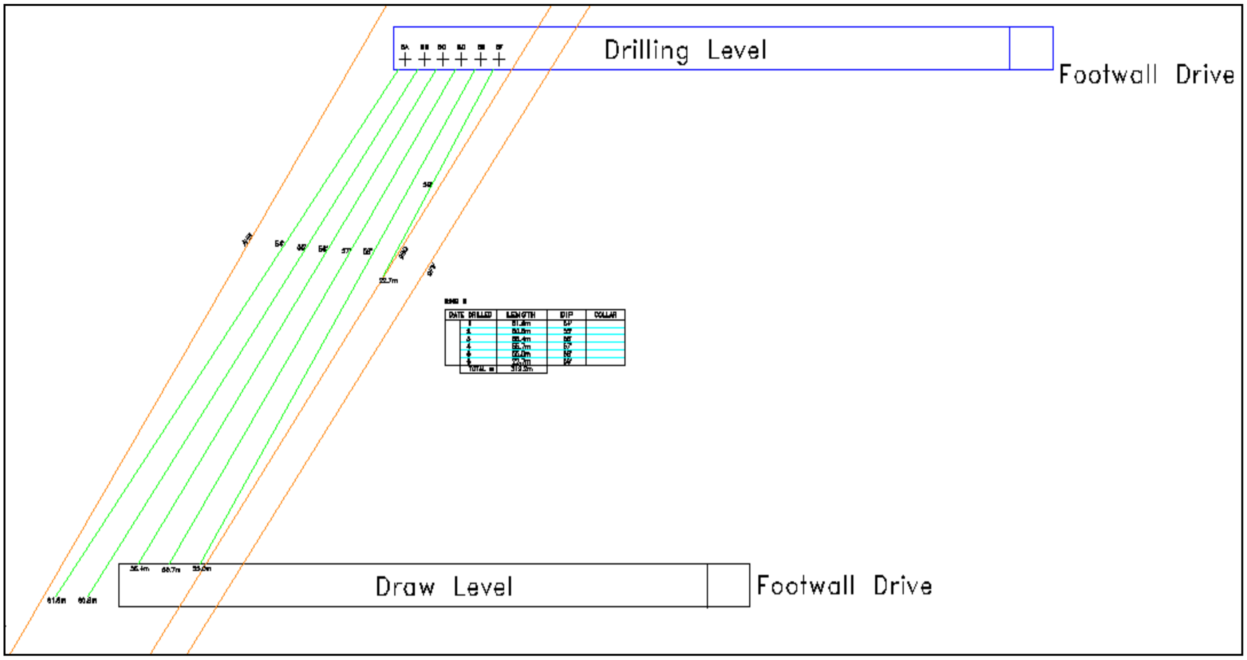


Figure 22: Typical Stope Drilling Layout Section looking north.

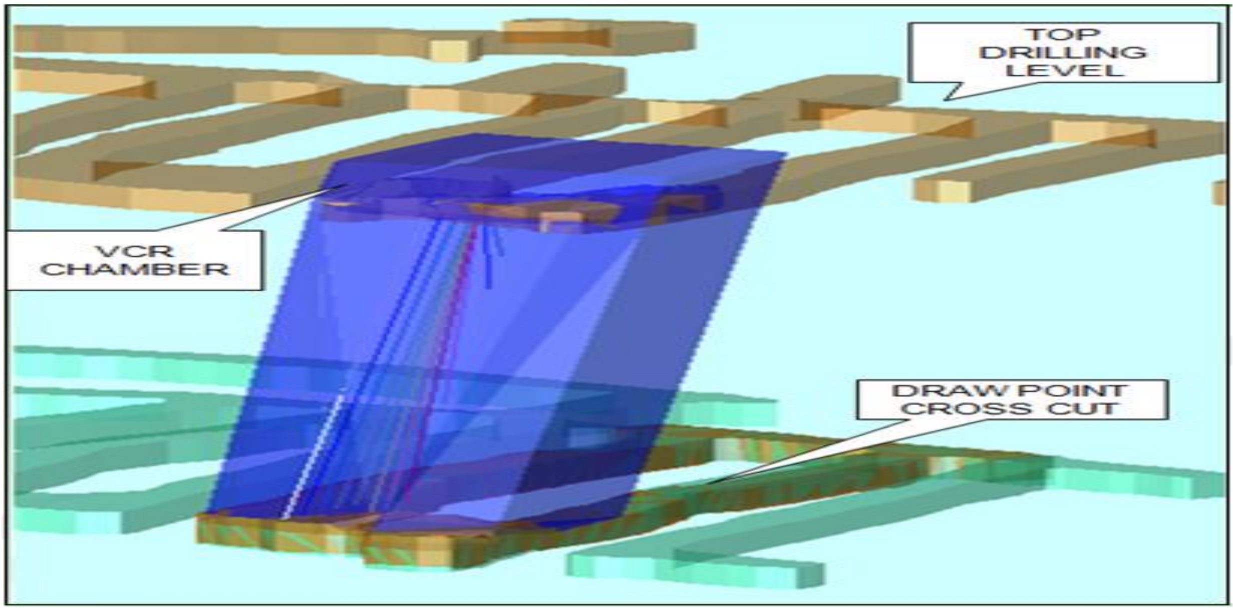


Figure 23: 3D view of the general concept

4.1.4 Matters affecting drilling of VCR stopes.

1 State of the drill rig

The drill rig state of repair has affected performance in both accuracy and efficiency. The major problems are: -

- Mast guide rail bushes: The wear between the rails and bushes can account for about 5° deviation.
- Mast Slide Over Rail Bushes: Similarly, this wear could account for up to 5“deviation.
- Drill rod centralizer bushes: The wear in this area should be checked because it will make collaring very difficult.
- Some jacks will fail after having been set and this adversely affects the direction of the drill hole.

- The stingers are also not given the necessary attention they deserve. Stingers give the firm stand the unit requires during drilling.

- The control panels are nonfunctional for most functions, making control of equipment difficult, consequently control during collaring is unattainable.

- Nonfunctioning compressors: Sometimes the compressor is made to operate at 50% capacity. This results in poor equipment efficiency, and risks failure to flush out drill chippings, winch in turn risks sticking the drill string.

2.Operator checklist

The checklist should be re-introduced and information should be charged to somebody to capture arid periodically and analyse.

3. Engineering personnel attitude

Personnel attitude should embrace team achievements. The state of the equipment with all the problems listed above is unacceptable. The titter will force the operator to use the machine in a defective state, and in this scenario availability' of the machine remains high and forth with higher drilling performance expected from the operator.

4. Unreliable drilling accessories

The stock of drilling accessories in some instances have lower productivity, Higher failure rates, with some failures resulting in complete loss of drill string, and loss of drill bit. The blast holes which have broken pieces of drill bits are abandoned, because there no magnetic fishing units to remove broken Tungsten Carbide pieces, consequently men are forced to drill replacement holes. Further, in some cases the drill bits have serious problems with the foot valves which results in high failure rates. All DTH machines have no protractors, clino rules, rotation blocks for quality rotation of drill string.

5. Labour

In the study, reading of stope drilling layouts was also found to be a problem for some of Cubex operators. A program to be drawn up to ensure that all the operators and assistant operators have adequate training or refresher course for the machine operation. The DTH drilling crews are mobile crews and therefore the host personnel must take interest in controlling and assisting the crews. The operators requested for bonus schemes because of the environment they are working, a bonus to be bestowed when a stope is drilled through a specified period.

4.1.5 Folded ore body

As mining progress in deep areas, orebody folding has been noticed around active production areas. After intersecting the fold at various levels both at MSV and SOB, more development and exploration drilling has been done to understand the orebody geometry and structures. This drilling has shown a prominent a fold that forms a limb and anticlines/synclines and plunges at average of 45^0 down towards the south affecting 4-5 stopes at every mining level. For instance, the intersection of the fold at 5735Level-1750VCR on the northern side of the mine in the deeps required a change in the mining strategy that incorporated SLC and VCR mining method. A similar strategy used at 5220L 3250N stope was adopted that involved Cut, Bench and Fill mining method whilst for 1750N stope it involves, Cut, breast(fan) and fill. Though this practice results in increased development requirements, increased ore recoveries will be archived.

Figure 24 below illustrates three dimensions(3D) view of the general concept VCR stopes in MSV deeps section, for further illustration refer to figure A2 and A3.

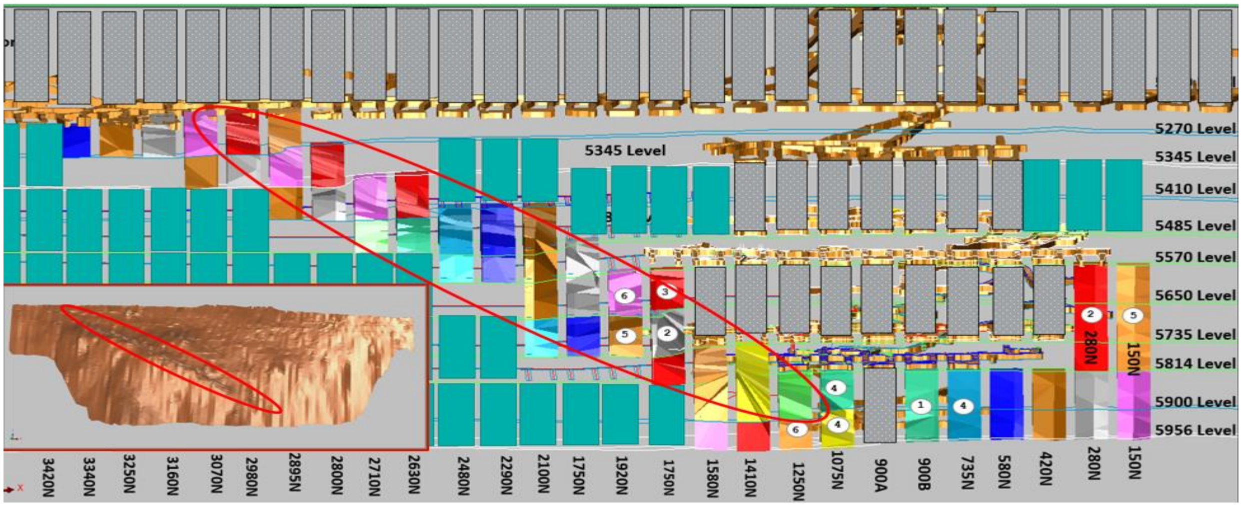


Figure 24 : Three dimensions(3D) view of the general concept VCR stopes

The study observed that in order to achieve maximum recovery of folded ore body and safety, fan-type production blast holes within a ring shall be drilled upwards as SLC and damped forward at an angle of 70-80 degrees from the horizontal in the direction of the stope face. For illustration figure 25 shows upward holes, slot and ring design of folded ore body and figure 26 displays sections showing XC 1 and XC 2 and figure 27 is showing production and backfilling in progress to stabilise the VCR stope prior to drilling and blasting. This technique shall;

- ✓ Improve safety,
- ✓ Reduce dilution,
- ✓ Improve ore recovery,
- ✓ Prevent a direct flow of back-fill waste material to the draw points,

- ✓ Reduce the throw of the blast and
- ✓ Maintain a void for the blasting of the next fan of blast holes.

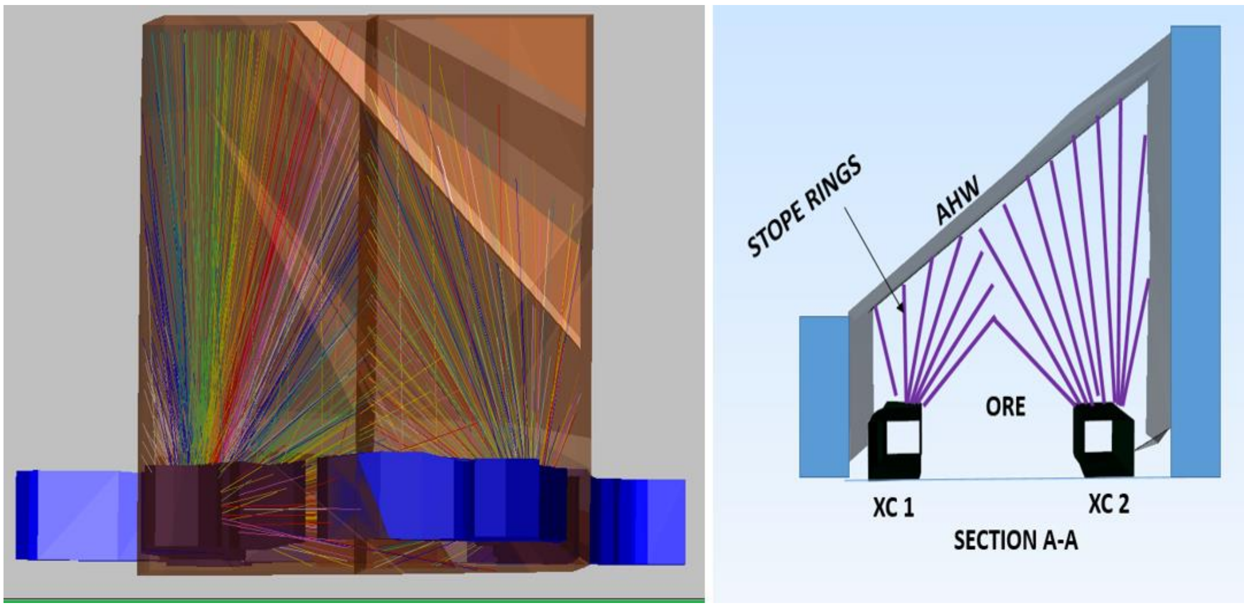


Figure 25: Sections showing upward holes, slot and ring design of folded ore body.

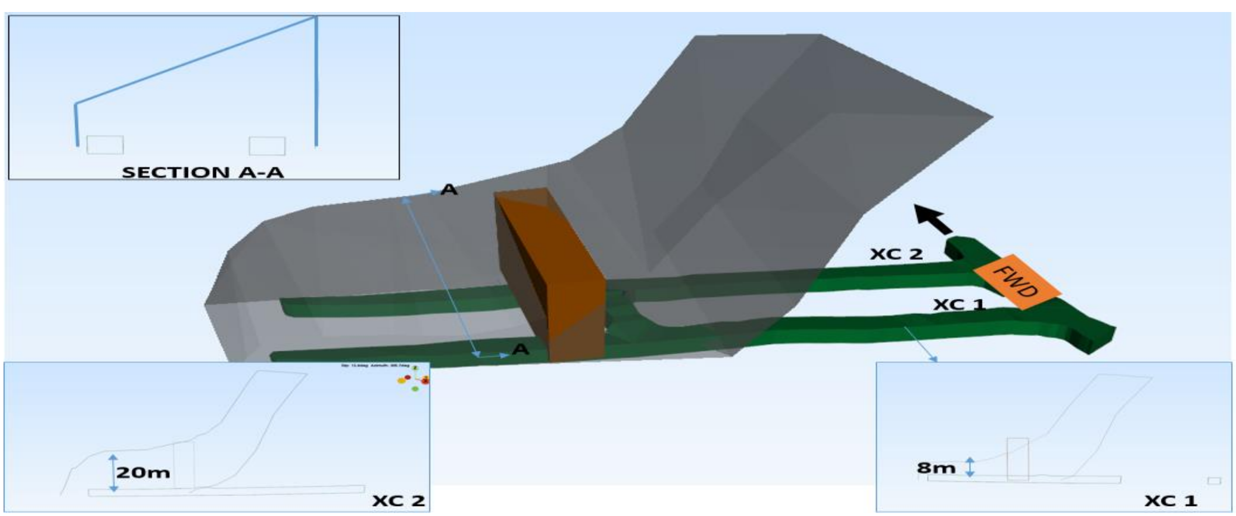


Figure 26: Sections showing XC 1 and XC 2

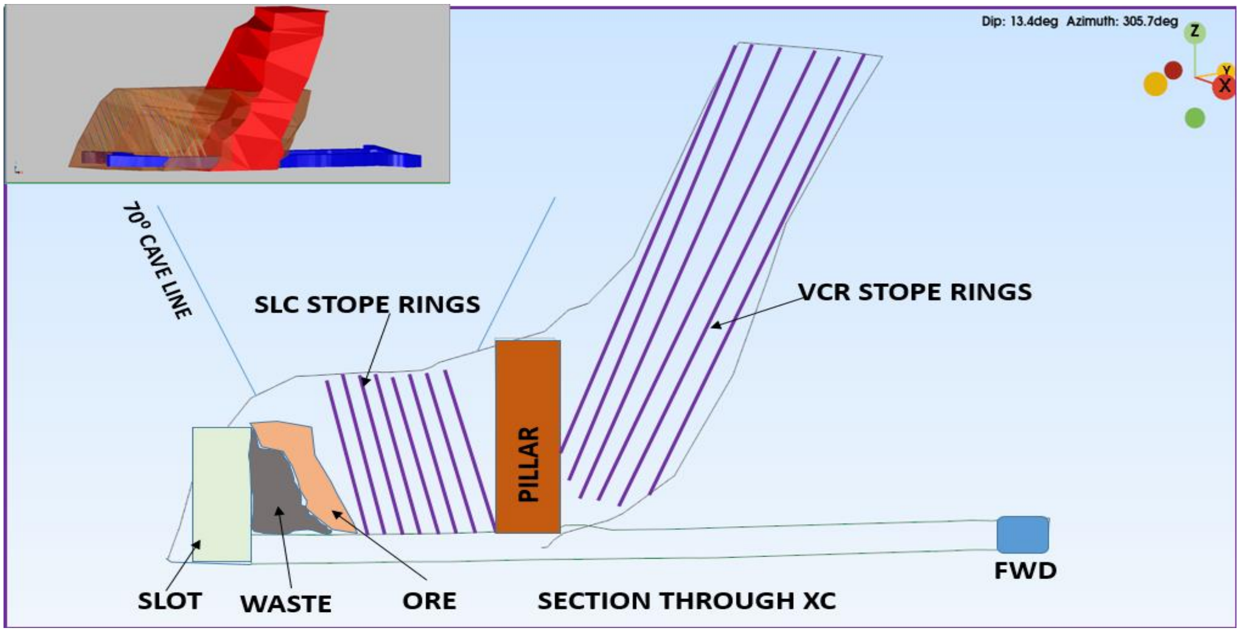


Figure 27: Showing production and backfilling in progress.

