

**Review of Successes and Failures of  
Mechanisation Trials on Platinum Mines of the Bushveld Complex**

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the Masters of Science in Engineering

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## DECLARATION

I declare that this research report is my own independent work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. This project report has not been submitted before for any degree or examination in any other University.

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.....day of ..... (Year).....

## **ABSTRACT**

Mine mechanisation seems to be failing in the Bushveld Complex (BC) although it has been promoted on the basis of superior qualities to the conventional mining methods. This is particularly true for the extra low profile (XLP) mining method. The reasons for the successes and failures were observed from case studies and previous work captured through a comprehensive literature review. Interaction with industry experts and mine operators provided further insight into the suitability of mechanised mining systems on the BC.

Technology trials on the BC included non blasting mining methods in the form of cutting discs which were not successful but provided encouraging data for future development. The low profile (LP) and extra low profile (XLP) mining technology is the only tried technology that has formed part of the mining mix in the BC albeit with challenges. In some operations where mine mechanisation technology was tried the performance was poor resulting in discontinuation, conversion to hybrid mining method and/ or reverting to the conventional mining method.

Dilution makes the XLP and LP mining unsuitable for mining narrow tabular ore bodies due to the amount of waste that dilutes the ultimate grade of the mine. The technology that is suitable for mining mechanised equipment must be able to ensure that it does so safely and without compromising the value in terms of grade. The current mining methods utilising mechanised equipment found in the BC has resulted in lower grades because of dilution caused by large excavations which are required to accommodate the equipment.

It is imperative to understand the impacts on value the mining method creates and/or destroys for the Life of mine. There are other mining methods which must be further investigated. These include non-blasting and long hole stoping mining methods, both have the same attributes of safety and high grade. Both systems remove persons from dangerous working areas and mining is concentrated on the mining channel width resulting in higher grades. Higher grade contributes to ultimate value of the mine.

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## LIST OF SYMBOLS

DME	Department of minerals and energy
DMEDRE	Department of minerals and energy: Directorate of minerals economics
DPTGSU	Department of geology: Stellenbosch University
XLP	Extra low profile
LP	Low profile
LHD	Load haul dump
SA	South Africa
Capex	Capital expenditure
Opex	Operational expenditure
NPV	Net present value
IRR	Internal rate of return
IRUP	Iron rich ultramafic pegmatite
UG2	Upper group 2
MER	Merensky reef
MCF	Mine call factor
#	Shaft

## CHAPTER 1: INTRODUCTION

### 1.1 Background

South Africa (SA) holds the largest reserves of platinum group metals (PGMs) in the world at more than 87% of total world PGM reserves (DMEDRE, 2009). The PGM resources and reserves are mostly located within the Bushveld Complex (BC). South Africa supplied 56.7% of platinum in the year 2007 according to DMEDRE (2009). This makes SA a leading supplier of platinum in the world. Through its mines in North West and Limpopo Provinces, SA dominates the platinum mining industry in the world with mostly underground mines and a few surface mines (DMEDRE, 2009). The demand for platinum is driven mostly by its use in the automobile industry. The petrol and diesel car engines require platinum in the autocatalysts to clean up engine emissions. Other uses of platinum include jewellery, chemical, electrical component, glass and petroleum industries. The platinum group metals are a family of six chemically similar elements namely: platinum, palladium, rhodium, ruthenium, iridium and osmium. The by-products include gold, silver, nickel, cobalt and copper (DMEDRE, 2009).

Exploitation of the PGMs in SA is achieved by means of surface, conventional, hybrid and trackless mining methods. Conventional mining methods dominate the exploitation of these reefs. According to DME, (2009) there are 22 mines exploiting the Merensky and UG2 platinum reefs, mostly using conventional mining methods.

Conventional mining refers to mining by means of handheld drilling machines for drilling blast holes and support holes. Cleaning is accomplished by means of scraper winches with scoops. The mining layout is dependent on development which is mostly in the waste rock or footwall below the reef horizon. The stoping is made up

of panels with strike and centre gullies for scraper path cleaning. Access to the stoping horizon is through the travelling ways used mainly for men, material and services. Ore passes are used as ore transfer points. Ore is scraped into the ore passes on the production level. Usually mine trains are used to load ore from boxes to the main shaft system. A typical conventional mining layout is shown in Appendix A1.

Hybrid mining method refers to a compromise between conventional mining methods and mechanised methods where use and symbiotic relationship between the two is optimised. Conventional mining methods are applied on the mining panels where mining heights can be reduced to control dilution and mechanised methods are employed in mine development to open the reserves at faster rates.

Mechanised mining method refers to the use of trackless mechanised mining (TMM) equipment for both development and stope mining. Use of labour is much lower as compared to hybrid and conventional mining methods. TMM equipment is used for every mining activity. These include drilling for blast holes, rock support holes and cleaning. However, there are other mechanised mining methods that have been tested on the BC. These are further discussed in Chapter 3.

## **1.2 Definition of the problem**

Mining mechanisation on the BC is considered to have superior benefits compared to conventional mining methods that are considered to be labour intensive. Improved mine safety and productivity, low cost of operation and lower labour requirements are some of the benefits attributable to mine mechanisation. According to Harrison (2008) the reason for mechanisation implementation

especially the extra low profile (XLP) equipment in Anglo Platinum is because of the following perceived advantages:

- Improved safety by removing equipment operators from the sharp end of the production face;
- Improved productivity by more accurate drilling, higher face advance and more square meters;
- Improved profitability compared to the conventional mining method; and
- Replacement of the conventional stoping equipment for example using dozer face cleaning to replace face scraping.

Mine mechanisation is considered to be a safer option for mining narrow reefs due to the reduction in the number of employees exposed at the work face and the safer operating environment that mechanisation brings (Pickering and Leon, 2008). The challenge however is that despite all these positive attributes associated with mine mechanisation, mining companies are still reluctant to introduce mine mechanisation at their operations.

Most of the projects and strategies to implement mechanization in narrow tabular ore bodies are almost certain to be withdrawn, delayed or converted to conventional mining methods despite benefits associated with mechanisation. This raises the question as to why mechanisation has failed despite its perceived benefits.

A number of mines in recent times have shut down their mechanised sections on the BC with varying degrees of reasons being given. Some of these reasons are discussed in section 1.3.

### **1.3 Examples of discontinued mechanised sections in platinum and gold**

Platinum and gold deposits have similar narrow tabular ore bodies. The mining methods are also the same. Some of the case studies observed in the BC and gold mining industry include the following operations where mine mechanisation sections were stopped:

- XLP mechanised equipment was introduced in July 2003 at Bafokeng Rasimone Platinum mine (BRPM) South “D” decline on Merensky reef. A year later the XLP suite was removed after the mine management decided that the effort required and high maintenance costs involved relative to the continuation of the XLP were not worthwhile (Harrison, 2008);
- Lonmin has experienced poor productivity in two of their fully mechanised mines. As a result Saffy shaft is being converted to a conventional mining method while the other fully mechanised mine, Hossy shaft is being reviewed (Farmer, 2008). According to Ian Farmer the major reason for reconsidering mechanised strategy is the associated poor productivity and high cost of production that have been observed; and
- An experience of mechanisation in the narrow tabular reef mining was first witnessed in the gold sector in the early to mid 1980s and early 1990. Randfontein Gold Estate went on to mechanise their mines due to the wider reefs and opportunities associated with optimal exploitation of their

resources, in terms of safety, production and lower cost of production. However the mining method was changed back to conventional mining method after TMM failed to deliver as per expectations (Brown, 1995). The reasons for the failure being that the TMM was capital intensive and with the devaluation of the Rand the cost of mining escalated. Spares and maintenance were some of the issues that were identified as the contributors of poor performance (Brown, 1995).

The observation here is that mines are constructed and motivated on the basis of better mining methods and technology. However the new mining technology tends to fail, as a result conventional mining methods are then reconsidered. These decisions usually come with huge costs due to the changes and impact on production when converting mechanised mining methods to conventional mining methods.

The intention of this research project is, therefore, to look at the drivers for mine mechanisation and output results which dictate the closure of mechanised projects or decisions to revert to conventional mining methods. Unfortunately at the time of writing this report most mining companies were reviewing their mine mechanisation strategies due to the 2008/2009 financial crisis that led to capital restructuring for most mining companies.

Mechanised mining projects have high initial capital requirements which tend to discourage investment in a low commodity price cycle hence put mining mechanisation projects under threat. Other pressures associated with strengthening of the Rand and its impact on local commodity prices, has impacted negatively on many mechanised projects (Egerton, 2004). Threats of mineral price cyclicalities and economic recessions have been a major impediment to mechanisation in SA mines (Egerton, 2004). These observations indicate that

mechanised project investment tends to be stronger in times of a weakening of the Rand and higher commodity prices.

#### **1.4 Objectives**

The objective of this research is therefore to critically review the successes and failures of mechanisation trials on platinum mines of the Bushveld Complex. The primary project output was to find out the reasons for unsuccessful mechanisation application in the Bushveld Complex. This should provide a greater understanding of mine mechanisation philosophy in narrow tabular ore bodies. The project drivers and mining environment for mechanisation were investigated. The field practices in the operations were investigated. Once the motivation drivers, mining environment and field practices were understood it was possible to recommend changes that can lead to suitable mechanised mining methods and systems. The benefit is to realise selection of a suitable mining method which will result in productivity and production improvement, enhanced safety and significant financial returns.

## **1.5 Content of the project report**

This chapter has discussed the background on mechanised mining on the platinum mines of the Bushveld Complex. Chapter 2 briefly discusses the geology of the Bushveld Complex and how it imposes restrictions or creates opportunities for mechanised mining. In Chapter 3 mine mechanisation trials on the Bushveld Complex are identified and conclusions are drawn with regards to those deemed to be successful and form part of the production mix in shafts or are implemented as a system in a mine. Mine visits formed the case studies found in Chapter 4, which concentrated on the operational issues on the mines which can contribute to a either a success or failure of mechanisation. In Chapter 5 mechanised mines are evaluated and compared against conventional mines. The findings of the research, conclusions and recommendations are given in Chapter 6.

## CHAPTER 2: MINING GEOLOGY OF THE BUSHVELD COMPLEX

### 2.1 Locality map

The Bushveld Complex is the largest layered mafic intrusion in the world. It is about 300 to 400 km wide and up to 8km thick and its total surface area is close to 66, 000 km<sup>2</sup> (Viljoen and Schürmann, 1998). The BC outcrops in the northern part of South Africa, in the provinces of the North West, Limpopo and Mpumalanga (DPTGSU, 2007). The extent of the BC is shown in Figure 2.1.