4.1.6 VCR Stope blasting

Once the holes have been checked and verified to be accurate, the information is plotted on blast hole sections to correctly interpret the blasting profile and breaking face. Blast holes are charged using bulk emulsion explosives. The stoping direction is always up dip. In the VCR stoping method, an explosive spherical charge is located approximately six diameters up a hole from the 'free face'. The charge is stemmed above the explosive and below the explosive on top of the plug just before the bottom of the hole. The stemming is a poor conductor of a shock wave or gas and can be in form of a liquid or solid material. The charged hole is shown in Figure 27.

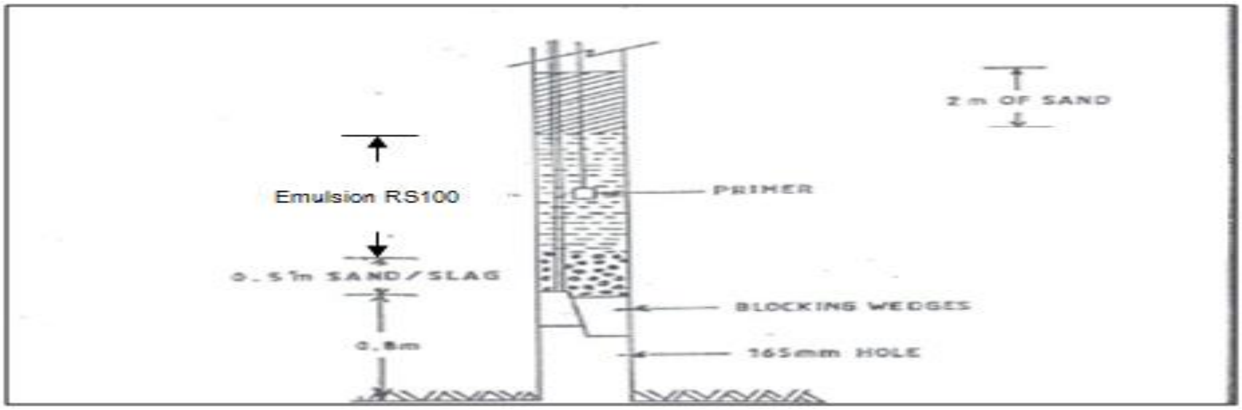


Figure 27: Charged VCR Hole

The holes are allocated delays using a logger according to the preferred timing. The harness wire is used to tag all the detonators. When the charge is electronically detonated from a remote distance, the blasted face forms a flat cone or crater in the ground. A series of such holes are drilled and so positioned to 'advance' a face of predetermined dimensions upwards. Refer to, (Figure 28)

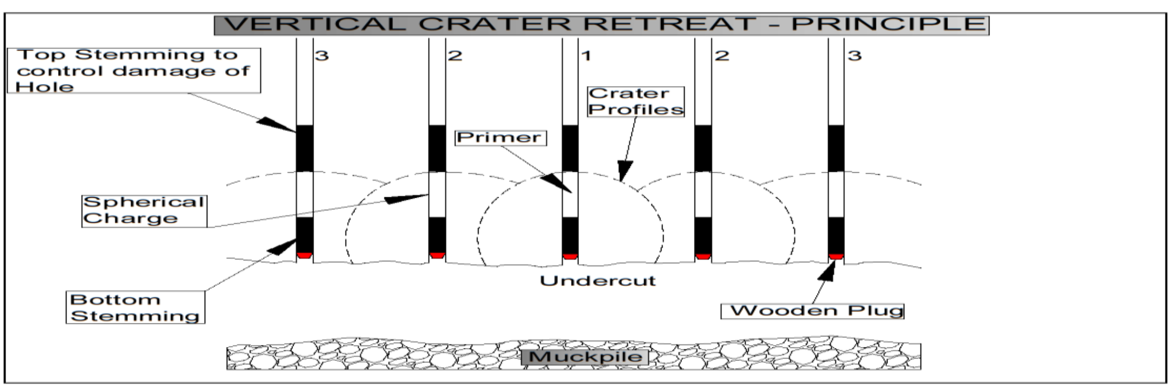


Figure 28: Spherically Charged VCR Holes

Ideally all the holes should be parallel to each other (Figure 29) and as vertical as possible. The ore produced by crater blasting falls down in the open space underneath.

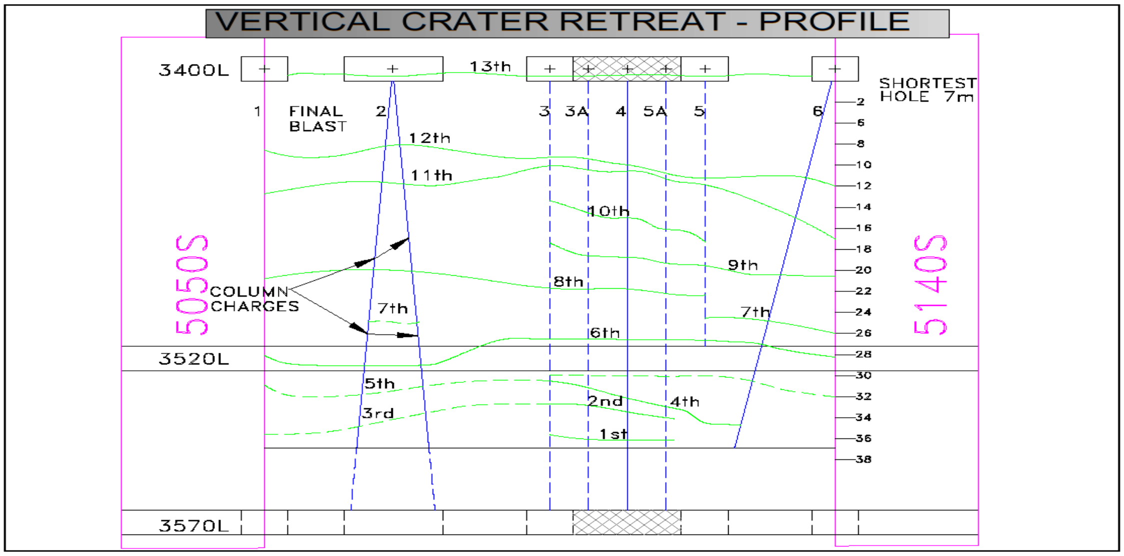


Figure 29: Parallel VCR Holes with Blast Advances

An advantage of VCR is that if well blasted, the ore is dropped uniformly across the stope to leave only sufficient void for the next blast. Therefore, the rock mass in the stope continuously supports the stope walls. This reduces waste dilution from hanging wall and footwall.

4.1.6.1 Bottom Stemming

In the research, it was observed that the purpose of any stemming operation is to allow detonated explosives to stay longer so that the released energy may do slightly more exertion before being released out of the charged-up hole. It was further observed that the blasting may not hold the same view, on the need to increase the stemming length, but also the amount of explosives being used is 50% more than the VCR design quantity.

4.1.7 Underground water management

Management of water is important in underground mines. Mining activities require a lot of water to keep the mine running i.e., all rigs need water to drill development ends and VCR chambers and at the same time water has to be regulated and pumped out of the mine. However, it was observed in the study that, pumping system failures in major pump chambers causes flooding and interrupt smooth running of mining operations. This affects productivity in drilling and production as there is always delays in completion of drilling tasks as scheduled. For instance, flooding of the Banda Ramp from 5900L to 5956L thereby restricting production and mining of critical ends and flooding of the Redpath decline to the shaft bottom affects and restricts ventilation to the deeps section. See figure 30 illustrating underground flooding, for further illustration refer to figure A7 and A8 in the appendices.

Figure 30: Underground flooding

4.2 ANALYSIS AND INTERPRETATION

This section discusses how the collected data was analysed and interpreted after identifying the influencing parameters of productivity in drilling and blasting of VCR stopes. It was necessary to monitor and regulate the performance of all contributing factors in stoping as regarding to technical, mining operations and maintenance factors. The data was composed, analysed and interpreted. The VCR redrills analysis is done by quantitative and the rest of the analyses by qualitative method.

4.2.1 Management and supervision

Mine productivity issues in drilling and blasting of VCR stopes materialise as a result of unsteady supervisory and management elements in technical, operations and maintenance works. Management strategic and supervision decision have great role making progression of mine productivity goals. The mine productivity factors are basically classified into three elements in any underground mine setup. The major function of the supervision and management is to give strategic expertise and overall supervision of the technical, mining operation and maintenance services to operational demand of the mine. Worldwide, all mining industries, management and supervisory is anticipated to make swift evaluation decisions at different stages of underground projects based on limited and uncertain data (MacEwan, 2020).

Mine productivity and production hinge on availability and reliability of equipment. The team working on the machines needs to have a performance drive for work and time improvement on attending to machines break downs. Globally, mines have introduced policies on maintenance of equipment, program on effective assets management, human capital management plan to action improvement on incentive of staff, decreasing worker turnover (Punkkinen, 2016). *Nkana* *sites both at MSV and SOB, Mine productivity in drilling and blasting perspectives, supervision and management of operations factors are basically predominantly concerned with planning, organizing, leading, and coordination and controlling. However, it is significant for MSV and SOB operations management and supervisors to gain knowledge, skills and willingness to vigorously monitor, and support values and ensure that employee are self-managed. From the questionnaire questions that were conducted in the production areas, particularly in VCR chambers and results collected, it clearly showed that there is lack of skills and knowledge in mining unit processes such drilling, charging stopes and blasting.*

4.2.1.1 Interpretation on management and supervision

From the questionnaire carried out in the field, it was established that there is poor supervision of factors of technical, mining operations and engineering maintenance activities at MSV and SOB; this has greatly impacted on the mine productivity in drilling and blasting of VCR stopes and production performance.

4.2.2 Mine productivity technical factors

Globally, mine technical factors perform significant role in making mine profitability and productivity viable. All underground mines, technical administrative decision and policies for control of input variance have a great influence on mining activities (Whittle, 2018).

4.2.2.1 Mine planning

Research considered two analyses and proven the significance of technical factors in mine productivity and its effect on production. Scenarios where done at two different VCR chambers and production levels to ascertain if adequate geological information was provided prior to mining of the VCR Chambers. These comprised:

Scenario A Analysis

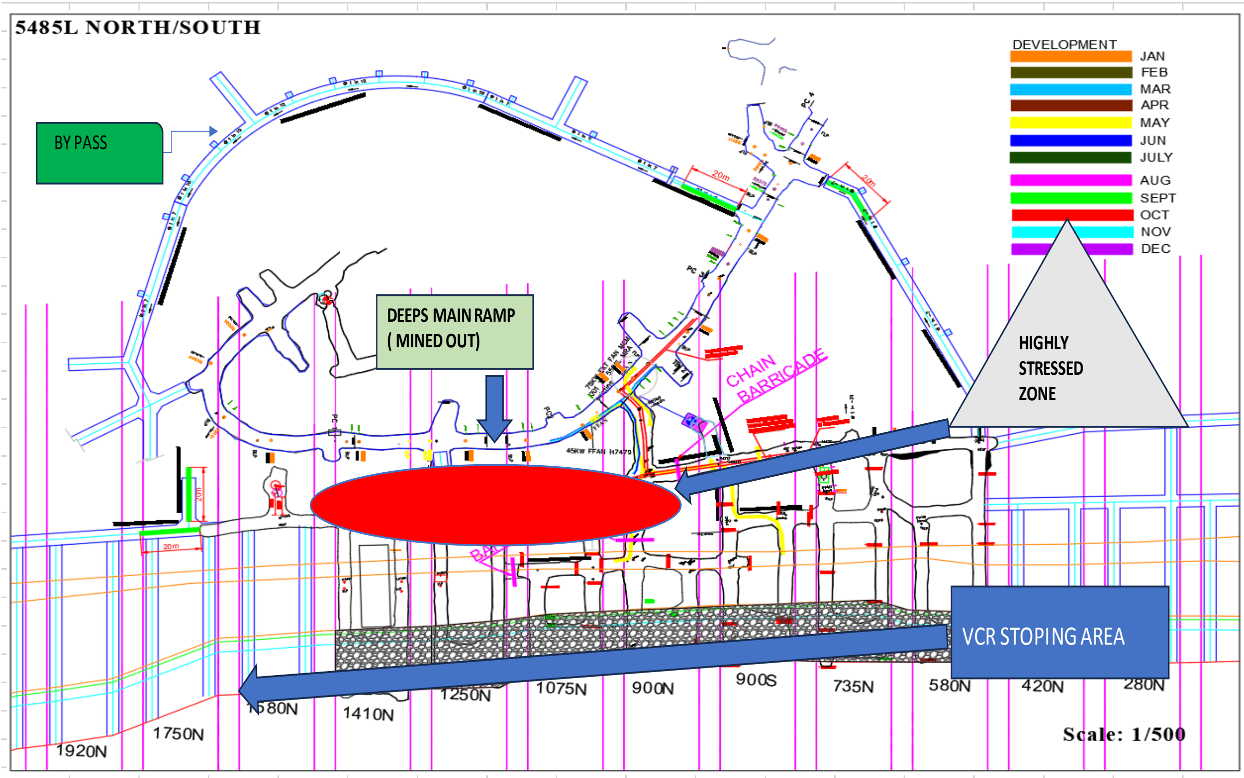


Figure 31: Plan of 5485L north/ south

Analysis (A) in Figure 31 demonstrates a highly stressed zone excavations at 5485L north/ south and the deeps main ramp, six green blinking fog lights were mounted to assess excavation stability. The two lights shortly turned red signaling the area having more stresses around the excavations. The site ruins a danger to men and machinery. However, the support rehabilitation plan has been put in place to make the area safe and commencement of mining a bypass away from stoping area. The results of the findings proved that the area had no adequate geological information, and this ended up with wrong mining of the area and subjecting it to more stresses and causing further delays to drilling and blasting of VCR stopes.

❖ **Scenario B Analysis**

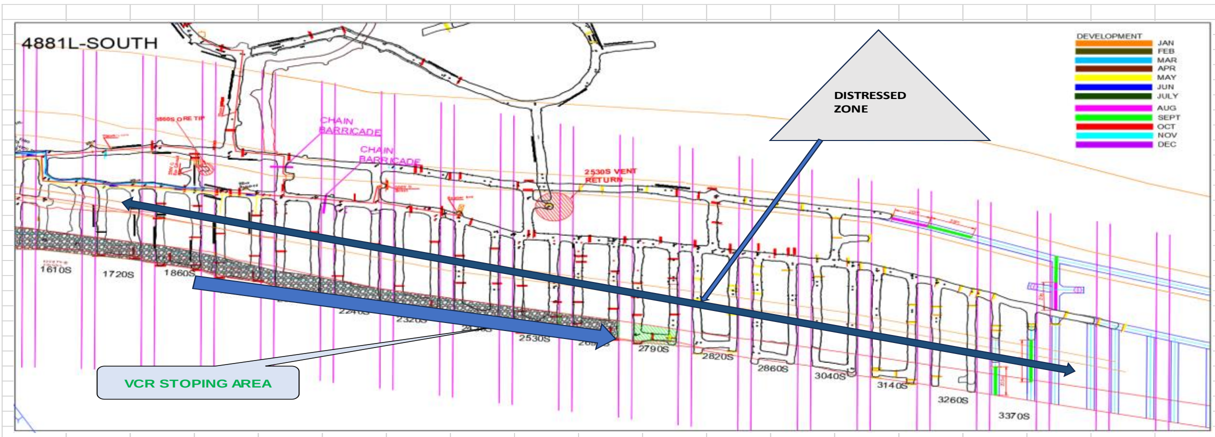


Figure 32: Plan of 4881 level south

Analysis (B) in Figure 32 displays VCR stoping area at 4881 south. Six green blinking fog lights put in place; and all installed lights were green for specific period required for the analysis. After investigations of the area, the zone had exploration holes drilled by Timaja diamond drilling company and geological information was adequate for technical personnel. The planning section issued a lay out with adequate information hence mining was executed appropriately and no delays drilling, blasting of VCR stopes and ore generation, also for reference of adequate and good mining as per geological information refer to figure A9 and A10 in the appendices.

4.2.2.2 Interpretation on mine planning

In scenario A analysis, the highly stressed zone and rehabilitation of the excavations delayed on the drilling and blasting of VCR stopes and this greatly impacted on quantity of tonnes planned to be produced from the area. Explorations in the area were not done by diamond drilling to establish the formation of rock. This clearly exhibited that there was failure to actually *drill the exploration holes as a result the planning team had insufficient data about the area and thus, lead to in designing a layout that created rock mechanics problems for the mine. There was poor planning of production and development actives, i.e. tasks execution in close proximities. Additional support works were planned to be installed to stabilise the area and redesigned a bypass stretching 250 meters to enable further drilling and blasting of VCR stopes. Extra mining definitely caused delays in drilling of VCR stopes, losses in annual planned DTH meters, ore production and extra mining costs. Scenario B analysis clearly demonstrated that the excavation was stable and stresses free. In analysis B, diamond drilling explorations were carried out and provided adequate geological information; and was also useful to other technical personnel for their technical expertise. Additionally, underground exploration drilling is cardinal in all unground mining operation as it assists the technical team to gain enough information of the mining area before issuing out any mining dopes, determines ore body size, depth, and grades in the stoping zone. Scenario B had the area properly mined out with no extra support installation and managed to attain planned VCR drilled meters and ore production.*

4.2.2.3 Mining of folded ore body analysis

Due to wide span created by stoping out the bottom part of folded ore body prior to VCR drilling, the horizontal hanging wall is expected to cave though delayed as the hydraulic radius (HR) falls on the transition line. However, caving is not expected to propagate far deep into the hanging wall due to the back fill and swelling (SF = 0.65). In figure 33, a fully integrated three-dimensional layout (CAD), visualization (GIS) and stability analysis package -Map3D boundary element stability analysis package for excavations was used to model the mining strategy. This was used in analysing two scenarios to determine VCR stope stability in section 5.2.2.3.1. See the graph in figure 33 below.

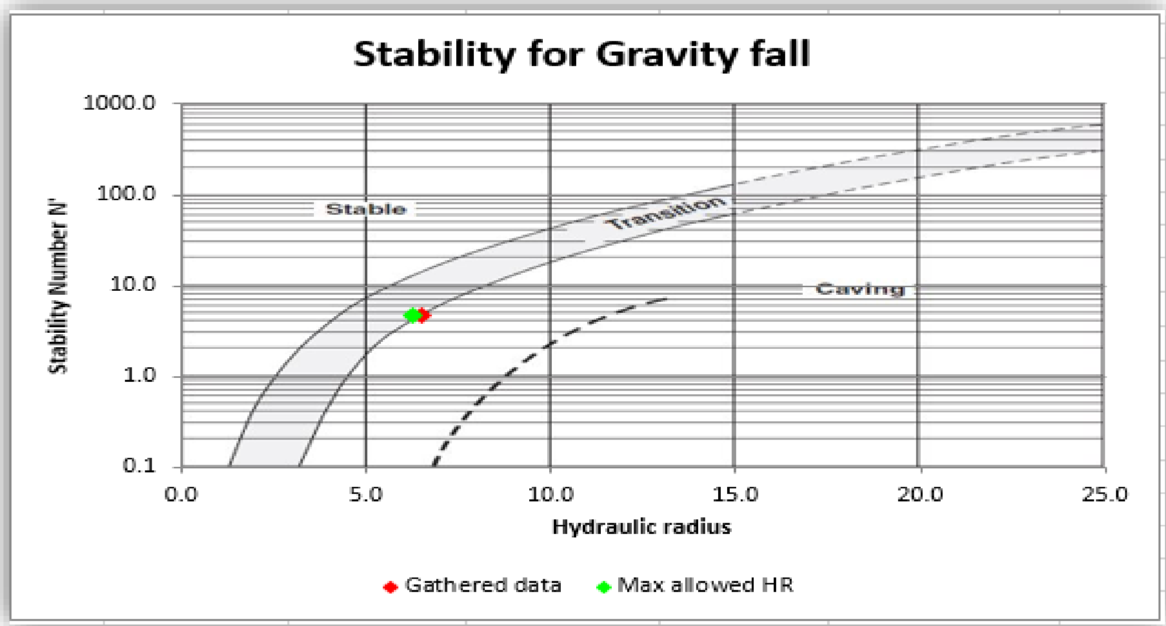


Figure 33: Map3D boundary element showing stability analysis package for excavations.

4.2.2.3.1 Folded Ore Body pillar Stability Analysis-Numerical Modelling

Research considered two analyses of mining folded ore body to ascertain the stability of the ground after extracting ore on the bottom level of the VCR chamber using SLC mining method and prior to mining of the VCR Chambers and consideration of ore dilution as a result of waste rock material contamination. The two scenarios are as below:

- **Scenario C: Stability Analysis-Numerical Modelling with 7meter pillar**

In scenario **C** folded ore body, a stability analysis-numerical modelling with 7meters pillar was conducted and give the following outlook. See figure 34 set up and figure 35 showing induced stress state after mining SLC and VCR stope with rib pillar. Figure 36 shows strength factors and volumetric strain state after mining SLC and VCR stope with rib pillar:

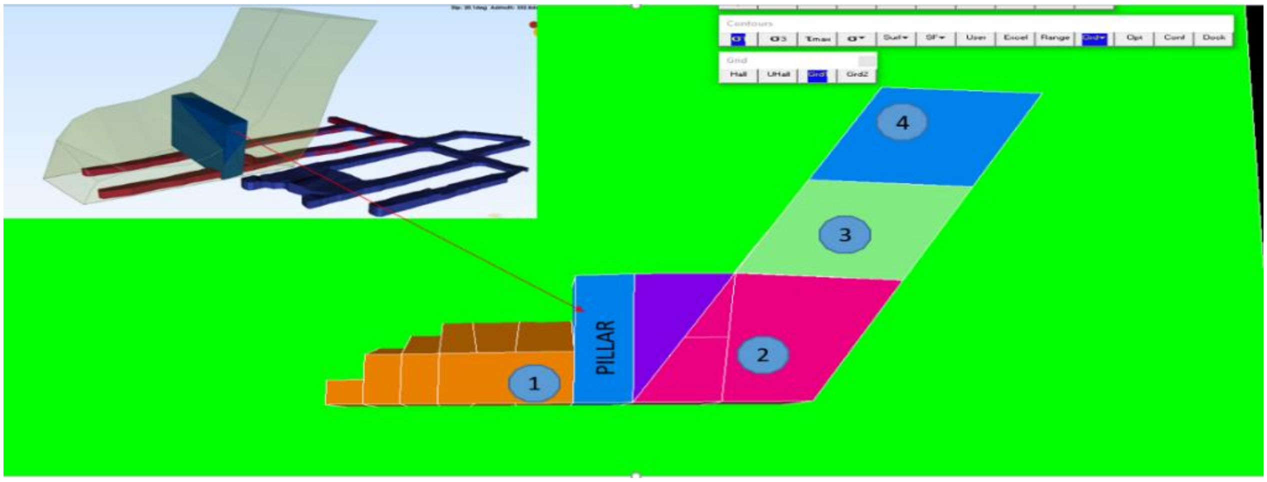


Figure 34: Model set-up

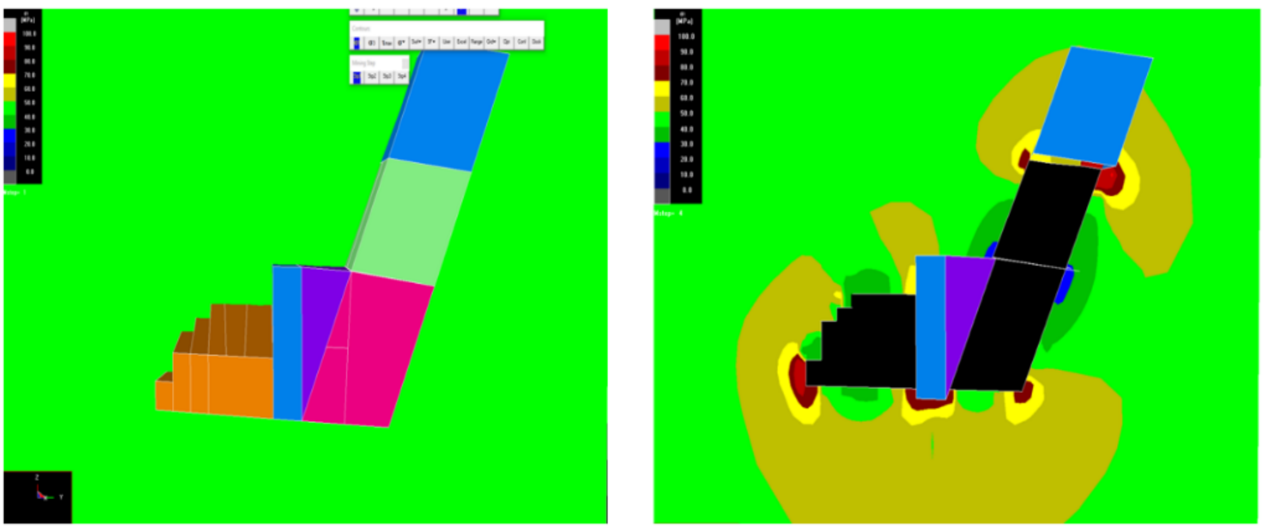


Figure 35: Induced stress state after mining SLC and VCR stope with rib pillar

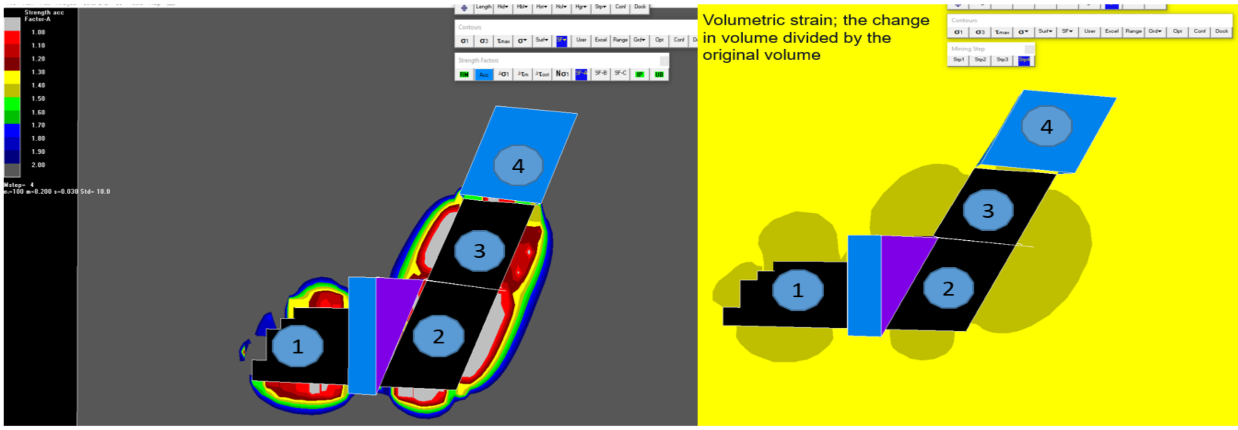


Figure 36: Strength factors and volumetric strain state after mining SLC and VCR stope with rib pillar

❖ Scenario B: Stability Analysis-Numerical Modelling without 7meters Pillar

In scenario **D** folded ore body, a stability analysis-numerical modelling without 7meters rib pillar was carried out and gave the outlook as shown in figure 37 set up, figure 38 is showing induced stress state after mining SLC and VCR stope and figure 39 shows strength factors and volumetric strain state after mining SLC and VCR stope without rib pillar:

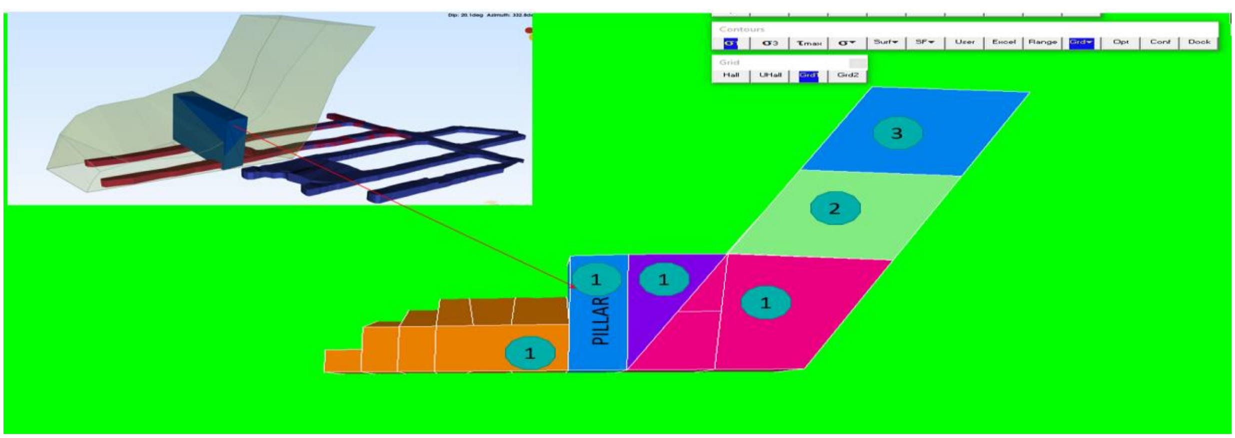


Figure 37: Induced stress state after mining SLC and VCR stope without rib pillar

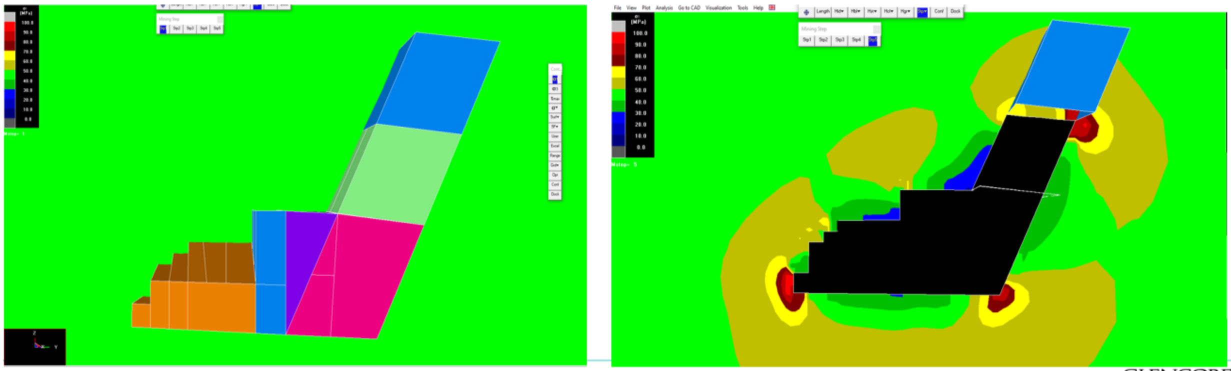


Figure 38: Induced stress state after mining SLC and VCR stope without rib pillar

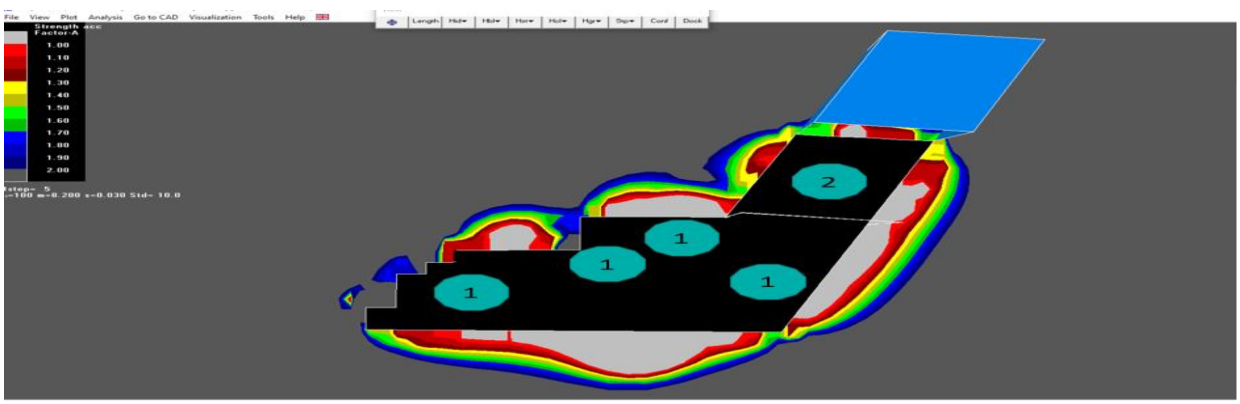


Figure 39: Strength factors state after mining SLC and VCR stope without rib pillar

4.2.2.3.2 Folded Ore Body Modelling Results

In the two scenarios **C** and **D,** Extraction of the folded orebody in scenario **C** with introduction of rib pillar 7meters ore body and pillar in existence of the receiving VCR holing level shows potential stability of the mining block with less stresses and a reduction in damaged zone. However, in scenario **D** where **7-meter** pillar is in non-existence at receiving VCR holing level shows potential instability of the mining block with more stresses and increased damaged zones as compared to the one with presence of a **7 meters** rib pillar.

In the study it was analysed that during blasting operations of folded ore body, single hole delay must be implemented to minimise the generation of a high shock waves that might trigger seismicity in the mining block. Figure 40, show an illustration of up-dip side (XC 2) of the ore body that should lead to provide enough breaking face for the shorter rings from lower side (XC 1). This will also improve ore recovery and minimize dilution.