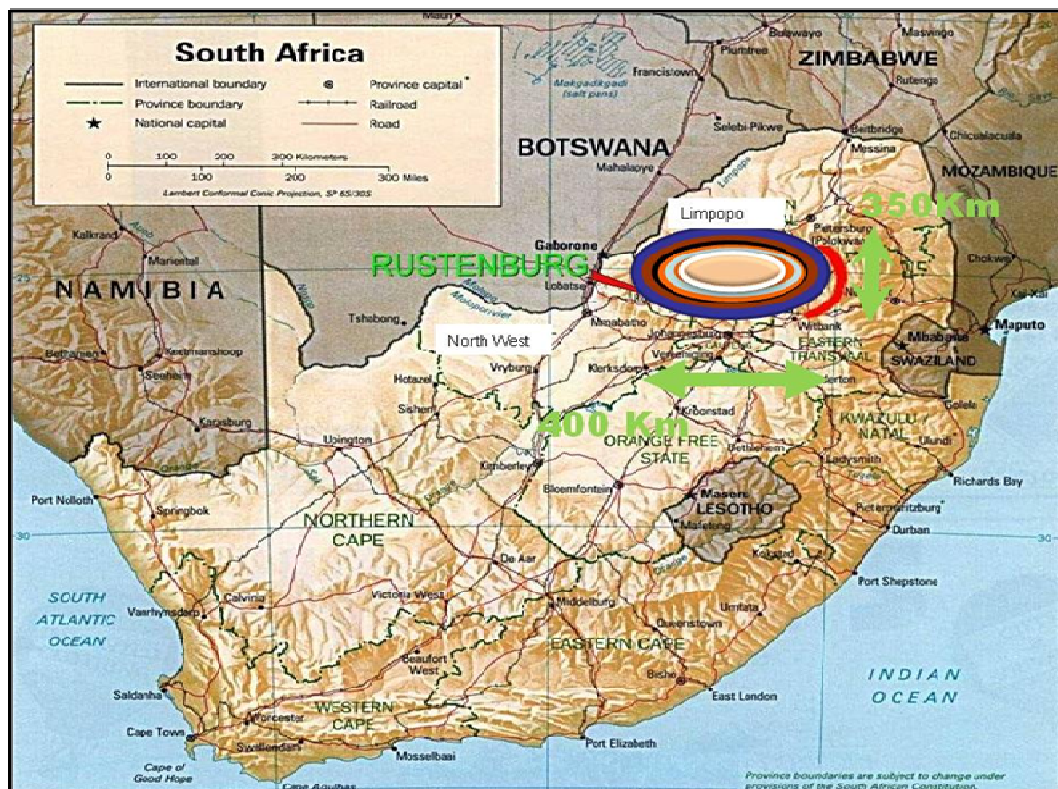
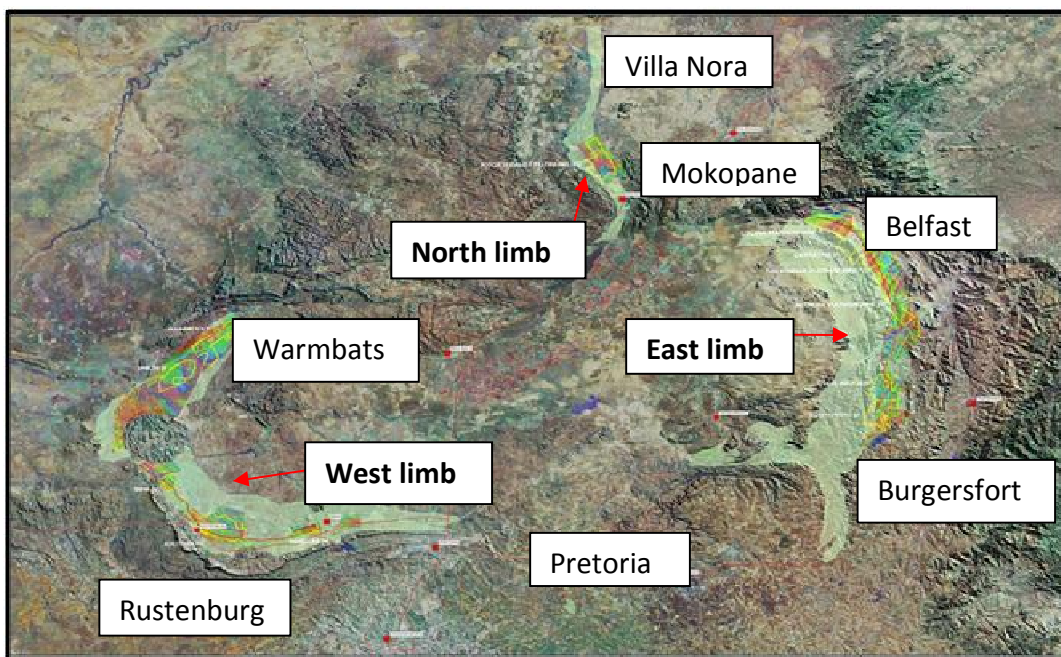


Figure 2.1: Location and extent of the Bushveld Complex (Courtesy of Anglo Platinum).

The BC consists of three distinct limbs referred to as the Eastern, Northern and Western limbs. The Western limb forms an arc from Pretoria to Rustenburg and to Warmbaths. On the Eastern limb the structure could be traced from north of Belfast to Burgersfort in the south and the Northern limb from Mokopane to Villa Nora in the north. Figure 2.2 is a satellite impression of the three limbs of the BC.



**Figure 2.2: Satellite impression of the Bushveld Complex limbs (Courtesy of Anglo Platinum).**

## **2.2 Formation**

It is generally understood that the Bushveld Complex was formed by the repeated injection of magma into an enormous chamber. Due to huge volumes of magma involved, cooling and subsequent mineral crystallisation of the magma was a slow process. Different minerals were formed as the magma cooled. These minerals accumulated into sub horizontal layers, building from the base of the chamber. These processes were repeated by the intermittent replenishment and addition of existing and new magma, thus producing a repetition of the mineral layering. Some individual layers or groups of layers can be traced for hundreds of kilometers (Cawthorn, 1999).

## **2.3 Geology of the Bushveld Complex**

The Bushveld Complex is made up of the mafic layered suite of rocks. The mafic component can be divided into a number of sections which are associated with their deposition and post deposition activity into the Bushveld Complex. The Bushveld Complex layered units are grouped into four major categories and they owe their nature to the way they were deposited. The current acceptable subdivisions are the Lebowa granite suite, Rashoop granophyre suite, Rustenburg layered suite and Rooiberg suite as indicated in Table 2.1. Within the Rustenburg layered suite is the critical zone which hosts the world's largest known resource of platinum group metals, making it the most important in terms of long term economic benefits.

**Table 2.1: Subdivisions of the Bushveld Complex (after Cawthorn *et al*, 2006)**

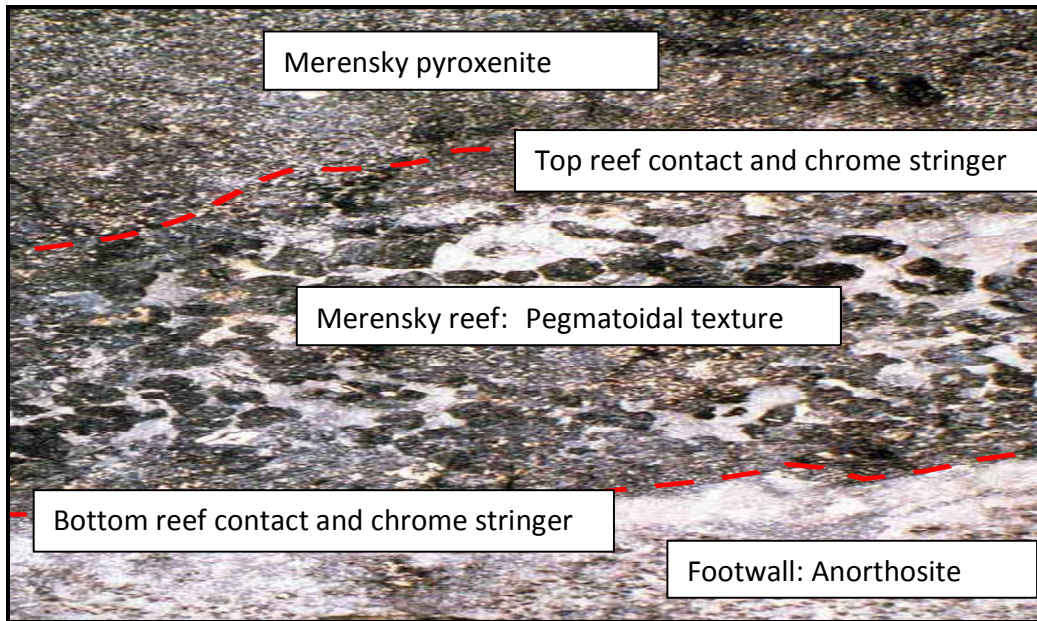
<b>Lebowa granite suite</b>	Nebo, Makhutso, Klipkloof, Bobbejaankop and Verana granites
<b>Rashoop granophyre suite</b>	Stavoren and Diepkloof granophyres, Rooikop porphyritic granite, Zwartbank pseudogranophyre
<b>Rustenburg layered suite</b>	<b>Upper Zone:</b> Subzone C (diorite), Subzone B (gabbronorite), Subzone A (gabbronorite)
	<b>Main zone:</b> Upper subzone (gabbronorite), Lower subzone (gabbronorite, norite)
	<b>Critical zone :</b> Upper subzone (norite, arnorthosite, pyroxenite), Lower subzone (pyroxenite)
	<b>Lower zone :</b> Upper pyroxenite subzone (norite), Harzburgite subzone, Lower pyroxenite subzone
	<b>Marginal zone :</b> Norite
<b>Rooiberg group</b>	Schrikkloof formation (flow banded rhyolite), Kwaggasnek formation (massive rhyolite), Damwal formation (dacite, rhyolite), Dullstroom formation (basaltic andesite)

The mafic rocks in the critical zone also known as the Rustenburg layered suite are divided into five distinct zones classified as the Marginal, Lower, Critical, Main and Upper zones. The marginal zone which is variable in thickness does not have any known economic mineralisation. The critical zone is the most important one in terms of economic mineralisation. The complex comprises an array of diverse igneous rocks ranging in composition from ultramafic to felsic. Contained within the well layered ultramafic to mafic succession are two horizons in the Critical Zone which host economically exploitable quantities of PGMs, namely the Merensky reef and the underlying UG2 reef. These two economic horizons can be traced for hundreds of kilometers around the Bushveld Complex. Below the UG2 resource there are other chromitite layers that are mined for chromium as their PGM content is low.