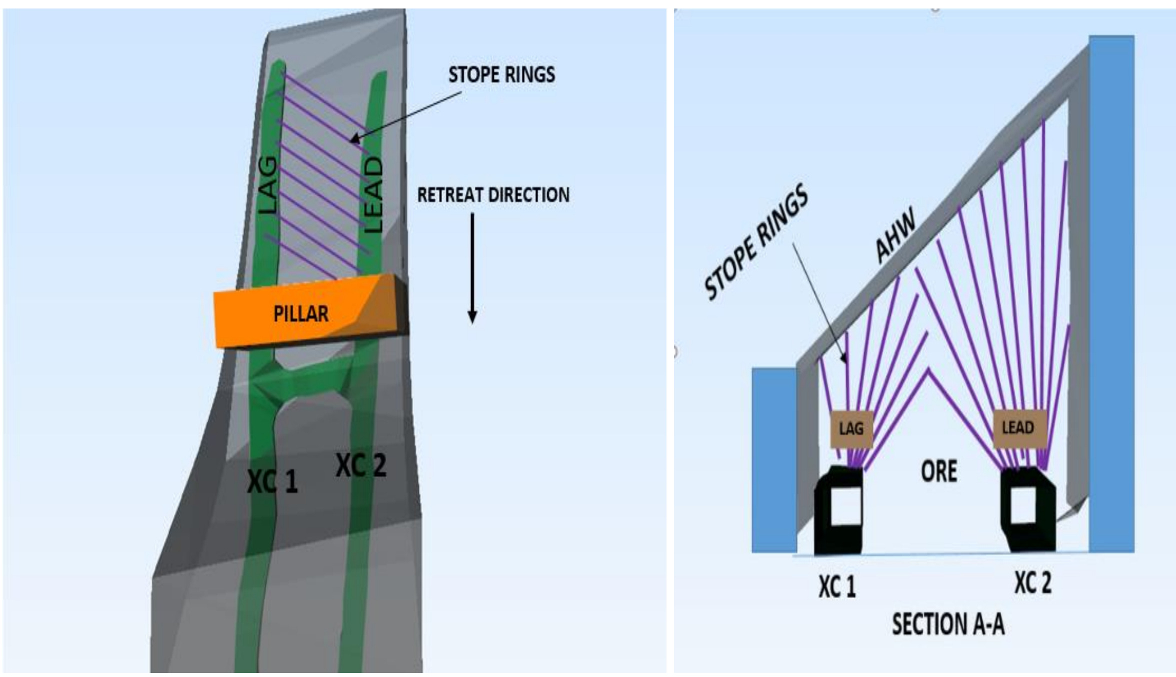


Figure 40: The up-dip side (XC 2) of the ore body

4.2.2.3.3 ***Interpretation of folded ore body Numerical modelling results***

Numerical modelling results shows that the folded ore body VCR stopes will be unstable without rib pillar support and the stope can have massive dilution of ore due to uncontrolled collapse of the hanging wall material and this can affect the VCR stope ore grades. The low grade is mixed with rock material mainly after an abnormality in the stope. The dilution causes great losses in *recovering planned ore to be drawn from the stope and therefore a 7m pillar must be left to help minimise deformation and caving.*

Thus, all development must be adequately supported as follows:

2.4m Split Sets (Black Split sets)

Split sets per ring = 9

Bolt spacing within ring = 1.0m

Ring spacing = 1.0m

Maximum allowable unsupported span (during drilling and charging) = 0.5m from the face. Welded mesh should be:

- *5.6mm gauge x 3.0m wide x 2.4m long welded mesh (installed on 0.9m split set stubbies in 2.4m split sets). Maximum unsupported span for split sets and mesh 0.5m from the advancing face.*
- *38Ton x 6.0m in the roof and 4.5m in the sidewall cable bolts in lengthy (mechanical anchors)*
- *Support in terms of cable bolts should be as below:*

Cable bolts per ring = 5

Bolt collar spacing within ring = 1.5m

Ring spacing = 2.0m

- *6.0m cable bolts should be installed from the final brow position up to 20m from the GFW.*
- *All excavation intersections must be supported with 6.0m cable anchors and 9 cable bolts should be installed per intersection at 2m ring spacing and 1.5m within rings.*

- *A 3m mark from the brow position should be painted beyond which the driver should not go cross during lashing operations; otherwise, remote loading must be used.*

4.2.2.3.4 Interpretation of technical factors

Technical factors in mine productivity are key phase in underground mine production. The study concluded that:

- ❖ All MSV and SOB technical group disciplines play dynamic roles to mining operations and have great impact on ore production.
- ❖ The MSV and SOB technical group offer technical knowledge to mining operations officials.

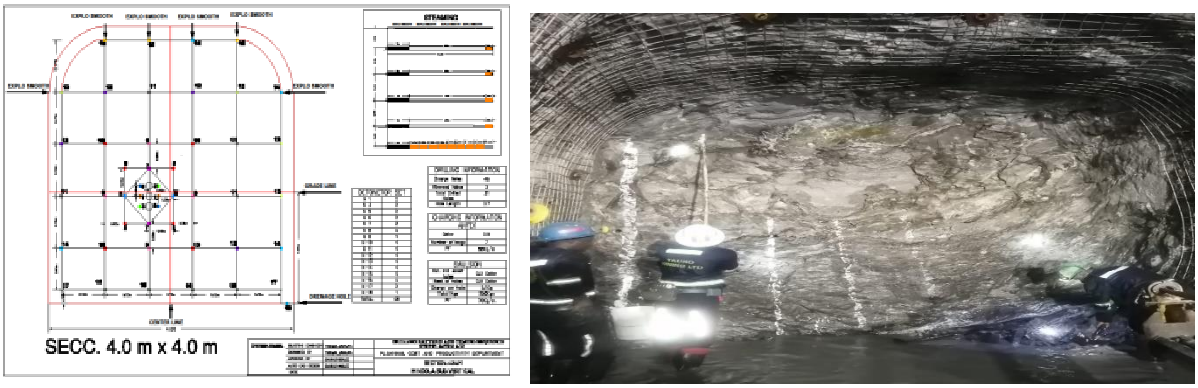
4**.2.3 Mine productivity operations factors**

Mine operations are key factors and play an important part in mining of ore underground. The study looked at MSV and SOB overall mine productivity in drilling and blasting VCR stopes and production efficiency relating to daily operations activities in stoping.

4.2.3.1 Marking of ends

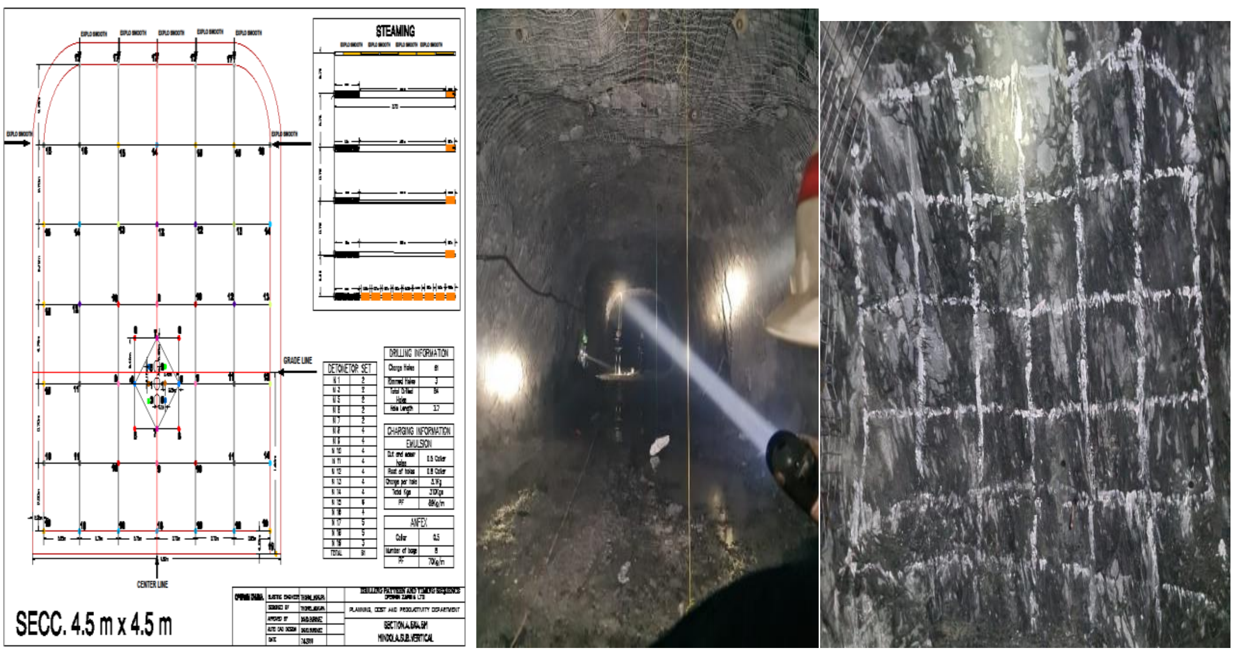
Marking of development ends were observed and evaluated, the findings were that primary and secondary faces were inaccurately marked on the face due to;

- ❖ On site layouts absence for marking ends.
- ❖ Short holes being drilled by rig operators as a result of poor end preparation, holes not drilled to full length i.e. 3.3 m instead of 3.5 m; and presenting 25 percent ineffectiveness.
- ❖ Spacing between holes, spacing of holes during marking was a main cause of poor rock fragmentation and bad advance (per pull). The miners marked the face not following standard spacing of approximately 0.7 m, but holes were marked at the range from 0.8 – 1.2 m. Refer to Figures 41 and Figure 42.



Mining layout 5814/1580 vent access face

Figure 41: 5814/1580 vent access face substandard end



Mining layout Survey parameters 5735/1410 crosscut 1 face

Figure 42: 5735/1410 crosscut 1 face standard end.

Figure 41 displayed a substandard 5814/1580 vent access end marked without following the layout. Figure 42 at 5735/1410 crosscut 1 face depicted a standard end marked according to the layout whilst.

4.2.3.1.2 Interpretation of drilling

Overall, physical dimensions of primary and secondary ends were more than 0.7 m in almost all ends picked instead of the 0.7 m standard spacing. The spacing of holes measured varied from 0.9 m to 1.2 m as contrasting to 0.7 meters standard marking of ends. Generally, substandard marking of ends has great effect on attaining anticipated development and VCR chambers results.

4.2.3.1.3 Drilling comparison

In the study, the analysis were done on selected ends namely, 5735/1410 crosscut 1 face and 5814/1580 vent access face to establish underground tunneling smooth opening of ends. Refer to Figure 43 and 44.

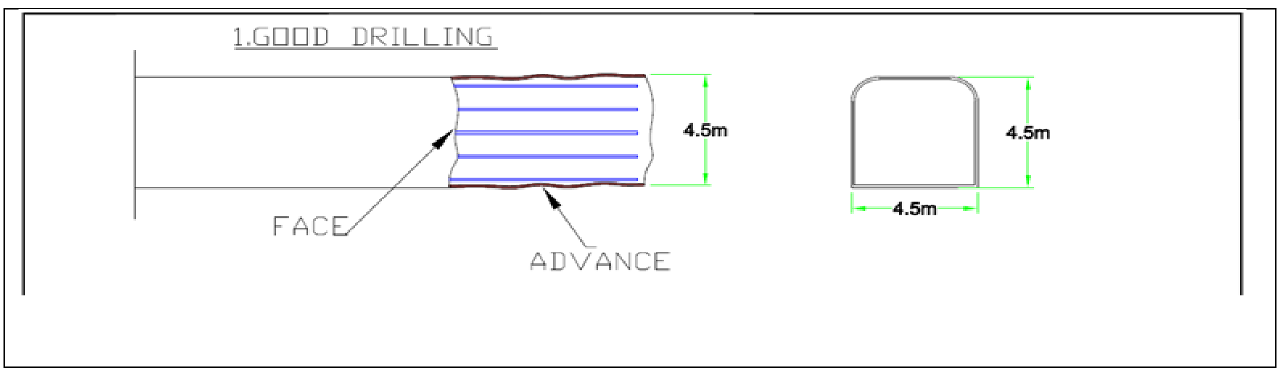


Figure 43: 5735/1410 crosscut 1 face accuracy

Figure 43 illustrates smooth drilling and blasting of the excavation; and which happened within the intended tunneling periphery.

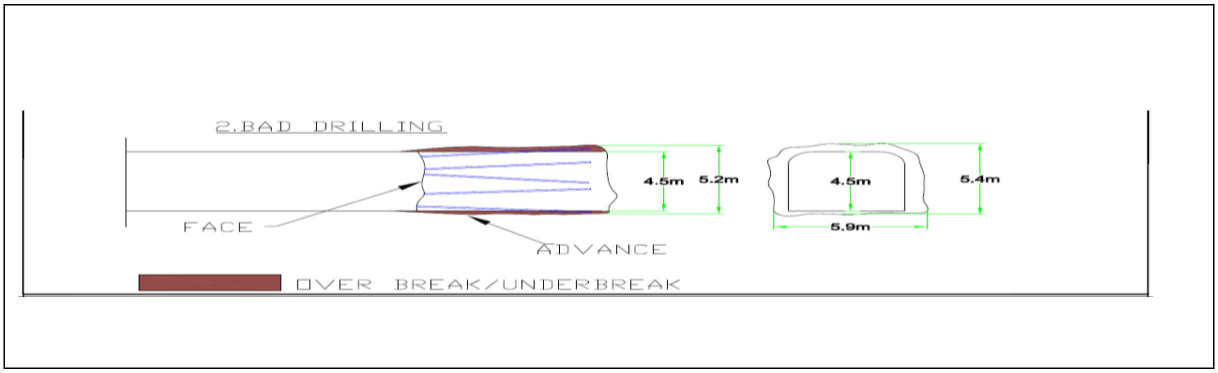


Figure 44: 5814/1580 vent access incorrect drilling

Figure 44 illustrates a tunneling with uneven rock breakage and irregular surface; the end was an over break which happened externally of the planned periphery of excavation.

4.2.3.1.4 Interpretation of drilling comparisons

In Figure 43, after blasting, the tunneling appeared to be straight and smooth pattern breakage of rock; and this evidently proved that the rig operator drilled the work appropriately and skillfully whereas in Figure 44 the rig operator drilled the end poorly, deprived drilling from missed or blocked holes results in loss of intended energy release resulting in poor blast results and resulted into having poor development outcome in the section i.e. extra support installation to make the blasted area stable and more waste material to be lashed out, henceforth poor drilling, spacing, and burden on the face results in many downstream impacts as; poor advanced, poor post blast profile, increased mining costs, poor fragmentation and further causing delays in preparation of VCR stopes.

4.2.3.2 vertical crater retreat (VCR) drilling and blasting

- **Drilling**

Mining VCR chambers takes an average of 2 to 3 months, so to accomplish and control stress build up, the sequence of stoping is retreating systematically from the middle and then up; and rib pillars left in tacked to stabilise the area. The mining of chambers and stoping sequencing starts from the lowermost levels and progresses out to levels above creating pyramid echelon. Figure 45 illustrates pictorial view of the VCR stope and figure 46 shows plan of the VCR development layout, also further illustration refers to figure A1 and A2 appendices.

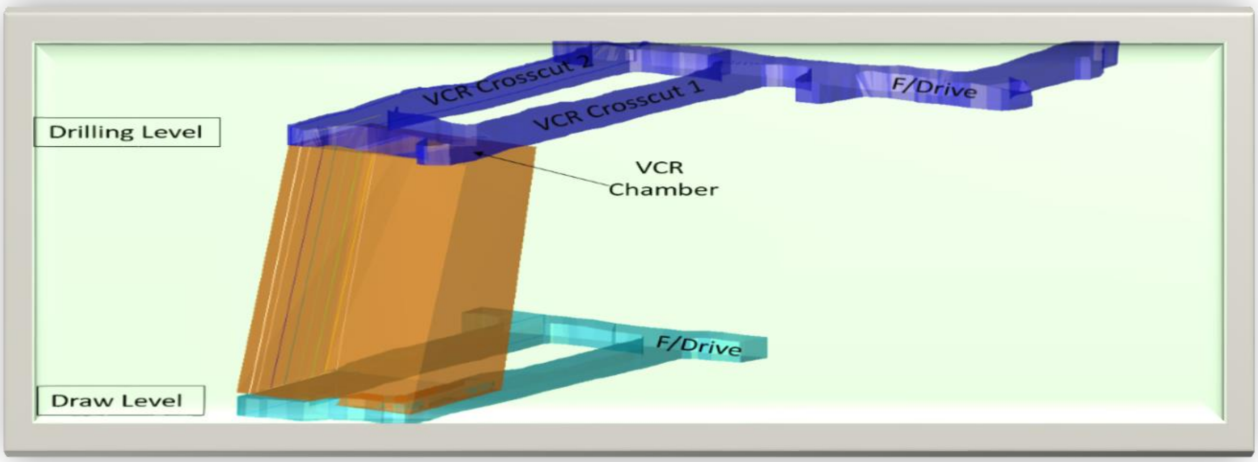


Figure 45: VCR chamber

The holes in the chamber are drilled by Cubex machines from the drilling level to the receiving level using 150 mm bit size. After drilling, VCR critical controls are checked and verified by both technical and mining operations personnel. Figure 47 illustrates good drilling of VCR chamber and figure 48 illustrates a void of VCR stope. For further illustration see figure A3 and A4- Nkana North target mining areas in the appendices.

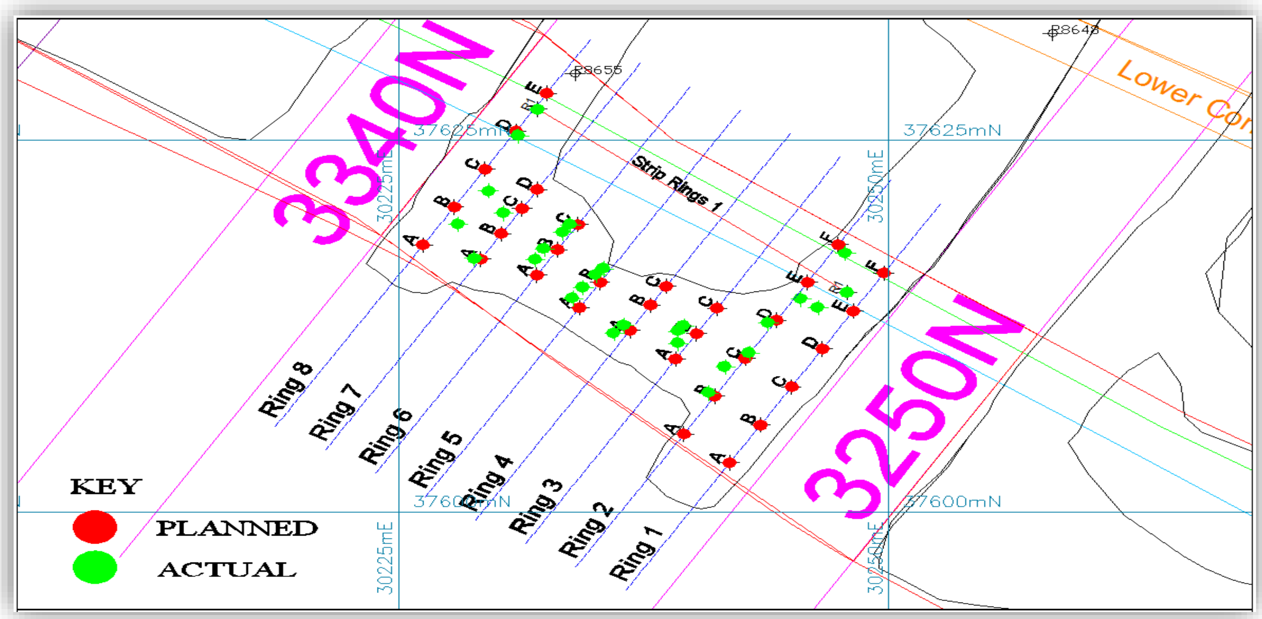


Figure 46: Plan of VCR chamber

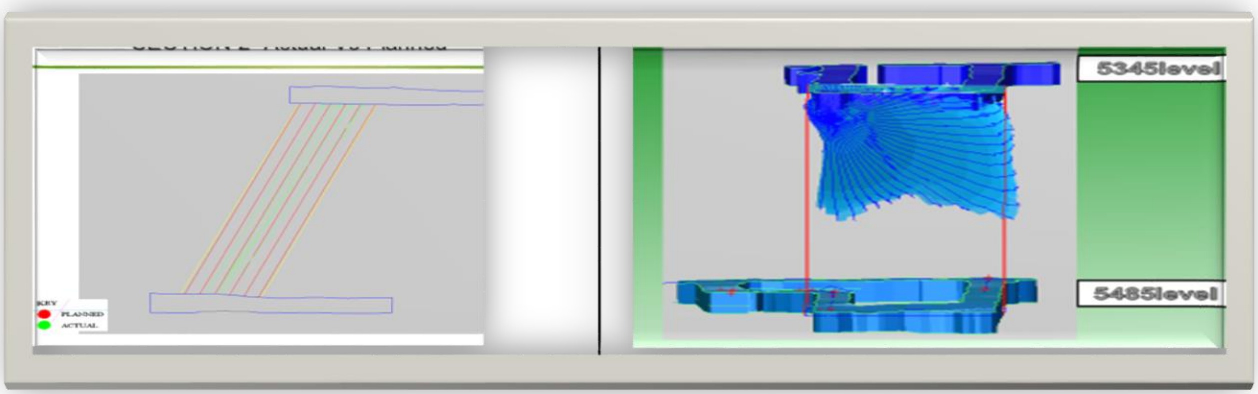


Figure 47: 5345 level /580 VCR void scan results

Figure 47 illustrates a void of VCR after depleting the draw. The planned tonnage was mined out and gave a drawn of 95% recovery and minimal dilution of ore, this was a good sign of decent stope drilling.

Figure 48 below shows poor drilling of VCR stope and void scan results.

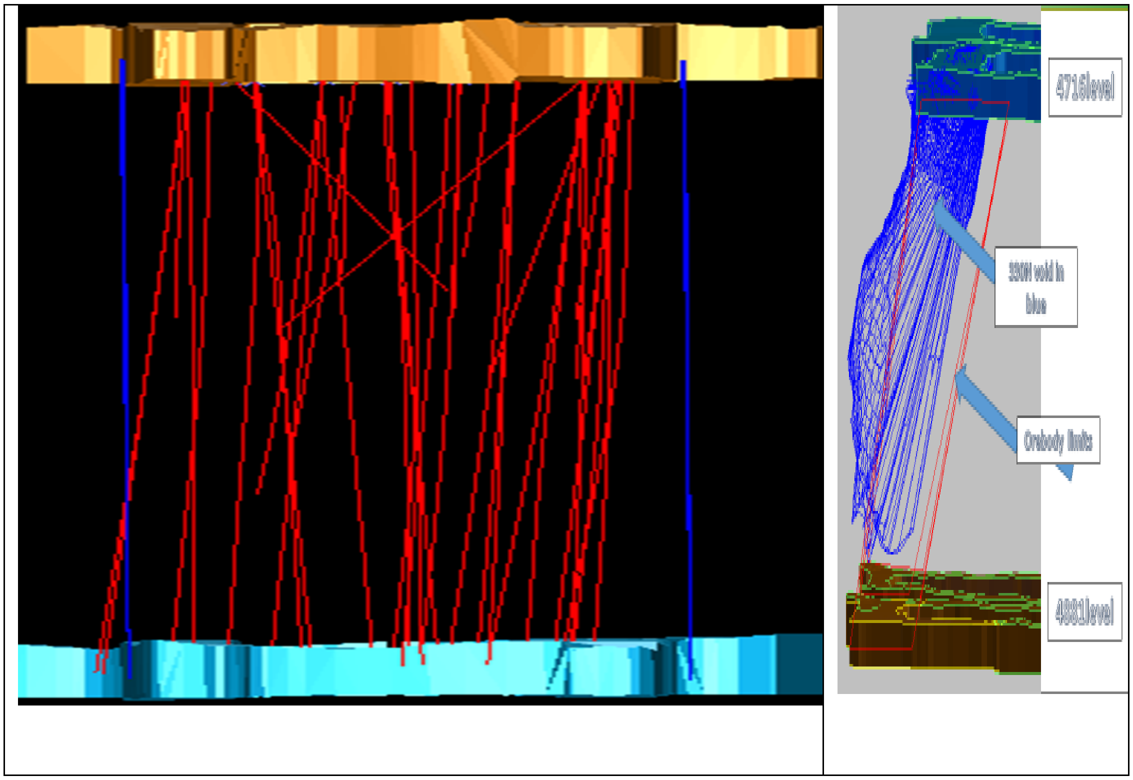


Figure 48: 4716 /3340 VCR poor drilling and void scan results

Figure 48 demonstrates a void of 3340 VCR. However, the deviated holes were drilled in the chamber HW between the drilling level from 4716level to the receiving chamber at 4881level. Assuming the red lines represent the planned ring holing contours, the green lines represent the idealistic final ring holing contours. The deviated holes caused stope unsteadiness after being charged and blasted off; and the surrounding areas were affected and had more stresses induced in the rock mass.

❖ BLASTING

It was reviewed in the study that most of VCR stopes on average the archived advance per blast 1.0m against a planned advance of approximately 2.0m. The blasting chambers have a lot of depressions on some blast holes, which is an indication of blasting operations reacting in a reverse direction, which is normally referred to as heaving or inverse cratering, refer to figure 49 and figure 50.

Figure 49: Top chamber inverse cratering of blast

Figure 50: Aggregate stones for stemming blast holes

4.2.3.2.1 Interpretation of (VCR) drilling and blasting

The performance of Cubex LHD drilling has greatly been interrupted by numerous aspects. These include workforce, mining air, drilling environment, machine failures and late availability of drilling chambers. These are seriously issues that need to be worked on and facilitate enhancement in LHD drilling performance. In Figure 47, after blasting and depleting the ore, the void remained in tacked indicating that there were no induced stresses coming from nearby stopes. The VCR yield good results and classic works due to good standard drilling and *blasting techniques. Figure 48 portrayed poor drilling of VCR causing seriously deviations of holes and adverse results of void scan. The 3340 VCR stope hanging wall was damaged severely thus triggering dilution of ore and tonnage losses. Quality of stemming material and quantity needs to be looked at as the observed material on site has too much sand it which compromises the efficiency of the aggregate. The aggregate stones need to form interlocking so that the explosives are confined. The current quality found on site cannot effectively contain the explosives. Inadequate stemming cause poor VCR blast outcomes and results into inverse craters called heaving on top chamber and ineffective advance and craters from the bottom chamber. In order to improve blasting outcomes, the of correct bottom stemming material and top stemming must be closely monitored and put in place by the blasters. And also, the stemming quality must be improved. Holing of all the blast holes should be identified and timing done from the bottom.*

4.2.3.3 VCR Redrills

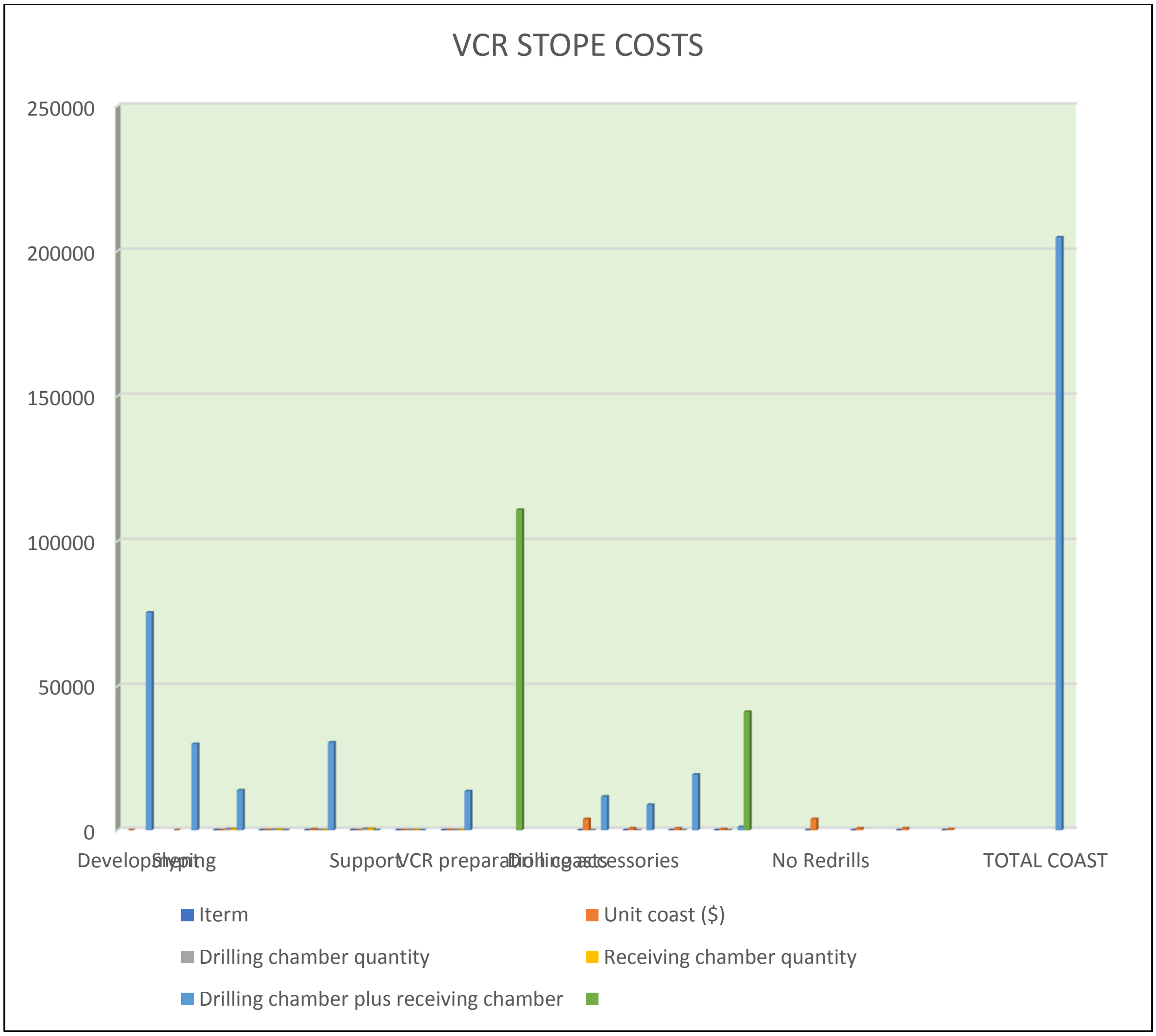
In the research, hole deviation during drilling is one of the biggest challenges at both MSV and SOB. The level of redrills which, in most cases are high and extra drilling holes of the VCR stopes prolong the finishing duration of drilling. These problems of redrills range between 40% and 80%. Research considered two analyses and compared the costs of two scenarios in drilling VCR stopes and taking into consideration of VCR redrills.

- **Scenario E: VCR chamber coast without redrills analysis**

In scenario **D**, the costs of development, slyping, support and drilling accessorise were added up and the results plotted inform of graphs. The average target cost to develop a VCR chamber both at drilling and receiving levels is $110867.90 and average consumables coast to drill a stope is about $41178.8 which summed up to $204797.90. see table 6 and graph 1 below.

Table 6: VCR chamber cost without redrills analysis.

	Iterm	Unit coast ($)	Drilling chamber quantity	Receiving chamber quantity	Drilling chamber plus receiving chamber	
Development		$37737.1 x(2)			$75,474.20	
Slyping		15014.4 x (2)			$30,028.80	
	Split sets	$16.22	430	430	$13,932.00	
	Cable bolts- 6m	$99.66	144	144	$28,702.08	
	Cable bolts- 20m	$332.20	46	46	$30,562.40	
Support	G5 Grout	$5.05	528	528	$5,332.8	
	Stubbies	$5.10	48	48	$489.6	
	welded mesh	$97.30	70	70	$13,622.00	
VCR preparation coasts						$110,867.90
Drilling accessories	Hammer	$3,918.27	3		$11,754.81	
	Drill bit	$681.24	13		$8,856.12	
	Drill rods	$668.77	29		$19,394.33	
	Adaptor	$390.94	3		$1,172.82	$41,178.80
No Redrills	Hammer	$3,918.27				
	Drill bit	$681.24				
	Drill rods	$668.77				
	Adaptor	$390.94				
TOTAL COAST					$204,797.40	



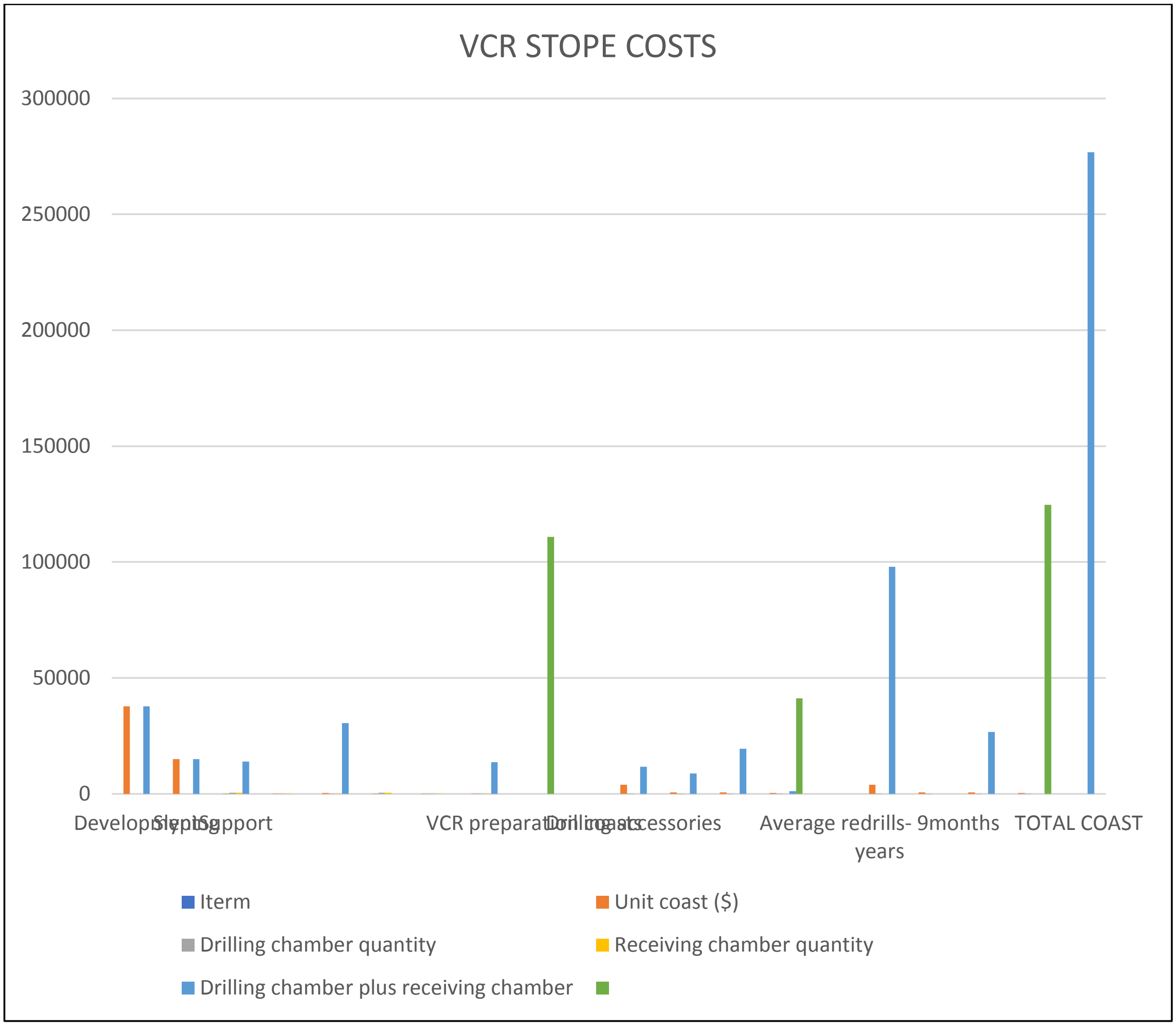
Graph 1: VCR chamber cost without redrills analysis.