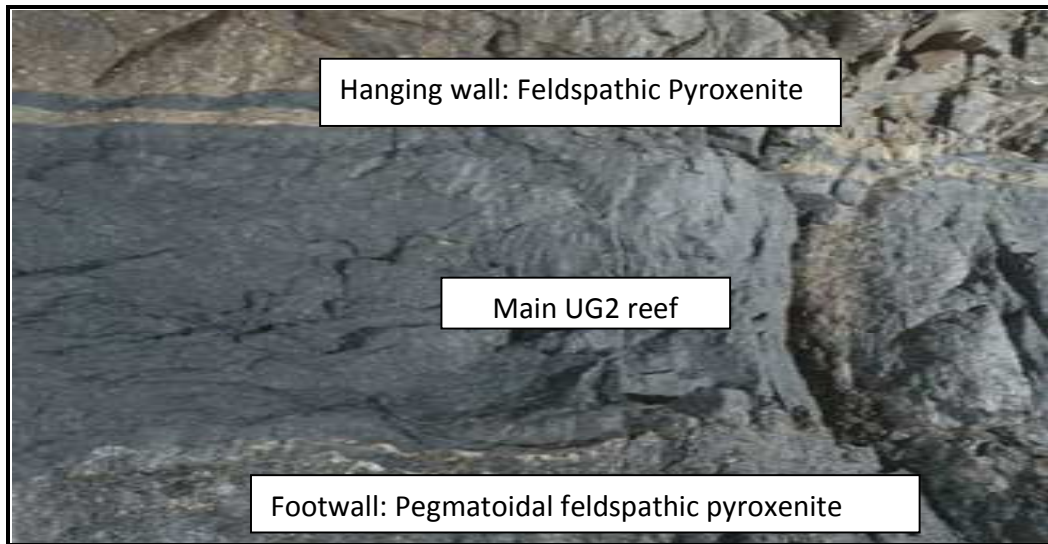
#### **2.4 Economic reefs**

In this study the economic reefs refer to the Merensky and the UG2 reefs which are located geographically within the critical zone. The typical reefs are shown in figure 2.3 and 2.4. The dip of both reefs can go up to 65 degrees, however most mines are operating at dips of between 9 degrees and 26 degrees. The UG2 occurs between 15m and 400m below the Merensky at various locations along the BC (SACS, 1980). This separation is smaller towards the western limb but higher on the eastern limb of the BC.

On average the width for both reefs is less than one metre. However there are areas where the reef is more than one metre on the BC. The wider reef offers opportunities of technology improvement in terms of trackless mining equipment, while thinner reefs are mined with conventional mining methods.



**Figure 2.3: Common Merensky reef**



**Figure 2.4: Common UG2 reef feldspathic pyroxenite**

The UG2's feldspathic pyroxenite hosts a succession of thinner chromite layers commonly referred to as the leader seam and triplets. The UG2 reef footwall consists of a pegmatoidal feldspathic pyroxenite which gradually changes into a norite. The triplets cannot be easily supported and mine designers are forced to plan them as part of the stoping width in some areas where they are located closer to the reef, increasing mining dilution.

The grade distribution is shown in Figure 2.5 where Merensky grade is higher on the western limb and slightly lower on the eastern limb. The grade distribution within the resources is an important determinant in selection of economic suitable mining methods.

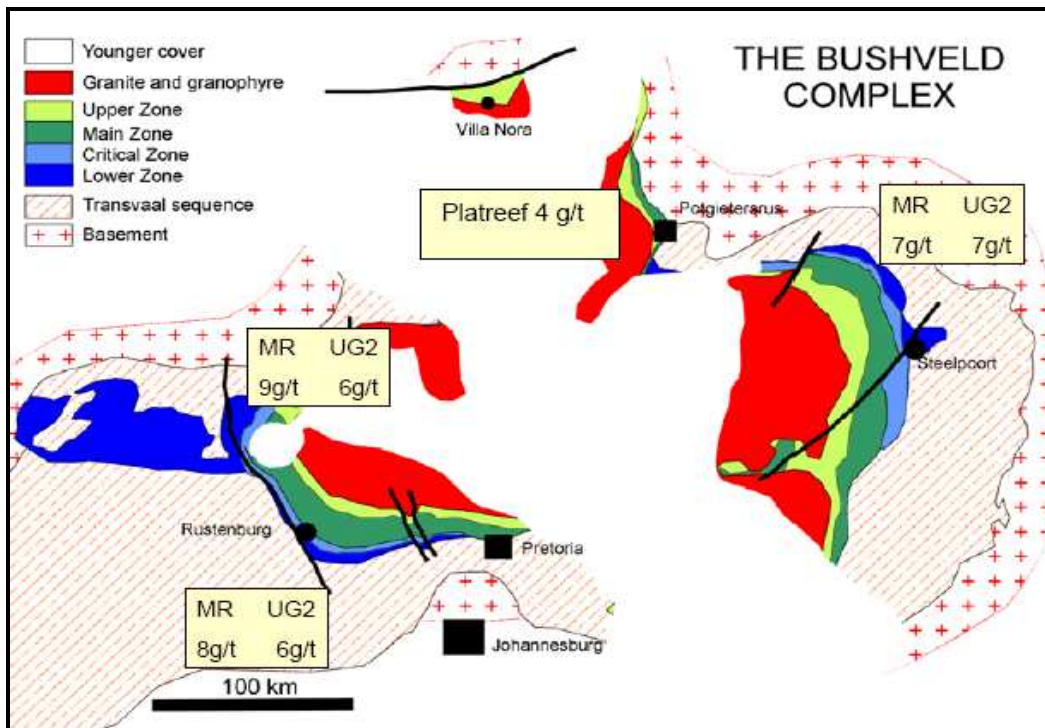


Figure 2.5: Generalised grade distribution for the Merensky reef, UG2 reef and Platreef. (Source: School of Geosciences, University of the Witwatersrand)

## **2.5 Geology complexities**

The geological complexities associated with the Bushveld Complex cannot be ignored. These include intrusions in the form of sills and dykes, iron replacement, faulting and high frequency of potholes. Other structures associated with rock mechanics include fracturing, jointing and parting planes. The structures are associated with compromised rock integrity and also interrupt the continuity of the reefs. Knowledge and characteristics of these structures is essential in the determination of mine design and selection process for suitable mining systems. Mechanisation cannot be utilised where the geology is complex with higher frequency faulting, potholes and dykes. It is also imperative that the mine design process must distinguish the structures within the ore body. Geological structures are usually disruptive and can influence the type of mining method depending on their severity. The size of the ore body and orientation are some of the attributes that are required in selecting a suitable mining method. To have a successful technically reliable mining method, geological structures must be reliably identified, variability of the reef dip determined and size of the ore body confirmed. There are a number of problems experienced with complex geology, size and dip that will render mine mechanisation difficult to motivate. These issues are looked at individually in sections 2.5.1 to 2.5.6.

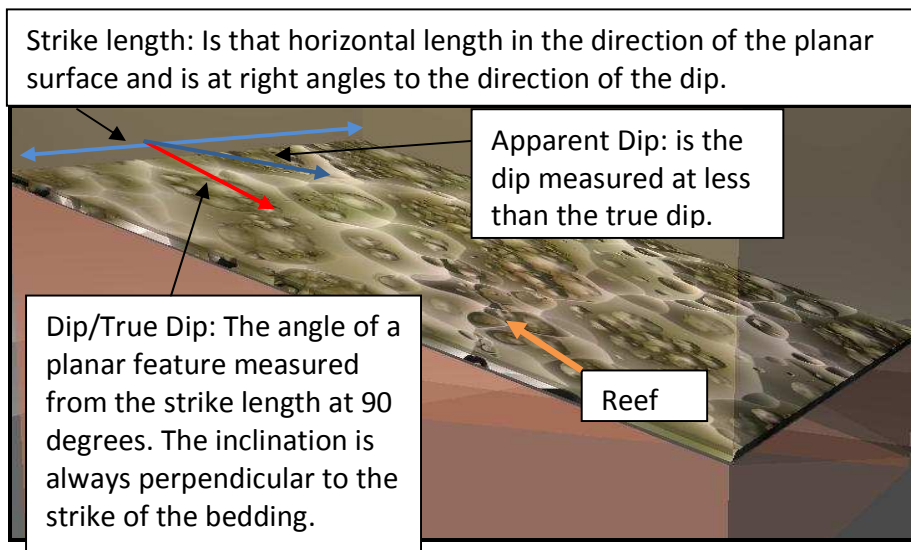
### 2.5.1 Dilution

In most cases waste is mined together with the mineralised zone, in the process diluting the *insitu* grades. Dilution can take place as a result of the mining activities, mine design process and poor waste management. It can be defined as ingress of waste material into the reef or mineralised rock during mining operations. It impacts negatively on the mill head grade. Using mechanised equipment requires larger excavations due to a number of factors. These include the sizes of the equipment and movement on the reef planes. The extra low profile machines are designed such that they can operate in stoping widths of less than 1.2m in order to minimise waste mining. The XLP equipment is currently in use in various operations across the BC and is proving to minimise grade dilution.

### 2.5.2 Dip, apparent dip and strike

The size of the ore body, dip and its strike length are essential in the mining selection process. In Figure 2.6 an illustration of the relationship between strike and dip is shown. The strike length gives an indication of the size of the body. A longer strike length will ensure that the mine has adequate reserves for the life of a mine. Where the dip of the reef is considered excessive at the dip of more than 12 degrees use of hybrid mining method could be considered. Currently TMM equipment functions well at a dip of less than 12°. There are some trials in the BC where equipment is being tested at dips of more than 12°.

Due to capital intensive requirements of the mechanised equipment, the ore body must be adequate with a long life to ensure that the viability and that the returns on investments are also realised. Longer strike length and longer dip length are indicative of large mining properties which are preferable where mining mechanisation is envisaged.



**Figure 2.6: Schematic representation of dip, apparent dip and strike**

### 2.5.3 Faults, sills and dykes

The geological structures (faults, jointing, sills and dykes) have a tendency to interrupt the continuity of the ore body. The structures are associated with poor ground conditions, harmful gases and are consistent with jointing and stress fracturing. Usually in the vicinity of these structures there is a drastic change of the contour lines direction signaling a change in reef dip direction. This influence on the dip of the reef can be severe if not identified early due to the associated ore body loss. The ore bodies with a high frequency of changes in dip greater than trackless equipment design requirement renders use of trackless equipment unsuitable. The faults can be described as clearly defined slip planes.

Dykes and sills although different in nature have similar characteristics to the fault planes. They interrupt reef and in some cases can displace the reef. However they can be extremely friable or hard in some areas which have an impact on the mining. Dilution is another nemesis associated with dykes and sills on the mines. It is imperative for the geological services to identify these structures as early as possible as they have an ultimate influence on the outcome of the mine design and reserve estimation. Where these structures exist in higher frequencies the ore body will not be suitable for mining with mechanised methods due to dilution and displacement of ore reserves. Loss of ground due to these structures impacts negatively on the production planning of the operations.