❖ **Scenario F: VCR chamber cost with redrills analysis**

In scenario E, the costs of developing a VCR chamber, drilling accessories and redrills were added up and the results outlined inform of graphs as shown in table 7 and graph 2 below.

Table 7: VCR chamber cost with redrills analysis

	Iterm	Unit coast ($)	Drilling chamber quantity	Receiving chamber quantity	Drilling chamber plus receiving chamber	
Development		$37,737.10			$37,737.10	
Slyping		$15,014.40			$15,014.40	
Support	Split sets	$16.22	430	430	$13,932.00	
	Cable bolts- 6m	$99.66	144	144	$28,702.08	
	Cable bolts- 20m	$332.20	46	46	$30,562.40	
	G5 Grout	$5.05	528	528	$5,332.8	
	Stubbies	$5.10	48	48	$489.6	
	welded mesh	$97.30	70	70	$13,622.00	
VCR preparation coasts						**$110,867.90**
Drilling accessories	Hammer	$3,918.27	3		$11,754.81	
	Drill bit	$681.24	13		$8,856.12	
	Drill rods	$668.77	29		$19,394.33	
	Adaptor	$390.94	3		$1,172.82	$41,178.80
Average redrills- 9months years	Hammer	$3,918.27	25		$97,956.75	
	Drill bit	$681.24	60		$40,906.2	
	Drill rods	$668.77	40		$26,750.80	
	Adaptor	$390.94	15		$5,864.1	**$124,707**
TOTAL COAST					**$276,753.53**	



Graph 2: VCR chamber cost with redrills analysis.

4.2.3.3.1 Interpretation of VCR Redrills

The review over the last 9 months indicated that more than US$124,707 had been spent in VCR redrills which means the mine lost three stopes in redrills at an average grade of 1.89%, 168000 ore tonnes in three stopes and 3,175.2 contained copper (Cu); and this construed to US$26,989,200m opportunity loss per annum in form of metal and cash flow that could have been recovered. The study compared two scenarios as demonstrated in table 5 and table 7. The analysis was that there was a huge difference in expenses between scenario D and F. The cost to *develop a VCR chamber both at drilling and receiving levels, average consumables cost to drill a stope and the cost of redrills in the graph escalated from $204797.90 to $276753.53. Poor drilling control makes blasting a nightmare, because choice of blast holes to blast requires very good appreciation of where the blast holes are holing. Poor state of the drill rigs, lack of appreciation of geometry by most operators and aligning of the rig are the problems that need urgent attention to curb and address the situation of hole deviation.*

4.2.3.4 Interpretation on operation factors

The study concluded that:

- The operation unit processes determine economic viability of the whole mine.
- Operations turn inputs to outputs in mine productivity.
- Operations are vital and tactically the forefront of productivity and production.
- Flooding cause delays in production areas and has great impact on Cubex drilling.

4.2.4 MINE PRODUCTIVITY MAINTENANCE FACTOR

The study highlighted several engineering maintenance activities. The gaps between maintenance and mining operations were picked and these include concepts in maintenance, mining equipment, maintenance failure, consistency and equipment availability.

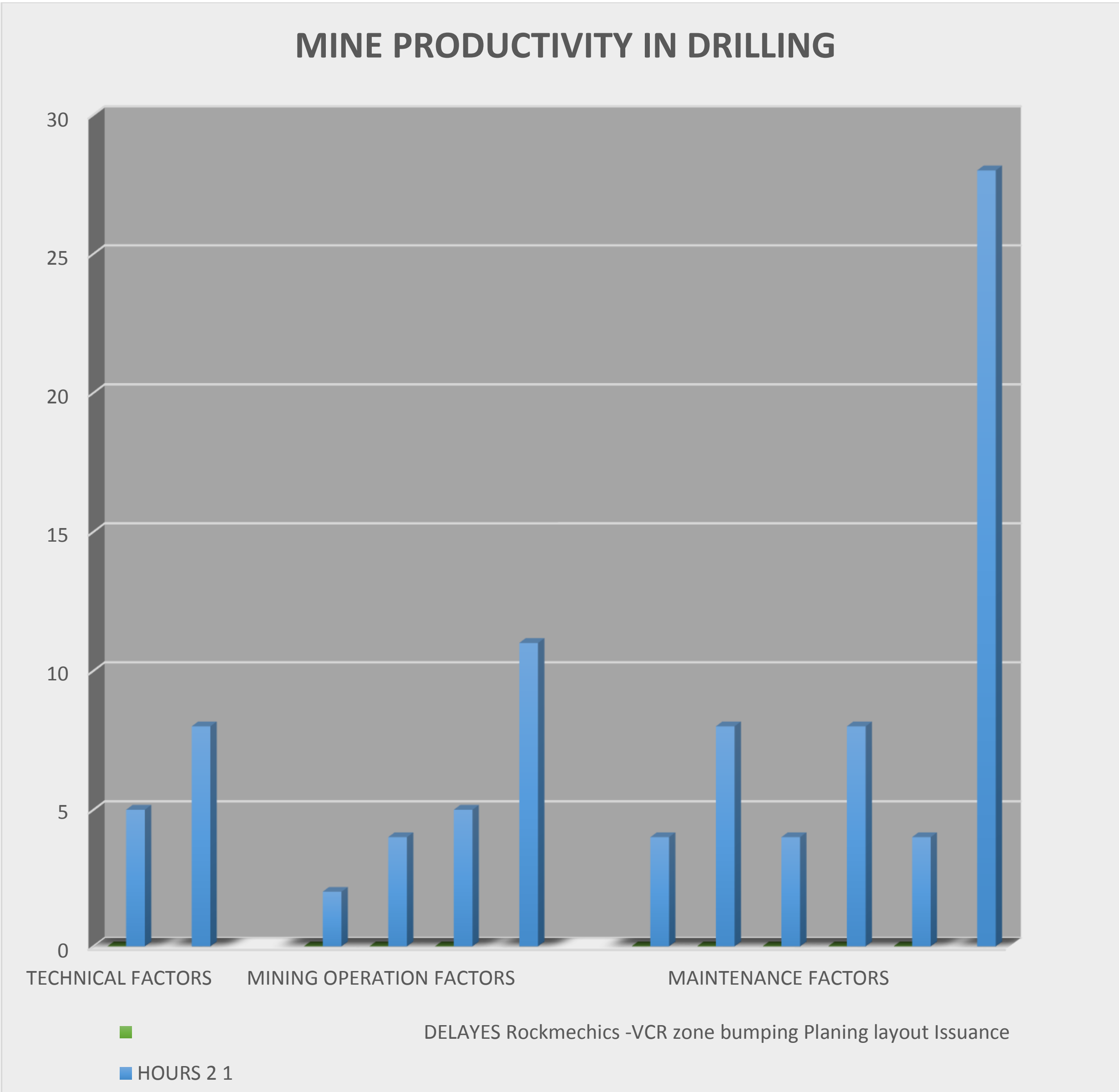
4.2.4.1 Cubex Machine availability

The inadequate and lack of availability of DHT spare parts at MSV AND SOB affect maintenance schedules negatively as well as availability of VRC drilling machinery. This creates failure to sustain required equipment for stoping and production. A bulky extent of targeted production tonnages in the Lower and Deeps sections can and only be achieved when there is good Cubex availability. The impact of Cubex machine availability and reliability on productivity in drilling of stopes is clearly illustrated in Table 8.

Table 8: September VCR drilling trend delays

	DELAYES	**HOUR**
	Rockmechnics -VCR zone bumping	2
	Planning layout Issuance	1
TECHNICAL FACTORS	Ventilation -hot temperatures and poor or visibility	5
	Total hrs	8
	Low mining water	2
MINING OPERATION FACTORS	Struggling to remove stuck silver hammer	4
	Material transportation	5
	Total hrs	11
	Hose rapture	4
	Replacement of extension cylinder	8
MAINTENANCE FACTORS	Oil leakage on the compressor	4
	Compressor tripped off on high temperature transducer	8
	Telescopic cylinder trunnion broken	4
	Total hrs	28

From Table 8, it is demonstrated that VCR drilling trend delays in the month of September 2023, demonstrated substantial delays in terms of Cubex machine drilling the stope were on maintenance factors as compared to other two mine productivity elements i.e. Technical factors (8hrs), Operation factors (11hrs) and Maintenance factors (28hrs).



Graph 3: VCR drilling delays, September 2023

Graph 3 illustrates September 2023 VCR drilling delays water fall graphs. The analysis from the graph clearly displayed great losses in VCR drilling was triggered by maintenance factors (59.6 %). The second one was operations factor (23 %) and last was technical factors (17%). The grand total was the sum of all three factors that caused delays in VCR drilling.

4.2.4.2 Interpretation of Cubex Machine availability

Table 8 clearly displayed that in September 2023 maintenance factors had caused a higher VCR drilling delays of 28 hrs (59.6 %) as compared to other two mine productivity elements which had Technical factors drilling delays of 8hrs (17%) and Operation factors delays of 11hrs (23%) respectively. Generally, the three mine productivity elements demonstrated that all of these units play a vital role in productivity in drilling and blasting of VCR stopes and works relatively in collaboration with one another. Strategically and tactically, MSV and SOB to be meeting planned VCR drilling meters targets requires good management and supervision throughout scheduled production period. Furthermore, these mine productivity elements deeply fail to conjointly coordinate and they are likely and possibly cause continuous shortfall of DTH-LHD meters.

4.2.4.3 Interpretation on maintenance factors

Maintenance factors in mine productivity in drilling and blasting of VCR stopes is an important aspect in ore generation and production at Mindola subvertical mine -MSV and South Ore Body -SOB. The study summarised that:

- ❖ The system is unable to sustain a large amount of targeted DTH- LHD meters to be drilled while maintaining high machine availability and acceptable performance.

- ❖ Low equipment availability, unreliability; and frequent break downs cause massive DTH-LHD meters losses as compared to other two elements in mine productivity.

4.2.5 AUXILIARY SERVICES

The study observed and concluded from the data collected that mining auxiliary facilities such as underground water management contribute to delays and losses in productivity in drilling and blasting of VCR stopes. For instance, flooding of production areas in the deeps and poor ventilation in VCR chambers. Usually other associated auxiliaries include low mining water for both development and stoping, delays in supporting VCR chambers and adherence to production schedules (Mining technology, 2023).

4.2.5.1 Mine water management

MSV and SOB have challenges in water management leading in flooding and failure by the major developers to meet planned targets. Figure 51 below shows water from the rock and nuisance water flowing in the foot wall drive which if not managed affects mining operations. Figure A5 and A6 in the appendices illustrate heath of pumping system and spares respectively.

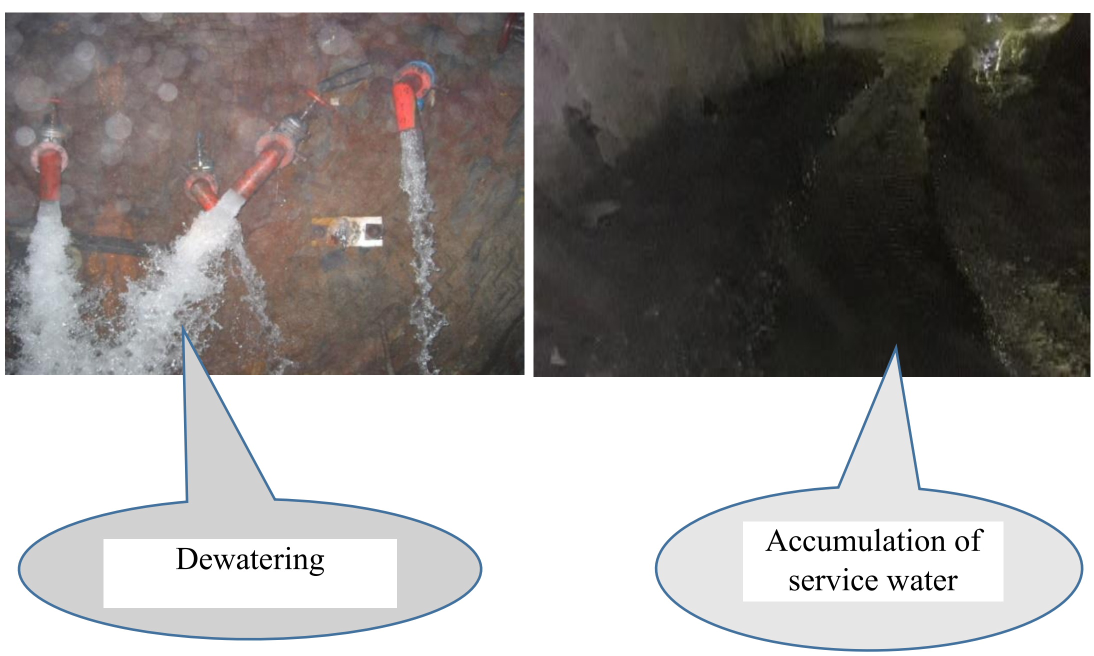


Figure 51:5790 level access to Redpath underground water

4.2.5.2 Interpretation on water management

Water management is at the moment one of most challenging factor in in stoping operations. Currently, underground operations have intersected major water bearing formations influencing the quality and quantity of water in the mining operations areas and in its surroundings and changes ground conditions, sometimes drastically. Water balance management and large water quantities have lately been one of the main reasons causing mine flooding especially when there are occurrences pump failures at main pump chambers like 2930l and 5360l exposing to some kind of risk related to stoping of VCR chambers. This circumstance cause significant effects on the smooth drilling and blasting of VCR stopes, for instance planned VCR stopes at 5960 levels schedule for production were not drilled and blasted due to the flooding of the area. There is failure in designing arrangement of handling water reticulation systems in development and production areas such in the deeps section.

4.2.6 SUMMARY OF FINDINGS

Management and supervision in mine productivity in drilling and blasting of VCR stopes predominantly concentrate on the planning, organizing, leading coordination and controlling. For good DTH -LHD production and focused planned meters and making sure of improvements in progressive productivity and effectively, it is important to turn inputs to yields in an effective way. From the interpretation of research review analysis findings, in summary it can be concluded that the mine productivity in drilling and blasting of VCR stopes depends on technical, maintenance of equipment and operation factors; and these elements require new innovations and technology both at strategically and tactical levels. Management and supervision of these key aspects of VCR stoping activities is dynamic and they have to be clearly analysed to understand failures of all contributing factors causing shortfalls in DTH LHD planned meters. Therefore, as observed from analysis, the challenges of mine productivity in drilling and blasting of VCR stopes, the following were the conclusions on data interpretation and major analysis summary findings:

4.2.6.1 Technical elements

The factors are first and vital in mining unit processes. Strategically, the technical personnel initiate plans of the mining firms and give guidance to operative crews on development and stoping of VCR chambers. Technical factors in mine productivity in drilling and blasting of VCR stopes are key phase in stoping and ore production. The study concluded that:

- ❖ Technical services provided to mining operations are alike at global, regional and local levels. For instance, planning section in the mining industry gives guidance as to how the development and stoping activities will be executed and geology section helps in prospecting i.e. providing information on folded ore body, estimating and establishing defined mine mineral resources. It also provides guidance to the mining companies' estimation of mining cost and production viability.

  - ❖ Provision of inadequate technical information such as development mining layouts to operations; and

  - ❖ Delays in providing strategic management plans for stoping operations and ineffective implementation of plans such completion of capital projects for instance mining of main ramps to production areas.

- ❖ Providing technical knowledge to mining operations officials to implement production activities.

4.2.6.2 Maintenance factors in mine productivity

Maintenance factors in mine productivity are an important aspect in ore production at MSV mine SOB. The study found that:

- ❖ Management failure in ensuring adequate machinery maintenance and replacements of spare parts for Cubex machines.
- ❖ Low equipment -Cubex drilling machines, availability, unreliability and frequent break downs resulting in massive delays and loses in productivity and production. This contributes massive DTH-LHD meters losses as compared to the other two elements in mine productivity. Based on the above, huge financial investment in maintenance is needed.