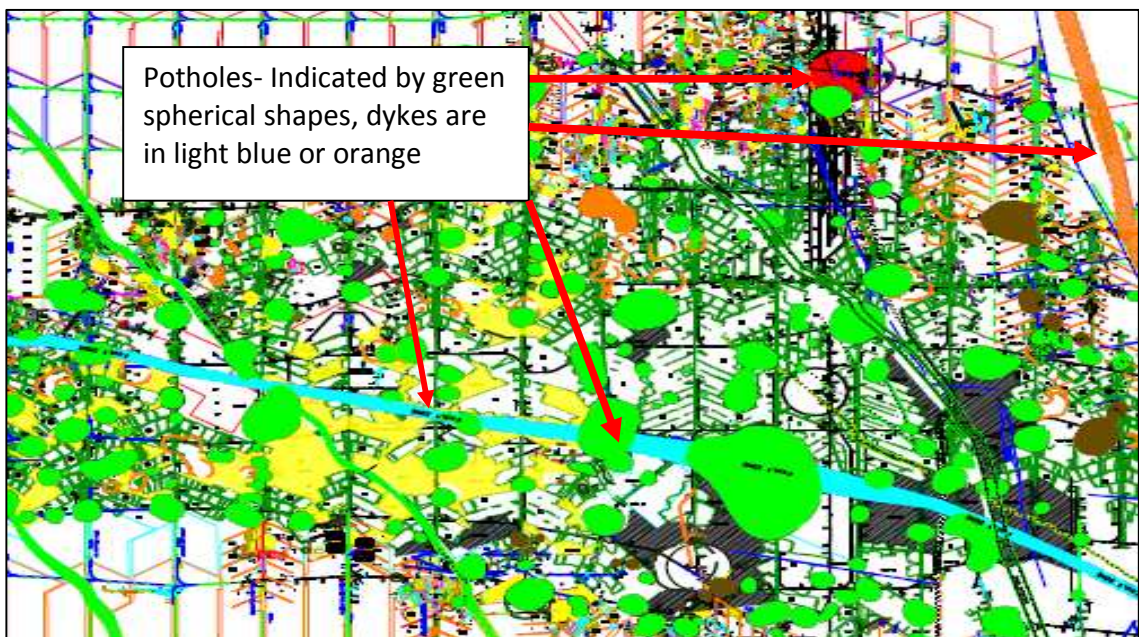
#### **2.5.4 Jointing**

Joints are the most persistent structural features encountered on the Bushveld Complex. The number of joint sets varies, however they can result in difficult mining conditions. Drilling and blasting advances are usually affected by frequent jointing on the face. The mining method orientation can change due to the impact of the joints for example from breast mining to up dip mining.

#### **2.5.5 Potholes**

Potholes are highly disruptive since they replace the reef completely and have the same attributes as the other geological structures. This includes poor ground conditions and dilution. The most pertinent aspect of the potholes is their higher frequency which can reach up to 30% on mining lease areas. In Figure 2.7 a higher frequency of potholing is shown and this is a typical mining area where mechanisation should not be considered. The higher pothole frequencies reduce the

mineable area of the resources and reserves. Areas affected by these anomalies cannot be suitably mined with TMM due to the frequency of the interruptions on reef horizon. A pothole is a circular or elliptical area in which a portion of the reef is deposited into a void. These voids can go as deep as 100m in some areas. The pothole comes with dilution and requires re-establishment of development to locate the reef horizon. The extra development can be done on reef and through the pothole where dilution will be mined with impact on grade. The development as in faults development will be limited to the equipment operating design angle of  $12^{\circ}$ . Where there is a high frequency of potholing, mine mechanisation is not an option due to dilution factors and poor productivity as a result of reef interruptions.



**Figure 2.7: Complex geology with high frequency of potholes (Courtesy- Anglo Platinum)**

### **2.5.6 Iron replacement**

Although the iron rich ultramafic pegmatite (IRUP) can be compared with potholes they are totally different due to the origin of formation. They are formed as a result of the replacement of the original igneous rocks by the late iron rich ultramafic pegmatoids. They take the shape of a vertical pipe or sheets or irregular body and result in changes of dip and strike of the reefs as well as the partial or total replacement of the reefs. Extreme iron replacement can replace a half level (section) of a mine. If not picked up in time, they can result in a significant loss of reserves. Due to similar tendencies with other geological structures for example potholes and faults, where IRP is prevalent then use of mechanisation will not be effective due to productivity and dilution factors.

### **2.5.7 Conclusion**

The Bushveld Complex is a large source of platinum group metals and will remain so for a long time to come. Its sheer size and economic importance will remain a pillar of sources of platinum group metals and other commodities found in the critical zone. Economic reefs in the form of Merensky and UG2 reefs are in a complex geological environment. The ore bodies intended for mechanisation must be large to ensure that the financial investments made are realised. Knowledge of the mining environment is essential for successful implementation of mine mechanisation. High frequencies of geological structures such as faults, potholes and dykes are not suitable for mechanised mining methods. It can be seen that the impact of these structures has a bearing on grade due to dilution and on production due to constant machine interruptions.

Therefore it is essential that the mining environment is thoroughly understood before mechanised mining methods are implemented in order to prevent changes at later stages which will have a negative impact on a project.

Use of mechanised equipment can have opportunities where geological complexities are well understood and the economic reefs are also stable. Higher stoping width is easily mechanised due to availability of mechanised equipment. Thinner reefs can be exploited with XLP equipment. The XLP and other narrow mining technologies appear to be the future of mining narrow tabular ore bodies with equipment design of less than 1.2m in height provided they are implemented successfully.

Mechanisation trials on the BC are not limited to XLP and LP equipment but include blasting and non blasting mining techniques. The following chapter describes different mechanisation trials on the Bushveld Complex.

## CHAPTER 3: MECHANISED MINING TRIALS IN THE BUSHVELD COMPLEX

### 3.1. Introduction

New technology is usually associated with improved production, high efficiencies and low cost of operation. According to Valicek *et al*, (2001) there is a need to mechanise mining activities and that the coal industry mechanisation drive was embarked upon many years ago. In narrow tabular ore bodies, new technology has been very slow and none existed due to the difficulties associated with the mining environment. Nevertheless in the last two decades the industry players have seen a need to embark on numerous research and technology development projects to take advantages associated with new technology. The benefits observed in the coal and massive mining industries have had some influence on the momentum of technology development especially within the BC. Technology, in the context of this report is a successful combination of mining method and mining tools for the exploitation of reefs. The complete system refers to actual mining and removal of rock using advanced technology compared to conventional systems.

In the BC there are a number of technologies tried for mining production; this includes development and stoping operations. The technology trials in the Bushveld Complex are classified into two major categories. They are referred to as non-blasting and blasting techniques.

The non blasting techniques do not involve use of explosives, rather they use mechanical equipment for breaking the rock, while blasting techniques follow a mining cycle of drilling, blasting, cleaning and support tasks.

### **3.2. Non-blasting techniques**

The non-blasting techniques refer to the use of disk cutting techniques to cut the rock continuously into small fragments. The coal mining industry has perfected the use of cutting technology for years. Coal is softer than rocks found in the Bushveld Complex. Softer rocks are easy to cut or grind as opposed to hard rocks found in the BC. The non-blasting mining methods are believed to be the future of high productivity in the mines. This is because a continuous method does not in essence have interruption associated with blasting and cleaning cycles. According to Pickering and Ebner (2001), the constraint resulting from mining cycles reduces advances but with continuous rock cutting technology as practiced in coal mines there is an opportunity to maximize the return on the capital expenditure and also contribute to safety improvement. This means that the equipment in non-blasting techniques is used optimally due to the continuous process of the system. The blasting mining methods are dependent on the cycle of tasks, these include the drilling, blasting, cleaning and support cycles. Where equipment is not required in some tasks, it is under-utilised. This makes the non-blasting techniques a very attractive investment where capital spent on the equipment is realised quicker due to the continuous nature of the operation.

Non-blasting mining technologies are further divided into heat, mechanical stress, high pressure and abrasion for rock breaking. Raise boring equipment is a good example of non-blasting mining technology. It is extensively used on the Bushveld Complex for development of ore passes and ventilation air ways. Other continuous type of technologies includes rock splitting technology which uses hydro-fracturing which is used with a flight conveyor for cleaning purposes (Murray, 2001). However none of these technologies are utilised as part of the production mix or a complete system for mining in the BC.

Although some of the trials have indicated success, most have not convinced the mining industry to change and pursue these technologies. This is because the reason for failures are associated with geological conditions and engineering issues identified at implementation and during testing. Other major reasons include movement of equipment in confined spaces, mechanical failures and poor training.

### **3.3. Blasting techniques**

For the purpose of this study the blasting techniques refer to mining methods that have in their cycle, blasting with explosive for breaking the rock and use of extra low profile (XLP) and low profile (LP) equipment for cleaning and drilling operations. Use of XLP and LP equipment is the only prevalent mining technology in narrow tabular ore bodies that is currently being utilized in different mines across the BC. The mining methods include room and pillar mining, hybrid-mining method and breast mining. Hybrid is not a complete mechanised system due to use of conventional mining equipment in the mining mix of equipment. There is use of hand-held face drilling machines (jackhammers) and/or winches.

### **3.4. Mining methods**

The mining methods used in the BC are conventional, hybrid and fully mechanised. The conventional mines have been tested and found to be successful in the history of narrow tabular mining. Although inefficient and labour intensive they have proved to be popular in the BC due to their flexibility. They can negotiate the geological structures much better and are relatively cheaper to implement. Mining can be done in smaller stoping heights where effects of dilution can be minimised. These attributes still make the conventional mining methods the most preferred method. Musingwini and Minnitt (2008) determined that conventional mining methods are the most efficient mining method. This result came from work done in determining the most efficient mining method based on the application of analytic hierarchy process (AHP) on a UG2 resource. The basic conventional mining layout is shown in Appendix A1.

The hybrid mining method is a compromise of conventional mining methods and mechanised methods. Its strength is derived from each system to maximise and complement each other. Narrower mining in stopes is achieved with hand held equipment where stoping of less than 1 m can be achieved which influences the head grade positively and higher reef development is achieved with mechanised equipment. The relationship is symbiotic although with some challenges. This includes winches with ropes that are often a source of hazard and use of hand-held drilling equipment which places operators directly at the face where most of the incidences and accidents are likely to take place. The typical hybrid layout is indicated in Appendix A2.

The mining method currently tried and found to be operating well with the XLP and LP is breast mining layouts and room and pillar mining method respectively. Room and pillar mining method was tried by Anglo Platinum using XLP equipment and was found not to be suitable according to Harrison (2006). However where the stoping widths are higher the LP mining using room and pillar mining method was found to be more suitable. The challenge associated with mine mechanisation is the mining stoping width which can contribute to high dilution. In response to this XLP mining equipment were developed, but the difficulty of narrower reefs still provide a challenge as waste continues to be a problem. The XLP mining method still requires on reef development which adds to waste due to the large development ends required to accommodate the LP equipment for development purposes. A range and availability of LP equipment make it more attractive for development since the technology has been in operation for some time. XLP mining is relatively new. The LP mining method has proven to be successful due to the sizes of the excavations which offer better manoeuvrability and with more space equipment damages are minimised. Through observation the following trend was experienced as shown in Figure 3.1. An increase in stoping widths results in higher stoping tonnes and notable increase in dilution.



**Figure 3.1: Production, reef width and dilution**

To counter this problem other mining methods and variations were developed in order to influence the mining head grade. These mining methods are complementary to the current mining system. A T-cut mining method was developed by modifying room and pillar mining by cutting slots on the pillars where the reef is concentrated with the purpose of increasing the mine head grade. According to Oesthuizen (2005) the T-cut was done purely to influence the mine head grade at Frank shaft. This type of intervention proves that engineering solutions can influence strategic direction of the mine. An increase in dilution will have an impact on the profitability of the mine. Another mining method is the long hole stoping method.