4.2.6.3 Operational factors in mine productivity

Tactically, operational unit processes control economic viability of mining firms at global, regional and local levels. The study found that:

- ❖ Management failure in providing and releasing funds for replacement of old reliable equipment (Cubex drilling machines);
- ❖ Management failure in strategic and tactical effective implementation of productivity and production plans in mining unit processes (drilling, blasting, charging) and auxiliary operations such as water management systems; and
- ❖ Delays in development and production drilling of ends and VCR stopes (mining of main ramps to production areas and preparation of VCR stopes), refer LHD tracking sheets and production performances in appendices in table A1 ,A2 and A3).
- ❖ Operations turn inputs to outputs in mine productivity in stoping operations.

- ❖ Ming operations are the forefront of productivity in drilling and blasting of VCR stopes and ore generation.

CHAPTER 5 DISCUSSION OF RESULTS

This chapter outlines the discussions based on of the prevailing mine productivity in drilling and blasting of VCR stopes, questions of the research and objectives of the research in contrast to the research findings and or comparison.

5.1 Discussion of findings with respect to existing literature

From the analysis of mine productivity in drilling and blasting of VCR stopes, all mining units processes contribute to production performance of the mines. To address the challenge of stoping productivity improvement, management and supervisors will need to make moves on two levels: first to achieve short-term gains in stoping operations, and second to set the operations on the right course for higher long-run productivity performance in drilling and blasting of VCR stopes.

On the first level, the way onward is vibrant. The research identifies that capital investment, maintenance and operating factors have been the main drivers of productivity in drilling and blasting of VCR stopes decline. Stoping works also needs to continue on lowering nonlabor operating expenditures such as reduction of VCR stope redrills, boosting output and major efforts have to be undertaken to drive costs out in operations.

Moving to the second level of actions, the research sees three important areas of focus to address the root causes of productivity in drilling and blasting of VCR stopes decline. These are as follows:

- ➢ Entrench effective management operating systems at both MSV and SOB mines. Doing this will create greater transparency on operations performance. The operating systems should also free up people and resources to prioritize productivity and operational excellence, and support effective performance management. This approach will help resolve an important challenge that the mining company has struggled with making productivity performance and its measurement a priority. There has typically been a focus on improving one or two of the variables, such as reducing cost, lowering capital intensity, or increasing throughput. But a holistic focus on the drivers of productivity in drilling and blasting has to be shared at multiple levels of the mines for instance from top management to the grass root of mining operations.

- Management has to priorities operational excellence and capabilities development of stoping areas. Operational excellence implies a continuous focus on improvement and enables ongoing cost reduction and throughput improvement. To do this requires a determined focus on eliminating all forms of waste, reducing variability, and improving productivity of assets through advanced reliability and maintenance approaches, together with increased flexibility about changing mining environment conditions. All three elements in mining struggle with capabilities constraints and need to address them: building up the capabilities of the three elements and other supporting services of the mining firm is a necessity for two mining sites to be able to deliver on all the levers involved in productivity improvement in stoping operations.
- Mining-company management should encourage openness to trying new approaches and to adopting new technologies. At the same time, mining firm should use advanced analytics to harness the potential of the vast amounts of data generated in typical modern mining operations in order to boost productivity-improvement initiatives. To make this happen will require a broadening of the expectations of what operations leaders are responsible for, and tighter integration with other corporate functions. It will also necessitate looking beyond the boundaries of the mining firm-Mopani to seek inspiration from other industries' successes. Partnering

between mining firm and stoping equipment and technology providers should also increase, so innovation in mining can succeed more broadly. This means that the mine will be able to succeed in the race to achieve higher productivity in stoping and this will be among the biggest achievement in in mining operations. The mentioned initiatives are important enablers of productivity improvements in drilling and blasting of VCR stopes. Thus, linked with a commitment from all stakeholders to monitor productivity performance in stoping, there will be great enhancement in run of mine production.

The article correspondence by Humphreys (2019), he stated that the mine productivity factors have significance in mining since mining operates in an industry with diminishing assets. Productivity growth has first to overcome the effects of mine units processes before mining firms can make any real production headway. Though much debate on mine productivity focuses on the issue of grade decline in the outstanding available resources, mine productivity goes a bit wider than this.

According to Carvalho (2017), in underground mine productivity, mining ores are usually aggregated in sectors such as base metals, fossil fuels, and precious metals. These metals such as iron have been mined for a long time, while others such as aluminum were recently mined and the total amounts of metals extracted depend on applications of technical skills, infrastructures, machinery, and tools to have viable production.

Also Flesher in 2018 carried out a study and showed that the mining industry's production efficiency performance is possibly the main element of its long-term capability to convert greater product prices into improved incomes. The research was specifically intended to track true underlying productivity such as how much total material (ore and waste) is being shifted by using what amount of resources. Matysek and Fisher also stated that success in mine productivity innovations needs a number of other mining aspects such as taking new ideas, converting ideals into useful processes, interacting with groups undertaking similar mining activities.

Generally, Underground mine productivity in stoping activities globally, regionally and at local level are cardinal chain links in production and require adequate participation from all three mine productivity element, namely, technical, operations and maintenance. The research found that technical, operations and maintenance factors, each contribute uniquely and differently to the productivity in drilling and blasting of VCR stopes and associated productivity, but must be coordinated together for the greatest effectiveness.

5.2 Discussion of findings with respect to research questions

- ***What are the major causes of stoping failures at Nkana.***

The deficit of DTH LHD meters/ major causes of stoping failures at Mindola Subvertical (MSV) and South Ore Body (SOB) leading into decline and disruptive of ore generation and delivery to the processing plant are basically technical, mining operations and maintenance factors and also auxiliary processes.

- ***What could be done to improve on mine productivity in drilling and blasting at Nkana mines to meet Nkana long hole drilling- down to hole -(LHD-DTH)) planned targets?***

The study reviewed three important aspects of the mine productivity and production, taking into consideration of all underground production aspects in stoping operations. The study shows that all three mine productivity elements at MSV and SOB are cardinal chain links in the mining business. The improvement on mine productivity can be attained by management and supervisors identifying issues affecting mining sequences, enhancing innovations in the productivity elements, strictly adherence and monitoring of management strategic and implementation tactic production plans as well as tackling each and every finding.

5.3 Discussions of findings with respect to main objective

The research objective was to investigate root causes of mine productivity in drilling and blasting setbacks and develop a criterion to achieve productivity improvement in drilling and blasting at Mopani, Nkana mines MSV. With respect to the technical, mining operation and maintenance factors in the chapter 2 and data interpretation and analysis in chapter 4 really gave clear illustration of the main objective of the research.

The research determined that serious challenges and shortfall DTH-LHD meters at MSV and SOB were as a result of the following root causes:

- Technical: Delays in making management strategically plans and tactical implementation of production concerns.
- Mining operation: Setbacks in mine unit processes such development, VCR chamber preparations, redrills (Table 7 and graph 2).
- Maintenance factors: Low Cubex machine availability, unreliability; and frequent break downs cause massive DTH-LHD meters delays and losses Table 8 and, graph 3.

In order to achieve a sustainable productivity in drilling and blasting of VCR stopes, proper practices should be followed when developing, preparing VCR chambers, drilling, charging and blasting stopes and adherence to standards such as drilling of holes as per plan and putting immense emphasis on the dope standards. Blocked holes to be opened by pumping so as to increase the number of holes being blasted. Remedial actions in combatting dilution control to be seriously taken by supervisors and set genuine targets in blending ratios for the life of the mine.

It is also imperative to provide enough numbers of personnel required to service and repair Cubex machines. Adequate numbers of service men will ensure not only better availability of Cubex machines but also better utilization which will translate into higher productivity in stoping.

5.4 Discussions of findings with respect to specific research objectives

a) Investigate productivity in drilling and blasting of VCR stopes;

1) With respect to Cubex machine availability in section 4.2.4.1, in table 7 and in graph 3 of chapter four, proved that all three productivity factors (technical, mining operation and maintenance) in mine productivity are key in both production and production. All three elements play vital roles in the economical aspect of the mining firms; and are influential in mine productivity in drilling and blasting of VCR stopes and vital in ore through put to improve production and always must be well looked into for enhanced mine stoping and production.
2) Virtuously, in order to have reduction of production delays and bottlenecks in in development and preparation of VCR stopes; management should ensure improvement in supervision and implementations of production plans and thus, this will enhance sustainability productivity in drilling and blasting of VCR stopes, ore through put and production.

***b) Determine root causes of drilling and blasting failures*.**

1) **Technical factors**

Factors such as inadequate geological information of stoping areas, delay in VCR preparation and issuing drilling layouts have great impact on production.

2) Mining operations

With respect to 4.1.1 in development drilling and figure 41: 5814/1580 vent access face substandard, figure 47 demonstrating VCR poor drilling and void scan results in chapter 4, the results showed that there are three main factors affecting productivity and production. These are technical, mining operation and maintenance. The study further revealed that there are delays in development such as drilling of ends and stoping activities in the production areas like folded VCR and SLC chambers, hence cause poor productivity and production. Stopes are taking longer to prepare so as to align with production and this has a negative impact in the short term on production because of limited ore sources.

In the review of mine productivity issues, the study clearly established the reasons as to why some of most chambers are being delayed:

- ❖ Stope development delay and chamber support delays – most contractors engaged in stope support are taking long to hand over the chambers in readiness for drilling. Therefore, the Cubex machine will be engaged in others works like drilling of water holes.
- ❖ Production and development too close to drilling sites, hence disturbing drilling during blasting operations as men will be cleared from the sections prior to charging and blasting either in Primary, Secondary or Stope blasting.

- Deviations during long hole drilling- This is as a result of centralizers, stingers and outriggers on most machines not working.
- Flooding in production areas delay drilling and affects ventilation circuit as it takes time to dewater flooded areas like 5956 level and Redpath area.

3) Maintenance factors

Maintenance factors such as low Cubex machine availability contribute most on the shortfall of DTH-LHD meters and loss of production at MSV and SOB**.**

c) *Recommend viable remedial measures to improve long hole drilling- down to hole -(LHD-DTH) meters output and productivity*.

With respect to the analysed results obtained in chapter 4 from the operation factors such as the drilling of development ends and drilling accuracy illustrations in section 4.2.3.1 and Figure 47 at 5735 level 580 VCR. It clearly demonstrated that poor VCR drilling has great impact on stoping and production. Furthermore, mining operation factors such as Development, VCR chamber preparations, charging and blasting in mining revealed delays in production.

With respect to maintenance point of view, the analysis such as the one in chapter 4, table 8 and graph 3 clearly demonstrate that the huge losses in DTH-LHD meters are due to the contribution of maintenance factors and trailed by operation factors.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter outlines the conclusions and recommendations of the research whose topic was “Mine productivity in drilling and blasting of VCR stopes”. It separately discusses the highlights on the conclusion and recommendations of the study findings.

6.1 CONCLUSIONS

Collusions with respect to the main objective

The main objective of this research was to investigate root causes of mine productivity in drilling and blasting setbacks and develop a criterion to achieve productivity improvement in drilling and blasting at Mopani, Nkana mines -MSV and SOB. The research determined that delays and shortfall of DTH-LHD meters in mine productivity in drilling and basting of VCR stopes was as a result failure of technical, mining operation and maintenance factors as well as supervision and management.

6.2 Conclusions with respect to the specific objectives

6.2.1 Investigate productivity in drilling and blasting of VCR stopes.

From the research observations, most of the optimal assessments and analyses of mine productivity in stope drilling and unit processes such as mine design plans in chapter 4 section 4.2.2 scenarios (A and B), 4.2.1 management and supervision and figure 48 demonstration at 4716 /3340 VCR poor drilling and void scan results. *Hence, all this evidenced that all three productivity factors in mine productivity in drilling and blasting of VCR stopes are key in* *enhancing in stoping, ore generation, production throughput and so they have to be well-thought-out for smooth operation of the mining firm.*

6.2.2 Determine root causes of drilling and blasting failures

From the survey questionnaire carried out at MSV and SOB, the results of the research show that there are main factors affecting productivity in drilling and blasting of VCR stopes and production. *These are in technical, mining operation and maintenance. The study further revealed that there are delays in development such as drilling of ends and stoping activities in the production areas like VCR and SLC-folded chambers, hence the cause of poor stoping and ore production. The supervisory, management, equipment for drilling, personnel in drilling activities and culture of working surrounding the mine productivity activities are the root causes in most extents of concern. The areas identified to be the major causes of shortfall in DTH-LHD operations and ore production require immediate mitigation to improve the efficiency of productivity and production by adhering to strategic and tactical accomplishments of stoping plans.*

6.2.3 Recommend viable remedial measures to improve long hole drilling- down to hole - (LHD-DTH) meters output and productivity.

From the analysed results obtained in chapter 5 from the operation factors such as the drilling of VCR stopes and drilling accuracy illustrations in section 5.1.1 and Figure 46 and 47. *It is evidently clear from the three elements that MSV and SOB have all the mining systems in place. However, the noticeable teething troubles remain with the personnel influence towards work. This is attributed to midst other things obliviousness over the benefits of adhering to mine productivity activities critical controls, procedures in mining unit processes, worker fatigue management.*

6.3 RECOMMENDATIONS

The research has brought to light a number of key issues that determine mine productivity in drilling and blasting of VCR stopes. Based on the findings from the field, the researcher recommends the way forward to kick start the process of enhancing stoping operations at ore production sustainability at Mindola subvertical- MSV and South Ore Body -SOB.

6.3.1 Recommendation on operation factors in mine productivity

6.3.1.1 Drilling and blasting

This play critical role in mining unit processes, and hence the following have to be adhered:

- ❖ Holes to be drilled as per plan with immense emphasis on the DTH drilling pattern.
- ❖ Stemming to be bagged for standard packaging.
- ❖ Ensure correct plugging at 0.5 m – 0.8m
- ❖ Blocked holes to be opened by pumping so as to increase the number of holes being blasted.
- ❖ Proper practices should be followed when drilling, charging and blasting stopes in order to improve on stoping efficiency.
- ❖ In order to improve stope blasting outcomes, the of correct bottom stemming material and top stemming must be closely monitored and put in place by the blasters. And also, the stemming quality must be improved. Holing of all the blast holes should be identified and timing done from the bottom. Strict use of trained personnel in plugging and charging of stopes.

6.3.2 Recommendation on technical factors in mine productivity

6.3.2.1.1Mine planning

- Detailed technical information about development and production has to be obtained prior to issuance of dopes/ layouts to mining operation crews. This has to be seriously taken care of by supervisors and management as this will combat unnecessary excavation of bypasses like the ones at 5485 level.
- Production indicators must be developed to look at quality rather than quantity.
- Drilling crews to be trained on mining of VCR stopes and interpreting layouts and mining plans.

6.3.3 Recommendation on Maintenance factors in mine productivity

6.3.3. 1 Machine availability

- The management must ensure that there is proper planned maintenance and availability of Cubex machine spare parts. There is need to speed up the repairs and maintenance of Cubex machines (Cubex 18 at MSV) and consequently increase the availability and utilisation of equipment.
- Management should provide enough spare part inventory to reduce machine between mean time failures.

7.4 6CADEMIC RECOMMENDATIONS FOR FURTHER STUDIES

In the current study, mine productivity in drilling and blasting of VCR stopes and production delays were confined to Nkana underground mine environment. However, further studies on mine productivity in the mines to improve on production from ore sources to processing plants should be carried out both underground and surface environments.

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LIST OF APPENDICES

APPENDIX 1: QUESTIONNAIRE (CITED ON PAGE 63)

SELINUS UNIVERSITY
OF SCIENCES AND LITERATURE

Doctor of Philosophy in Mining Engineering

Faculty of Engineering & Technology

All respondents:

I am Jairo Ndhlovu, UNISE2495IT, a student at the Selinus University pursuing Doctor of Philosophy in Mining Engineering. At present, I am in the final stage of my study and conducting research on **"MINE PRODUCTIVITY IN DRILLING AND BLASTING OF VERTICAL RETREAT STOPES."**

Study questionnaire is merely for educational purposes and any positive response to the research questions will be greatly appreciated.

Please should you need any clarifications on the matter call the following lines:

0976854023/0964696869

Email: Jairo.ndhlovu.jn@gmail.com/jairo.ndhlovu@mopani.com.zm

Questionnaire directions:

Only answer one option in the box.

Write short notes where necessary.

No writing name or contact details.

No appending signs.

Segment 1

1. Sex

Masculine ()

Feminine ()

2. Oldness- years

20-25 ( )

26-30 ( )

36-40 ( )

41-45 ( )

46-50 years ( )

3. Schooling

- ❖ Licence/permit ( )
- ❖ Certificate ( )
- ❖ Scholar Degree ( )
- ❖ Advanced degree ( )

4. Job position…………………………………………

5. Mining experience

- ○ 1- 10 years ( )
- ○ 11 – 20 years ( )
- ○ 20 – 30 years ( )
- ○

RATING SCALE				
1=Very poor	**2= Poor**	**3=Good**	**4=Very Good**	**5=Excellent**

MINE PRODUCTIVITY IN DRILLING AND BLASTING QUESTIONNAIRE

	ITEM	**1**	**2**	**3**	**4**	**5**
1	Preparations of development and production mining areas (drilling layouts, electrical services, ventilation systems and machinery).					
2	Mining officials making follow ups on mining regulations (appointments of mine captains, section bosses and qualifications).					
3	Mining officials checking compliance, critical controls of vcr stopes (support size of excavations and back filling requirements).					