A paper by Van Dorsen *et al*, (2001) described in detail the opportunities to increase head grade of the mine by using the long hole stoping mining method. This mining method is also a variation of LP mining layout where long holes are drilled between drives and the rock throw-blasted into a gully for cleaning. The mining method also proved that the dilution associated with mining equipment can be influenced and that mechanisation can be implemented in narrow tabular mining. A typical mechanised mining layout is shown in Appendix A3. The successful mechanised mining layout takes cognisance of a working system where drilling, blasting, support and cleaning cycles form an integral part which ensures that equipment is utilised in an efficient manner. The most vulnerable equipment in this mix is usually the LHD which removes broken rock from gullies to tipping points. This is because other equipment works directly closest to the face like rigs and bolters, they do not travel long distances to do their work. This equipment will tend to have higher efficiencies and utilisation. However the LHD does have a challenge of loading in one area and tipping in some place. This was identified and to complement this, belts are used extensively to ensure that the tipping distances are within acceptable operating efficiencies of LHD.

### **3.5. Typical mechanised equipment**

The mining equipment can be classified into XLP and LP equipment. The equipment is supported by different material handling, lubrication and fueling cars with cassettes. The typical XLP equipment suite includes drill rigs and bolters which can operate in stoping heights of 1.2 m while the LP equipment can operate in stoping widths of more than 1.2 m. Typical XLP, LP and support equipment are shown in Appendices B1 to B3. The XLP equipment suppliers were initially limited, but this has since changed with the entrance of the local suppliers in the market. The market has become competitive, pricing structures and after sales services are some of the considerations by project managers when selecting appropriate equipment. However in addition an understanding of the equipment, operating parameters must be taken into account. This includes size requirement, operating parameters, predictive operating costs, capital cost of acquisition and operating constraints.

The mechanised equipment has some operating constraints that are critical in the successful operation and these include:

- The operating height: The operating heights dictate the type of mining equipment to be used;
- Operating gradient: Mechanised equipment can operate in a limited gradient of 12 degrees. The reef dips in the BC can go up to 65 degrees. This makes the use of equipment in steeper dips impossible. Apparent dip with hybrid mining can be used but is limited depending on the nature of the reef and extent of the dip;

- Reef planarity: Undulating reef is not good for equipment since the wheel base of equipment should be taken into account. Risk of machine being stuck underground increases with undulating reef; and
- Choice of mining method: in the breast mining method where XLP is used, the in-stope excavation is mined at an average of 1.2 m but the on-reef gully development excavations are large for LP equipment. LP equipment can open the reserve faster ensuring sustainable replacement. Mining lower at the stope face has the benefit of keeping dilution to a minimum. In room and pillar mining excavations are normally large which are similar to normal development ends. The LP equipment has been used in chrome mining, massive ore body mines, coal mining industries and construction in the tunnelling environment. This technology has shown reasonable success in the industry.

### **3.6. Drivers of mechanisation**

Mining mechanisation is driven by a number of factors in the platinum mining industry as discussed under section 1.2. These factors are reasonable since they refer to safety, productivity, profitability and improved technology. For any business, these are the success factors and motivation for implementation of XLP and LP technology. Safety has been one of the major drivers for mine mechanisation. All mechanised mines, although different, have the same objective to mine safely at higher productivity efficiencies.

### **3.7. Conclusion**

Technology trials on the Bushveld Complex are made of two types of mining methods. The non-blasting which are continuous and blasting based mining methods which are dependent on production cycles. These methods were tested extensively, however only the mechanised blasting techniques are the only methods that are currently an alternative to the conventional mining methods. There are a number of reasons why mechanised methods are preferred over conventional mining methods. These include safety, improved production, and better returns. In the following chapter case studies are based on visits to mechanised mines. With all these benefits associated with mine mechanisation, probing questions and underground observations were done to seek reasons for the success and/or failure of mechanisation at the mines.

## CHAPTER 4: CASE STUDIES

### 4.1 Introduction

The technology used on the Bushveld Complex as alluded to in the earlier chapters is the use of Low Profile (LP) and Extra Low Profile (XLP) equipment. As part of this study visits were undertaken to mines to observe the equipment and the operating environment. The objective was to identify the problems that can result in discontinuation or continuation of mine mechanisation on the BC. The following operations were chosen due to the employment of XLP and LP equipment. These include Hossy and Saffy shafts of Lonmin, Waterval of Anglo Platinum, No 12 Shaft of Impala Platinum and Millsell of Samancor, a chrome mine. The objective was to get various perspectives from different companies. As a result an odd visit to a De Beers block cave mine was also done to look at the approach to mine mechanisation in a massive mining environment where conventional mining methods are not an option.

In the 90`s chrome mines were able to implement mine mechanisation with success (Egerton, 2004), as a result Millsell of Samancor was chosen as one of the sites for observation. An odd visit to De Beer`s Finsch mine was chosen due its advanced stage of mine mechanisation. Finsch is one of the most modern mines in SA. The mining method used at Finsch is different from those operating mines on the BC. However, it was felt that there could be some learning points to be gained that affect all the mechanised mines in terms of level of technology, skills, and management of data.

All the mines' experience and culture are different. This is driven by the tendency of parent companies' life of mine strategies and mining method selection. Those that have used advanced technology believe in it and that there is no other way, whilst the traditional conventional mining operators think that labour intensive methods are better. Although the exploitation strategies are different they have the same objective of mining safely, achieving higher productivity with higher efficiencies and lower costs of operation. Some of these results are apparent in some of the mines however, there are also distinctive differences in terms of operational activities that separate a success and failure of a mine due to technology application.

The successes are convincing in that they show consistency in all the operations, however where the issues of failure are identified they are due to the differences in approach from individual mines. The mining equipment utilised, maintenance issues, geology and mining methods are some of the contributing factors for most successes or failures. Each mining site has challenges of its own, but some of the issues are common in all the operations visited.

There are other issues like absenteeism that are considered but not as part of this study since they are not considered to be a threat to mine mechanisation. As a result they were not investigated further.

## **4.2 Saffy and Hossy Shaft: Lonmin - Case study 1**

### **4.2.1 Background**

Saffy and Hossy are Lonmin's shafts situated in the Marikana area. Saffy has provided a history of mechanisation and a learning curve for Lonmin. Initially the mine was planned for a conventional mining method. The change in strategy resulted in the mine implementing a mining method that was fully mechanised with XLP equipment. However, due to the difficulties experienced with implementation for the mining method and poor production performance the mine then changed to Hybrid mining method. At the time when a visit was undertaken to the mine, the plan was to change this to a complete conventional mining method. The results are best captured by The Chief Executive Officer's operational review of 2008, where he said that the low productivity and high costs had been identified as the major reasons for change in strategy. This was in defence of the change of mining method to hybrid and ultimately to conventional mining method at Saffy Shaft. However, he also alluded to the fact that Hossy shaft will continue to operate as a fully mechanised mine but under review to ensure that it fulfills the production mandate.

#### 4.2.2 Geology

Only the UG2 chromitite is presently being mined on Saffy and Hossy Shafts. The average dips of the UG2 reef are  $10.7^{\circ}$  over the Hossy Shaft area and  $11.5^{\circ}$  over Saffy Shaft. The strike of the UG2 reef over Hossy and Saffy Shaft blocks is approximately east-west tending towards south-west, north-east in the Hossy Shaft. The average resource width varies from 0.3m to 1.6m. The resource thickness is ideal for the mechanised mining method. The reef width goes up to 1.6 m in height. The dip is well within  $12^{\circ}$ , the operating gradient for mechanised equipment. The stratigraphic column is shown in figure 4. 1. This shows how wide the UG2 is and the mining resource width does not have to be increased further into the hanging wall due to the location of the triplets. The triplets are a nemesis in the BC as they are difficult to support and are usually taken out with reef if located closer to the reef with a consequence of dilution. The amount of geological losses in both shafts varies between 10 to 14%. This includes faults, dykes, iron replacement (IRUPS) and potholing. The major structures are clearly identified and can be dealt with in advance. The frequency of potholes is not severe. This setting is favourable to mine mechanisation.

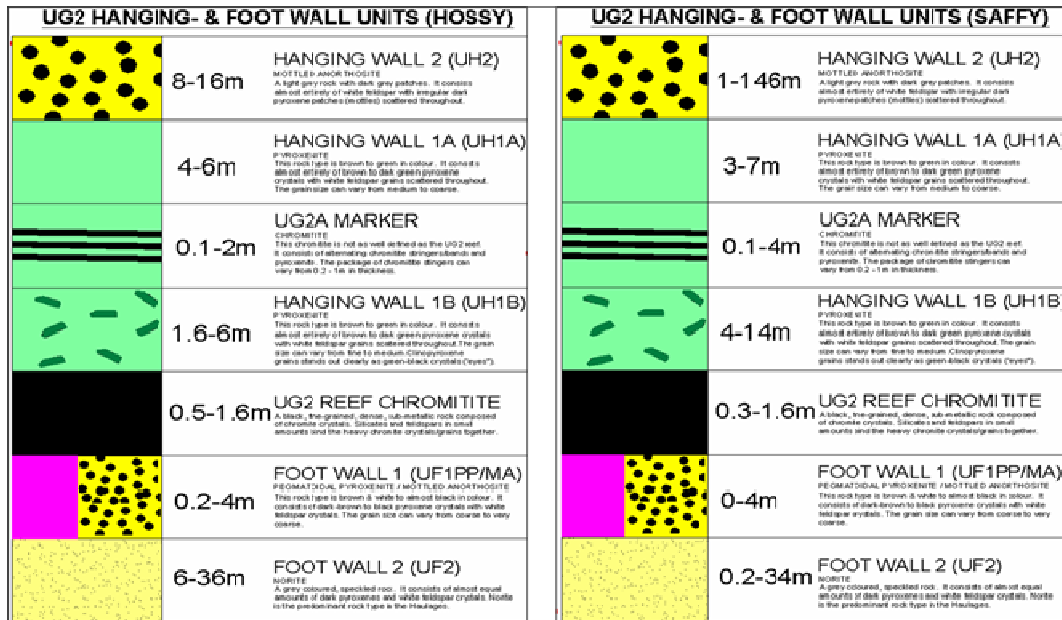


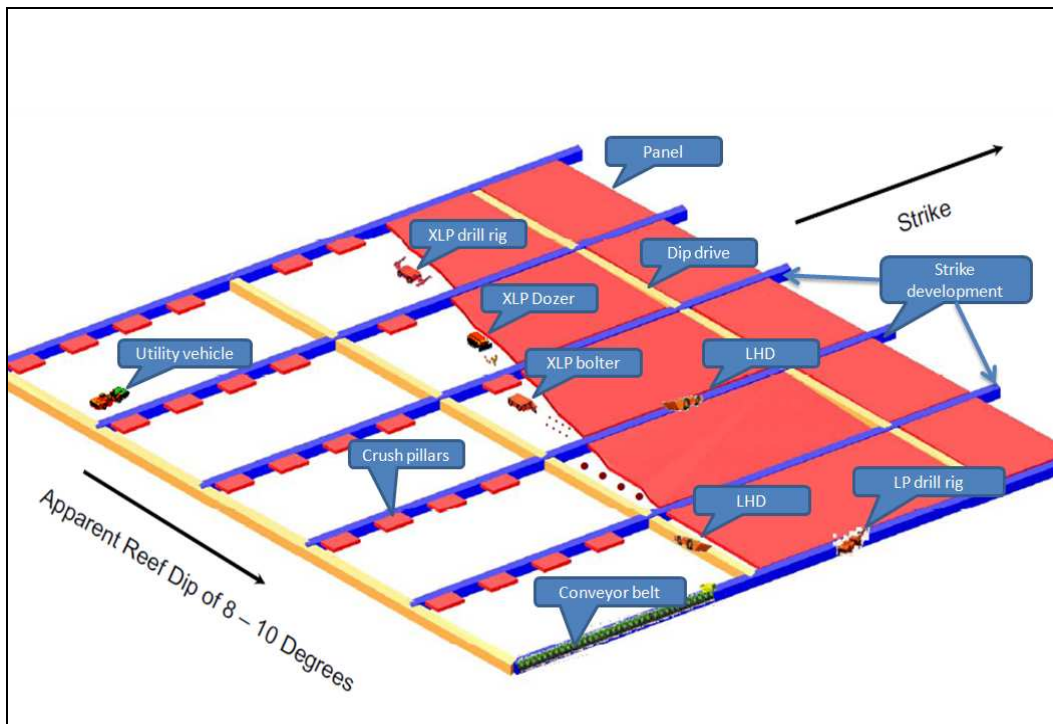
Figure 4.1: Saffy and Hossy stratigraphic column (Courtesy of Lonmin)

#### 4.2.3 Access method

Access into Saffy is through a vertical shaft with final mining depth expected to reach 840m. Hossy is accessed through a decline system. The mining environment of Hossy is shallow compared to Saffy, which is placed in an intermediate mining environment. Saffy's access to the reef horizon is such that stations are cut much close to reef to allow flexibility and minimize waste development for equipment to get to reef. Footwall development is minimal, all development is concentrated on reef. On-reef development is preferable for fully mechanised mines. All development tonnes can be sent to the plant as the support infrastructure is also on reef horizon.

#### 4.2.4 Mining method and layout

The mining method at Hossy is fully mechanised and Saffy changed recently to the hybrid mining method. The plan is to change Saffy Shaft to a conventional mining method due to the reason highlighted in the introduction above. The purpose of this study is to look at complete mechanised mining and look at the successes and failures, therefore Saffy is being looked from this perspective. The changes done or anticipated at this mine (Saffy) do not form part of this study. The mining method and layout were similar as shown in Figure 4.2.



**Figure 4.2: Mechanised mining layout (Lonmin)**

A mechanised mining layout is done to facilitate a working system of in-stope and development equipment. The back length is varied according to the panel sizes which are varied from 26m to up to 32 m at Hossy Shaft with the stoping width at 1.2 m. The in-stope development is cut between 3.5 to 4 m in width. These dimensions were cut to accommodate the equipment and conveyor belt. In-stope drilling is done with XLP rigs and support holes are done with bolters in the stopes. In-stope cleaning is done by dozers. The LHDs load broken rock from strike and dip drives and tip on the conveyor belt. The mining philosophy is planned to follow mining cycle of drilling and blasting, cleaning and support to ensure that tasks follow each other. This proved to be difficult where equipment failure was experienced. The bolter was identified as a constraint in the mining cycle. At Hossy hand-held drilling crews were introduced to assist the bolters. Although this has some benefit it was defeating the objective of removing men from the operating face and hence compromising on safety.

#### **4.2.5 Typical mining equipment**

The equipment used was mostly from Sandvik. The typical equipment is shown in Appendices B1 to B3. This included the following equipment:

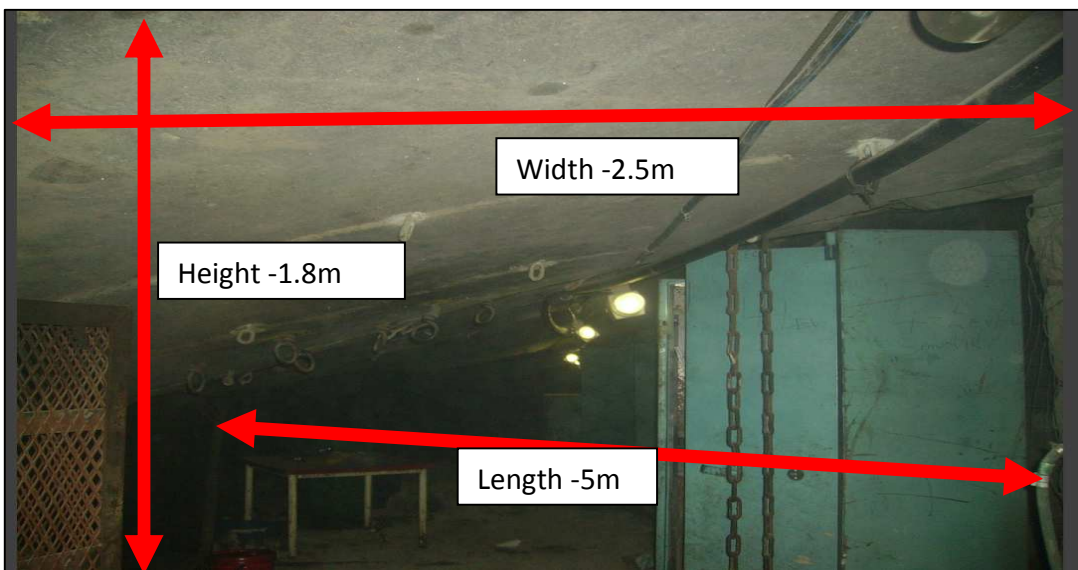
- Development: LP drilling rigs, LHDs, charging vehicles and utility vehicles; and
- Stoping: XLP double boomer drilling rigs, in stope bolter, hand held drilling equipment and dozers for cleaning.

#### **4.2.6 Findings**

Operational readiness for implementation and operation was not adequate especially at Saffy Shaft. Operational readiness means that strategic needs, risk identification, planning and deployment of procedures to enable a complete system to operate to design expectation. In this case these will encompass mine design parameters, communication systems, trained labour, working maintenance workshops and working procedures defined to enable the system to operate. The major drivers of successful mechanisation are an ability to communicate, accumulate data, and maintain equipment, and a high level of training and skills. Workshops at the mine were not ready from an operational perspective. The satellite workshops that were visited underground were small and inadequate to do maintenance as shown in Figure 4.3 with measured dimensions of 2.5 m x 5m x 1.8m (width, length and height). The purpose of a satellite workshop is do minor maintenance on the equipment, but the workshop visited was physically unable to render the service. This can only mean that the main workshop will have to do random maintenance as well. This would have an effect on the overall maintenance strategy of the mine contributing to the quality of maintenance of the equipment. The low productivity and higher costs identified in the Chief Executive's (CE) report of 2008 can be attributed to the poor quality of maintenance and time taken to do the actual maintenance. The main workshops visited are large but are not designed to handle large volumes of equipment. The workshops do not have ramps and coordinated functions for refueling, major or minor maintenance purposes. It is important to have adequate maintenance facilities to ensure that equipment productivity and utilisation is high. Lack of spare parts or critical spares was apparent with equipment taking longer to be maintained. Conversations with some

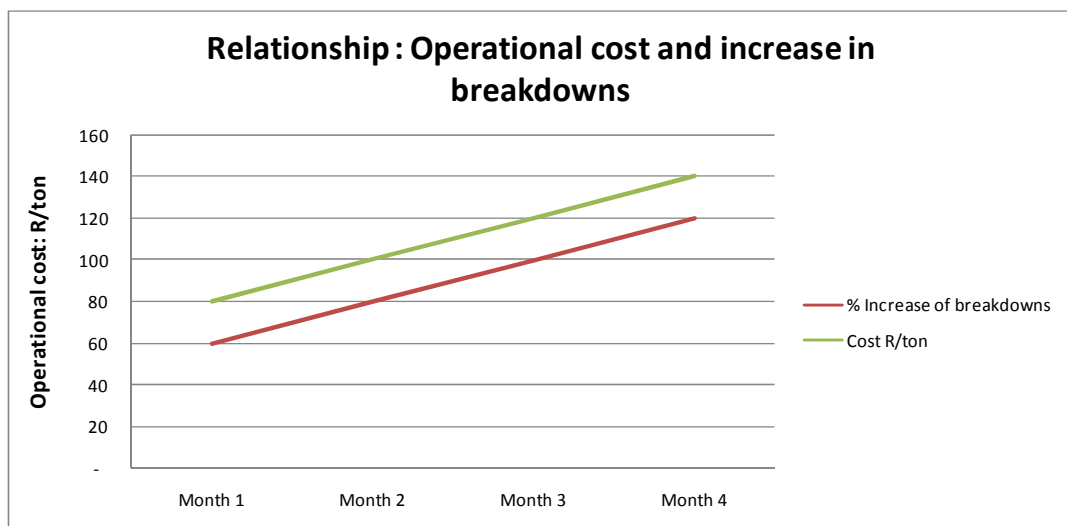
of the mine employees indicated that the parts were some of the problems due to unavailability and some were sourced from overseas.

These issues were more prevalent in Saffy. In Hossy the workshops were more coordinated, spacious and closer to the workings. Other operational issues identified included ore reserve creation. Development was stopped at some stage which resulted in lack of adequate face length for the mines. However this was corrected at Hossy with focus on development. Advance development has other benefits other than reserve creation, it provides prior knowledge of potholes and other geology features missed by boreholes during prospecting ahead of the mining faces and ventilation. A grid is developed within the stopes where advance strike drives are connected with the dip drives.



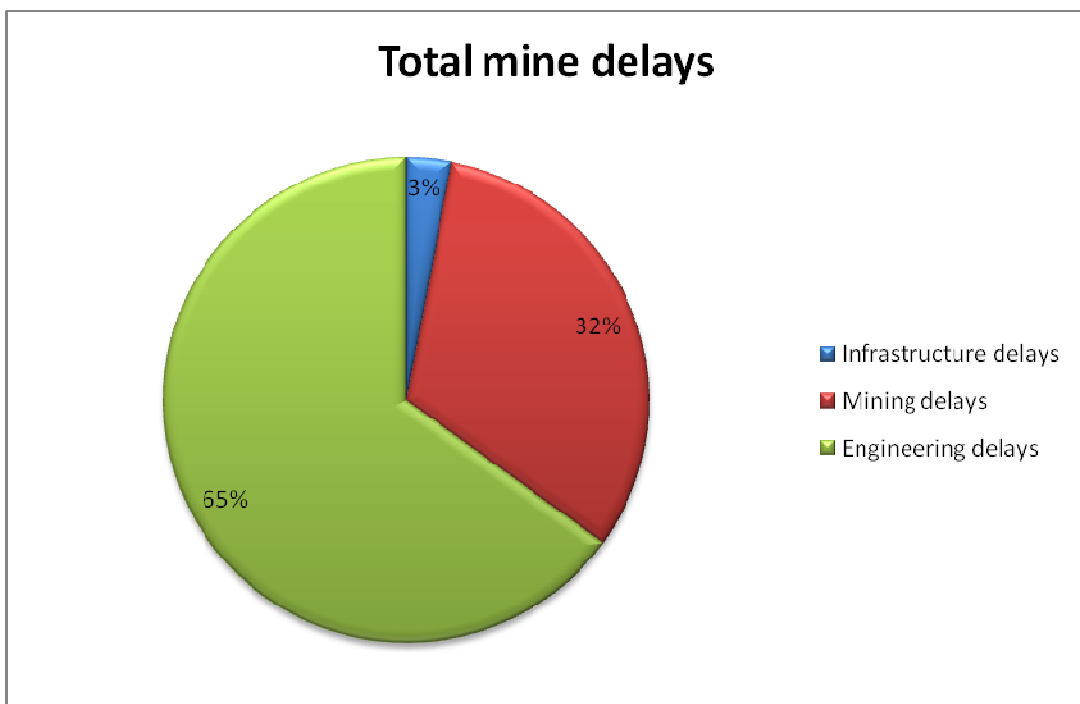
**Figure 4.3:** Satellite workshop at Saffy shaft

The constant breakdowns experienced at Saffy Shaft led to an increase in operating costs. This can best be illustrated by Figure 4. 4. Equipment down time means production is compromised hence resulting in higher costs of operation. In addition, although the equipment supplier was responsible for maintenance, the contract was not based on production and productivity key performance areas. Hence the cost affected the mine but did ensure more revenue for the supplier in terms of parts and labour costs on site.