MINING MEASURES AND OTHER CHECKS

	ITEM	**1**	**2**	**3**	**4**	**5**
4	Number of mining officials visiting working places and checking on standards					

	a) Drilling (drilling angle, length of drill rods and flushing of holes).					
	b) Charging (quality of charging rods, cleaning of hoes and stemming and charging pattern).					
	c) Blasting (blasting cable blasting schedule and blasting license).					
	d) Auxiliary services (quality of water ,water control and mine air)					
	e) Quality of track laying in main tramming levels (rails maintenance, scotch crews, installation, rail joints and electrical earth droppers installation).					
	f) Ventilation in working areas (ventilation seal quality, force fan installation and air take and temperature).					
5	**Equipment care**					
6	Cleanliness of workshop (waste management, dust, fuel handling and fuel separators).					

7) Any environmental and safety procedures in place (water treatment, working at height, energy isolation fatal hazard protocols) …………………………………………

Checks in development and VCR production holes

	ITEM	**1**	**2**	**3**	**4**	**5**

8	Preps in the drilling area (life line installation, ventilation compliance drilling accessories).					
9	Preps in the receiving chamber (removing of backlashed waste, support rehabilitation).					
10	Drilling accuracies by rig operator (rigging of machines, compliance to the drilling layouts).					
11	Machine knowledge (manual operations procedures, electrical and mechanical basics and training).					
12	Check list adherence (filling of check lists, signing, and handover notes record of break downs).					
13	Layout adherence (angles, length of holes number of per hole ring).					
14	Ground formation knowledge (bedding planes cracks joints and roof stability).					
15	Supervisors experience and skills (training and familiarity of operations communication with team members).					
16	Hole deviation knowledge (angles and machine rigging).					

25) Causes of poor DTH drilling in mine production areas……………………………………………………………….

26) Improve the DTH drilling productivity and blasting of VCR stopes production suggestions ……………………………………………………………………………………………………

THANKS FOR YOUR TIME

APPENDIX 2: MCM LONG HOLE DRILLING PERFORMANCE

TABLE A1: MCM LONG HOLE DRILLING PERFORMANCE

MOPANI COPPER MINES PLC

LONG HOLE DRILLING

		2nd Week (4th to 10th)			MTD			Month End		
Description	**Units**	**Actual**	**Internal Plan**	**Variance**	**Actual**	**Internal Plan**	**Variance**	**Forecast**	**Internal Plan**	**Variance**
Up-Hole Drilling										
Mufulira Mine	m	-1,951	2,866	-4,817		4,747	-4,747		11,298	-11,298
Sync North	m	0	0	0		0	0		0	0
Nkana South	m	-2,000	1,900	-3,900		3,900	-3,900		7,800	-7,800
Nkana North	m	0	1,200	-1,200	1,098	2,641	-1,543	3,755	5,755	-2,000
Total SLC	**m**	**-3,951**	**5,966**	**-9,917**	**1,098**	**11,288**	**-10,190**	**3,755**	**24,853**	**-21,098**
Down Hole Drilling										
NkS Cubex	m	-870	480	-1,350		1,320	-1,320		2,125	-2,125
NkS M6	m	0	0	0		0	0		0	0
Nkana South	m	-870	480	-1,350	0	1,320	-1,320	0	2,125	-2,125
Nkana North	m	549	480	69	933	480	453	2,200	2,200	0
Total DTH	**m**	-321	**960**	**-1,281**	933	**1,800**	**-867**	**2,200**	**4,325**	**-2,125**
Support Hole Drilling										
Mufulira Mine	m	-809	1,783	-2,592		3,565	-3,565		7,640	-7,640
Sync North	m	0	0	0		0	0		0	0
Nkana South	m	0	0	0		0	0		0	0
Nkana North	m	1,604	1,517	87	2,014	3,033	-1,020	6,500	6,500	0
Total Support	**m**	**795**	**3,299**	**-2,505**	**2,014**	**6,599**	**-4,585**	**6,500**	**14,140**	**-7,640**

Weekly Comments - Up Hole Drilling

Mufulira : Above
Sync North : Below budget due to Alpan equipment breakdown
Nkana South : On budget
Nkana North : Below target due to delayed drilling commencement by Opermin after the 4440L_5150N SLC stope was observed to be full of ore resulting from sloughing. The ore could not be trammed out of the stope due to shutdown works currently underway.

APPENDIX 3: LDH PERFORMANCE PLAN

TABLE A2: LDH PERFORMANCE PLAN

LONG HOLE DRILING (LHD) PERFORMANCE TRACKING				Date	17-Oct-23	17-Oct-23
	MTD				Monthly target	Projection
SAFETY	Clear					
	Plan	Actual	Var		Monthly target	Forecast
Longhole Drilling (Boomer)						
Opermin	3,041	448.00	-2,593		3,921	1,328
Tauro	1,600	672.2	-928		2,638	1,206
Total Longhole Drilling	**4,641**	**1,120.2**	**-3,521**		**6,559.0**	**2,534**
Support Drilling						
Relaint	0	0	0		0	0
Opermin	0	1,470	1,470		0	1,126
Tauro	0	1,164.5	1,165		0	1,012
Total Support Drilling	**0**	**2,635**	**2,635**		**0**	**2,138**
Cubex Drilling						
Cubex 15	1,440.0	1,130.50	-309.5		2,080	1,280
Cubex 16	880.0	0.00	-880.0		1,600	720

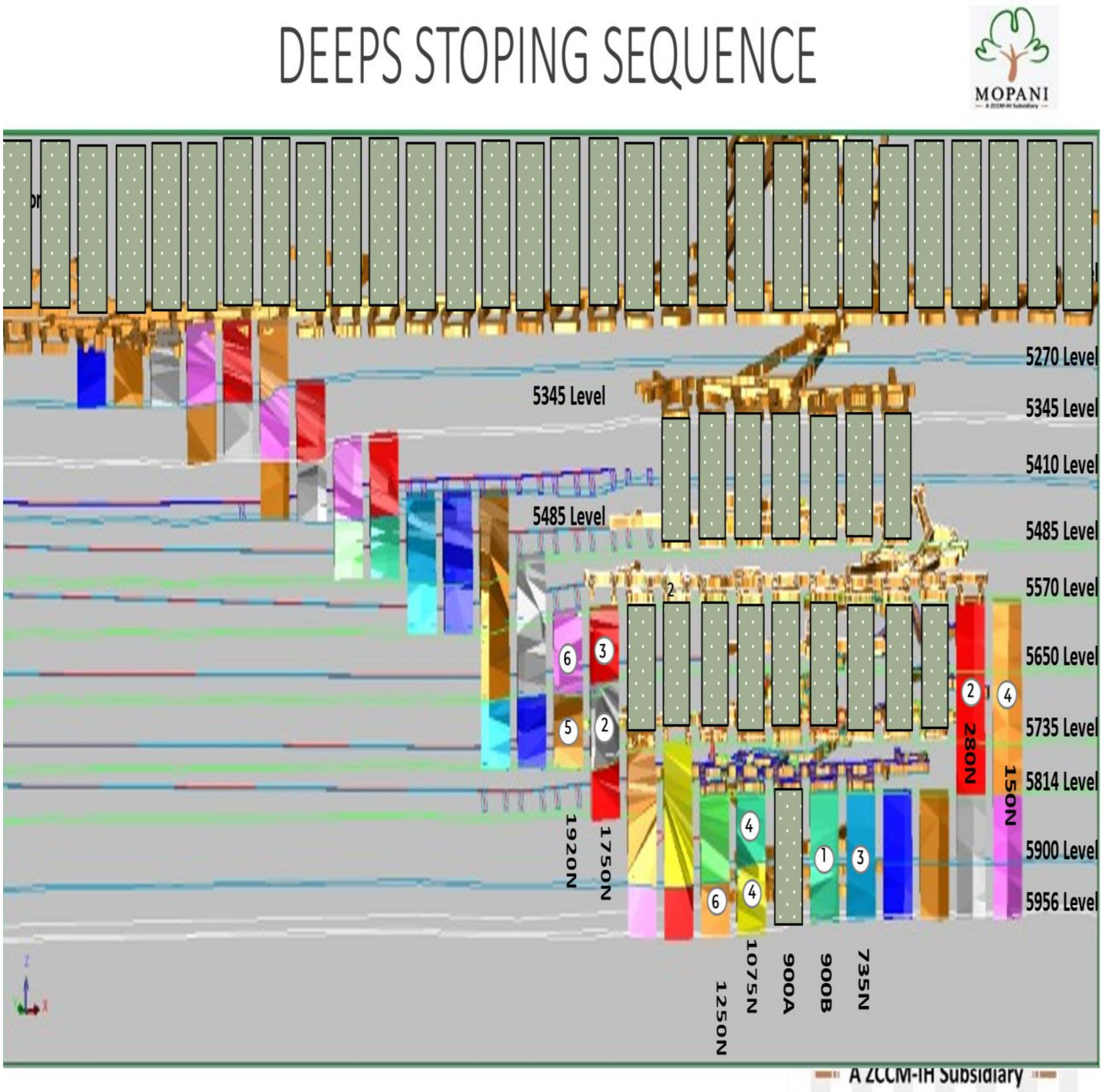
APPENDIX 4: MSV TRACKING REPORT NOVEMBER 2023

TABLE A3: MSV TRACKING REPORT NOVEMBER

		1	2	3	4	5	6	7	8	9
		Fri	**Sat**	**Sun**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**
TYPE OF LHD		**27-Oct**	**28-Oct**	**29-Oct**	**30-Oct**	**31-Oct**	**1-Nov**	**2-Nov**	**3-Nov**	**4-Nov**
Down Holes	**Internal Plan**	160.0	160.0	160.0	160.0	80.0	160.0	160.0	160.0	160.0
	Actual	148.8	186.3	125.4	152.1	153.9	143.1	175.2	-	-
Upholes	**Internal Plan**	-	-	41.0	400.0	400.0	400.0	400.0	200.0	-
	Actual	-	186.0	260.0	80.0	-	-	-	-	-
Total	**Internal Plan**	**160.0**	**160.0**	**201.0**	**560.0**	**480.0**	**560.0**	**560.0**	**360.0**	**160.0**
	Actual	**148.8**	**372.3**	**385.4**	**232.1**	**153.9**	**143.1**	**175.2**	**-**	**-**

APPENDIX 5: MSV-DEEPS STOPING SEQUENCE

FIGURE A1: MSV-DEEPS STOPING SEQUENCE



APPENDIX 6: PUMP CHAMBERS HEALTH STATUS

FIGURE A2: PUMP CHAMBERS HEALTH STATUS

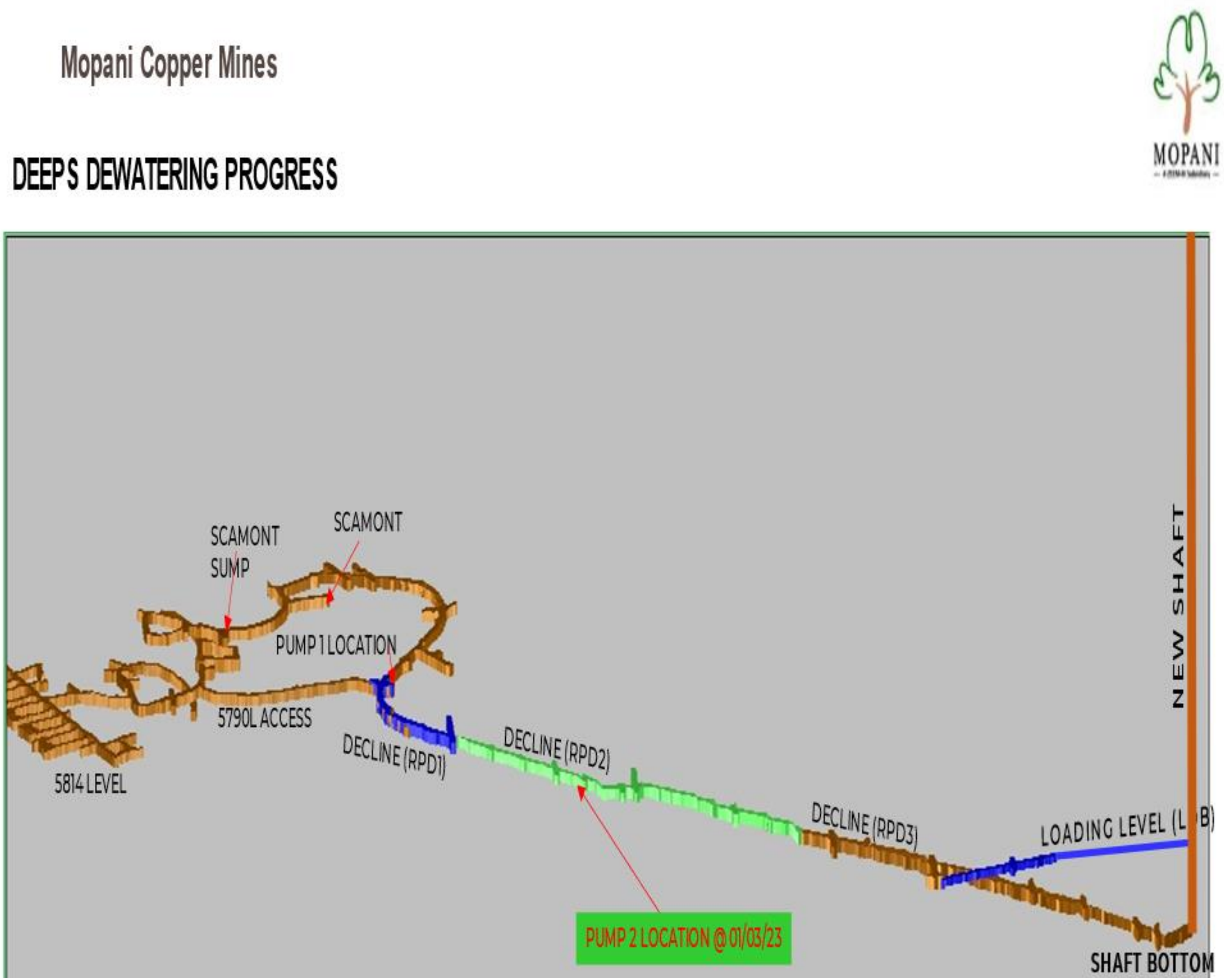
Pump Chambers Health Status

MOPANI

2930'L PUMPS	CONDITION	STATUS	GENERAL CONDITIONS	REMARKS (60% Safe)
SITE 1		Running	Pump in good condition	Pump in good condition
SITE 3		No pump and motor	Motor available but pump base needs to be fixed	Motor available. Pump needs to be sourced
SITE 4		Running	Pump in good condition	One of the trusted pumps (running at 165Amp)
SITE 5		No pump	Motor available. Pump not available	Motor available.Refurbished pump to be dispatched on 17th July 2023.
SITE 6		Running	Pump in Good Condition	One of the trusted pumps (running at 160Amp)
SITE 1		Pump and motor available	New 4 Stage pump installed. Pump in the process of being commissioned	New 4 stage (ECM)Installation WIP
SITE 2		Not running	No pump and Motor Down to Earth	No Pump, Motor under repair at rewind shop:
SITE 3		Running	Pump in Good Condition	One of the trusted pumps(SKMS) (running at 60 Amp)
SITE 4		Running	Pump in Good Condition	One of the trusted pumps(Aklin) (running at 60 Amp)
SITE 5		Running	Pump in Good Condition	One of the trusted pumps(Aklin) (running at 60 Amp)
5360'L PUMPS	**CONDITION**	**STATUS**	**GENERAL CONDITIONS**	**REMARKS(33% Safe)**
SITE 1		Running	Pump in Good Condition	One of the trusted pumps(ECM) (running at 80 Amp)
SITE 2		Not running	No Pump, Motor down to earth	Worn pump dismounted-13/03/23 and Taken to surface for repairs - SKMS;
SITE 3		Running	Pump running with low efficiency	Pump needs to be replaced (running at 60 Amp)

APPENDIX 7: DEEPS -RED PATH DEWATERING PROGRESS

FIGURE A3: DEEPS -RED PATH DEWATERING PROGRESS



SOLID MODELLING OBJECT REPORT

Layer Name: red_path2.dtm

Object	Triangulation	Object Name	Triangulation Name	Validated	Status	X Min	X Max	Y Min	Y Max	Z Min	Z Max	Surface Area	Volume	Dist (m)	Pumped (m)	Variance (m)	Volume (m³) Per Mtr	Pumped Meters to date	Volume Pumped (m3)	Remaining Volume to Pump (m3)	Remaining Days to Pump	FINISH DATE		EXPECTED FINISH DATE AS @ 1ST Feb
2	2	RPD1		TRUE	solid	30939.02	31037.35	37489.73	37512.01	-556.105	-533.715	3903	5217	110	110	0	47	110	5,217	0				
2	2			TRUE	solid	31007.73	31457.96	37466.96	37741.22	-621.225	-550.037	15089	19709	540	0	-342	37	197	7,104	12,575	47	18-Apr-23		17-Jun-23
1	1	RPD3		TRUE	solid	31324.68	31645.09	37257.06	37884.29	-658.199	-598.199	12059	15711	400	0	-400	39		0	15,711	0	19-Jun-46		23-Jul-46
2	2	LOB		TRUE	solid	31450.74	31556.45	37706.13	37763.34	-620.846	-607.672	2238	2170	852	0	-742	3		0	2,170	0	20-Aug-09		26-Aug-09
												33289	42807	1902	110	-1484	23	307	12,411	30,456	186	20-Aug-09		26-Aug-09

APPENDIX 8: DEEPS- BANDA RAMP DEWATERING PROGRESS

FIGURE A4: DEEPS BANDA RAMP DEWATERING PROGRESS