**Figure 4.4:** Cost and breakdown curves

The majority of the mine delays were as a result of engineering delays. This was attributed to the lack of adequate maintenance facilities, maintenance staff skills and shortage of critical spares. The summary of mine delays is shown in Figure 4.5 and it indicates that the majority of the down time is associated with engineering from both shafts. Engineering by far contributed to most delays of the mine. In engineering, the most breakdown results were for mechanical failures that also took longer to maintain. In mining, absenteeism and operator skills are cited as some of the factors contributing to production delays.



**Figure 4.5: Summary of average mine delays (Saffy)**

Saffy Mine experienced delays which were a result of a lacking of operational readiness. The mine was not ready to operate a mechanised mining system. The complete system includes proper workshops, maintenance plans and communication systems underground. The lack of a complete system resulted in delays that could not be fixed in time to continue with the mining process.

The relationship between the mine and supplier should have been performance based. Use of suppliers to do maintenance must be linked to equipment performances to ensure that there is mutual benefit of association. Mechanised mining methods are generally better in terms of safety. This is because there are less people under ground for the same activity. The rate of developing ends using mechanised equipment is 60m per end per month as compared to conventional mining method that achieves on average 20m per month.

### **4.3 Impala No 12 Shaft – Case Study 2**

#### **4.3.1 Background**

Each operation visited had common issues with other operations but also had its own unique characteristics. Impala 12 Shaft uses room and pillar mining at a depth of 1000m. Challenges of rock engineering are apparent. The pillar sizes along the belts are large because they are designed for long term stability. Mining offers different challenges of waste management due to high stoping width. The dilution has been recorded to go over 40% in some areas resulting in low grade with average head grade of 3.5g/t. The location of the triplet is just above the main seam forcing the stoping width to be higher so that the triplets can be taken out simultaneously with the main seam.

### 4.3.2 Location and geology

The Impala 12 Shaft is situated in Rustenburg close to Sun City. According to the resident geologist Pantshi (2009) the grades in 12# are different from the other Impala shafts. The grades are generally low but with distinct geozones in the mineralised zone, it is difficult to mine at lower stoping width which has the most grade/tonne. Due to the triplets, the minimum best cut was recommended to be 1.4 m which included other geological parting planes. However the decision was taken to mine at 1.9 m in order to mine large volumes of ore at an average grade of 3.5g/t. The dip of the UG2 chromitite layer ranges from 6° to 10° but averages about 10° in the area. This makes it an ideal environment for mechanisation. As indicated before, current equipment is designed to operate in gradients of not more than 12°. The generalised Impala stratigraphy is shown in Figure 4.6.

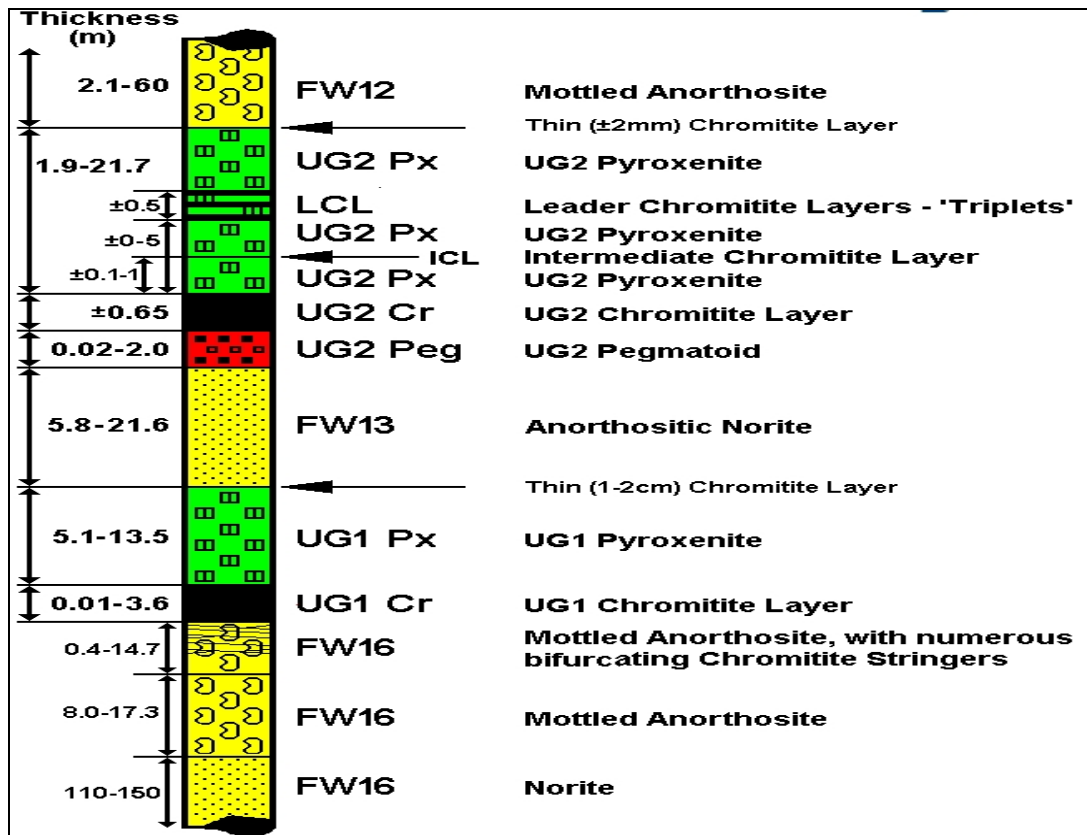


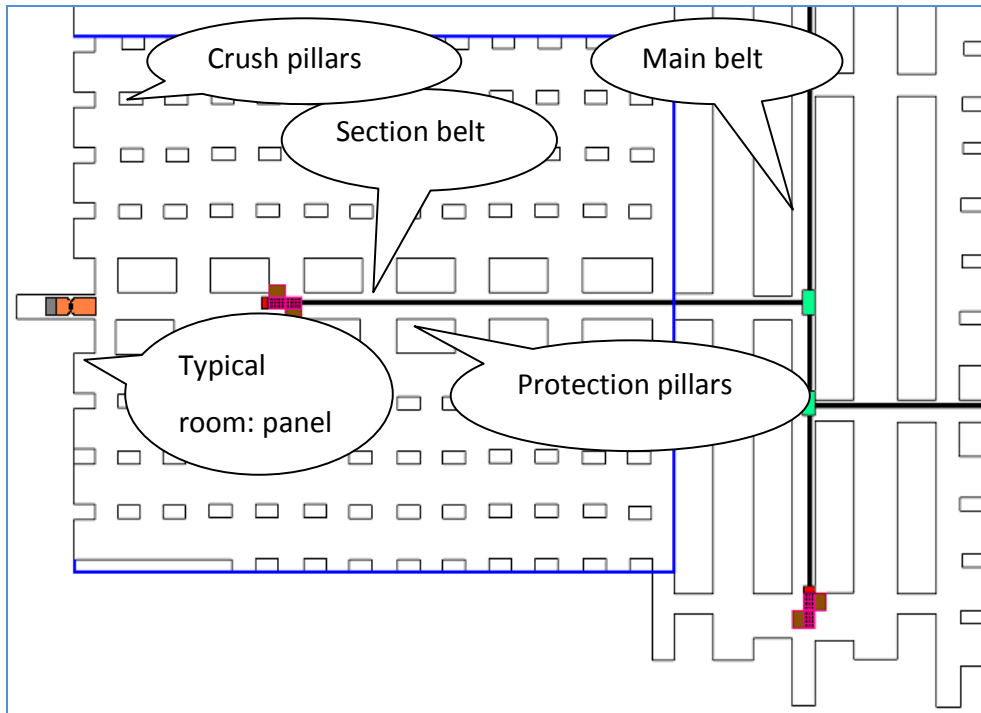
Figure 4.6: General stratigraphic column at Impala

#### 4.3.3 Access method

Access to underground is by means of a vertical shaft with haulages developed towards the ore body. A system of declines on reef is used to further access the ore body. This access also forms an integral part of the ventilation system of the mine.

#### **4.3.4 Mining method and layout**

Impala 12# uses a room and pillar mining method with a section consisting of 8 rooms with a conveyor belt located centrally as shows in Figure 4.7. The crush pillars are designed to be 4 m x 12 m (width x length) and stability pillars of 12 m x 36 m (length x width) along the conveyor belt. The stoping width is 1.9 m with rooms of 12 m panel lengths. The mining layout support uses LP mechanised equipment. The excavation sizes are large to accommodate the equipment. The room and pillar mining method does not have pre-development hence information is gathered by drilling long holes ahead of the mining face. Information is crucial and must be correct to ensure that production does not suffer if suddenly a geological structure is intercepted without prior knowledge.



**Figure 4.7:** Typical room and pillar layout (Impala)

#### 4.3.5 Mining equipment

The TMM section consists of an LP development drill rig, LHDs and utility vehicles. The swing or spare LHD is shared amongst three sections to ensure that production is not hampered during breakdowns and scheduled maintenance of LHDs in the sections. Installation of support rock bolts is done by hand-held equipment. This conventional equipment does not support the complete mechanised system. Mine mechanisation must be a complete system where human physical effort is minimised in all areas of operation.

#### **4.3.6 Findings**

In room and pillar mining, as mentioned before, there is no pre-development, hence all the geological interpretation is through exploration and underground drilling. This information can be very limiting due to the nature of the ore bodies in the BC. As a result in one section planning was done for a block with a misinterpretation of a fault. This had a severe impact on the mine planning due to additional waste and loss of production since this was not anticipated. The Impala 12 Shaft has an inherent problem of grade which is made worse by the mining method. This has constantly led to lower planned head grade. These problems suggest that the current mining method is not suitable for this ore body. The higher stoping width makes things worse in terms of grade which is a revenue driver.

The poor planning in terms of roadways and panels constantly gave rise to ventilation problems. This is as a result of mining out of sequence. The mining faces are mined faster than the ventilation planning. This has led to constraints on production due to lack of ventilation. The development is planned such that the pillars will be cut at exact positions past the pillar width to ensure continued flow of air. However, this seldom happens as this puts a delay on development or panel mining where most tonnes are sourced from. This proves that the mining equipment have capabilities to develop faster, unfortunately this was done at the expense of safe development practices as ventilation was compromised. The delays in production were as a result of maintenance issues, conveyor belt construction and moves. The belt moves were not built into the production schedule hence the delays experienced had an impact on the planned production. The workshops were also far from the operating panels. Plans were to move workshops closer to operating panels but these plans were not implemented. This also had a bearing on the

productivity of the mine. The short cuts taken are a result of these activities impacting on production. Therefore mine personnel compromise safety in trying to make up for the lost production time as a result of the delays.

At the time of the visit, the new fleet was being introduced. The old equipment had reached its economic life and was being replaced. The issue was that the new equipment gave problems to the operators. This was mostly due to mechanical failures. The suppliers of equipment were not from the traditional suppliers with experience and integrity in the market. To save on replacement capital other suppliers with more competitive pricing structures were being used but this came at a detriment to the production and productivity. Although it is imperative to continually save on costs, cognisance on quality must be taken into account when new suppliers are being used to ensure that mining production is not hampered. New equipment from a different supplier might require different spares requirements and different maintenance skills.

#### **4.4 Waterval: Anglo Platinum - Case study 3**

##### **4.4.1 Background**

Waterval is a flagship of mine mechanisation at Anglo Platinum with early production done by room and pillar mining. Soon it was discovered that room and pillar mining was not suitable due to poor equipment utilisation and entry into the panels was difficult. They then changed to the T-cut mining method. An XLP was utilised in reduced stoping width in a room and pillar mining method. The movement of people was restricted in the working area and production efficiencies were not being achieved. Since the mechanisation was entrenched at this mine, the mining method was converted to breast XLP layout. In many areas of the BC, mine mechanisation was judged not on the potential but on the outcomes as implemented. However Waterval was maintained as a mechanised mine with the changed layouts. According to the mine management, the breast layout had the benefit of face advance, efficient cleaning with the bigger excavated gullies, dozer cleaning efficiencies, equipment utilisation improvement and easy access for men and materials due to large excavated gullies.

At the time when the visit was undertaken, the new section was being started albeit with shortcomings of poor preparation in terms of satellite workshops. Other mine visits undertaken had indicated a huge shortcoming when mining without the satellite workshops. Although this was planned in the future, the reality was that it took a long time before it was actually done and equipped with the necessary spares and support equipment.

#### 4.4.2 Location and geology

Waterval is located in Rustenburg and forms part of the Anglo Platinum (AP) mine complex found on the Western limb. The average width of the main seam is 0.71 m across the ore body as shown in Figure 4.8. The average dip on the property is 9°. The reef consists of a stringer that is situated between 20 and 25cm above the main seam. What makes this stringer unique is the smooth parting plane with competent hanging wall hence it forms part of the stoping and mining width. The geology at Waterval is favourable to mechanisation requirements where the dip is well below 12° and the geological disturbances (although existing), can be managed better during the mining process.

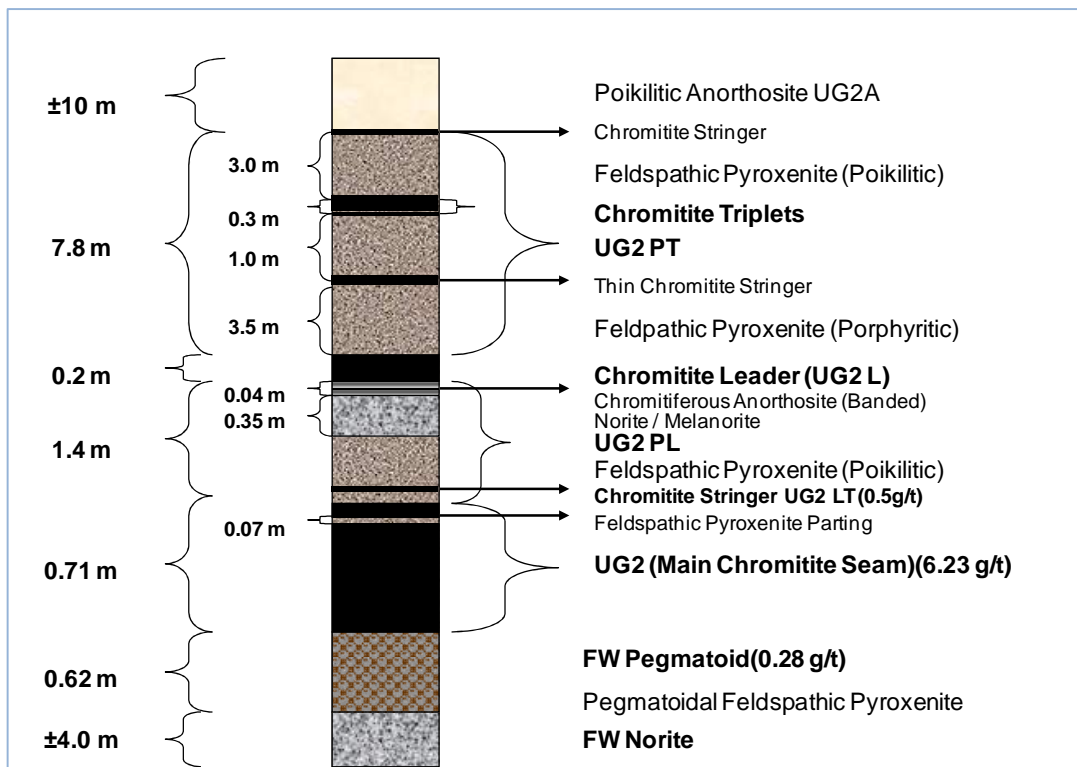


Figure 4.8: Stratigraphic column of Waterval

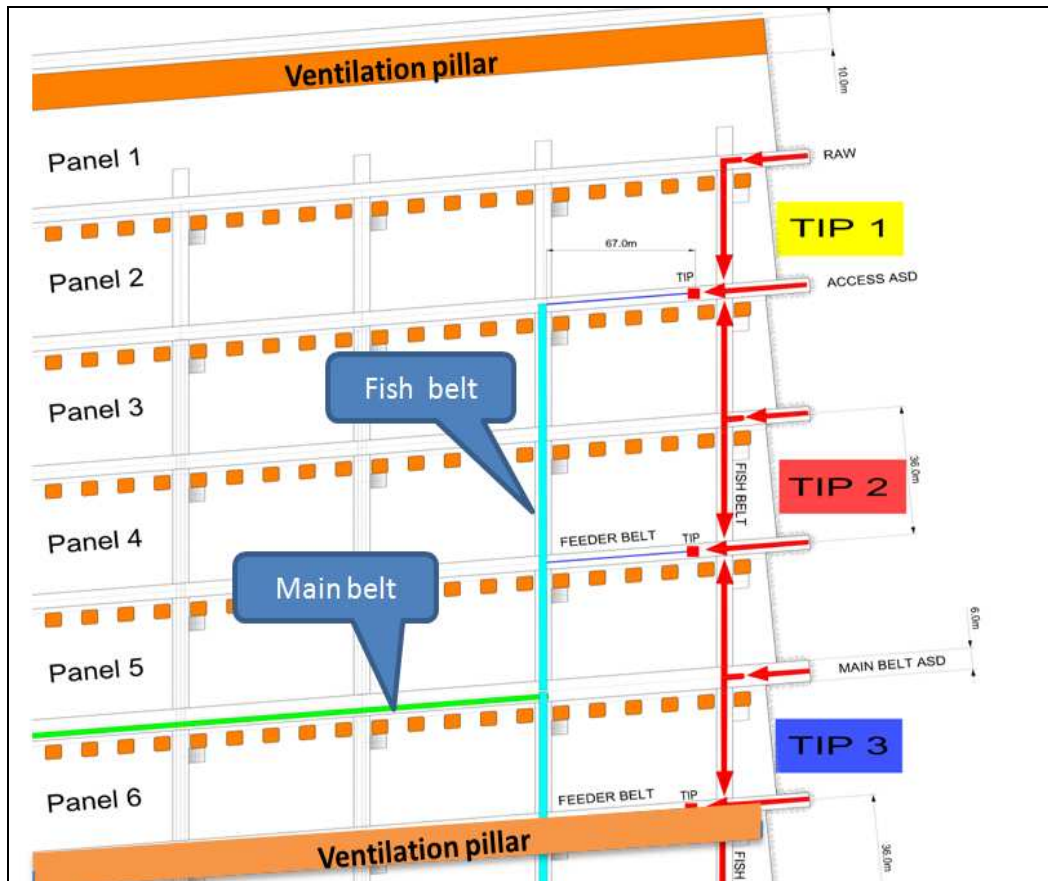
#### **4.4.3 Access method**

The mine is accessed via a series of declines set on reef. The mining horizon is situated less than 300 m below surface. The mining block visited is accessed from the declines by a series of strike drives connected to the dip drives.

#### **4.4.4 Mining method and layout**

Breast mining method using XLP equipment is employed with a 1.2 m stoping width and an effective panel length of 25.6 m. The strike advance gullies (SAG) and dip drive dimensions are 4.4 m by 2.4 m (Width x Height). Conveyor belts are used to improve and support LHD`s efficiencies. In AP the drive ways are developed such that there is adequate space on either side of the equipment for safety and protection of the equipment. A clearance of 0.5 m was maintained on either side of the equipment.

The section consists of six panels with a dedicated belt for ore handling. The mining grid is pre-developed every 45 m which gives the mine the benefit of ore reserve creation and also knowledge of geological anomalies ahead of the mining faces. A typical section layout is indicated in Figure 4.9.



**Figure 4.9:** Typical section layout details

#### 4.4.5 Mining equipment

The primary equipment is the XLP drill rig, dozer and bolter for the panels. The in-stope development equipment include LP LHD's, drill and bolter rigs. Other support equipment include utility vehicles with cassettes, mobile bridge for XLP transportation, supervision vehicles, and personnel carriers, graders for road maintenance and scalers for barring.

#### **4.4.6 Findings**

Waterval management embraced technology and they ensured that it worked underground. Provision was made for a workshop in the section visited, however it was not equipped with the necessary tools to render maintenance services. This was one of the findings in the other case studies, that without maintenance support production will suffer and operational cost will increase. The maintenance of the equipment was done by the major suppliers with consequences of escalating costs. The contractor costs were higher and the mark-ups on services were also very high. This was a concern and should be addressed by the mine. The escalating cost on a mine does affect profitability. The long term view of maintenance contract is to ensure that there is a balance between mine labour maintenance staff as well as supplier maintenance staff.

The underground layout at Waterval proved to be conducive to equipment with adequate excavations for equipment movement. However this has resulted in higher dilution rate on the mine. An XLP layout makes provision for large in-stope development for all the LP equipment for access of men, material, belts and equipment. In addition occasional potholes add to the waste load on the mine. These reduce the grade further. Waste rock replaces ore at the plant resulting in low recoveries and poor revenues. It is essential that the mine design process should take cognisance of the impact of grade when selecting the most suitable mining method.

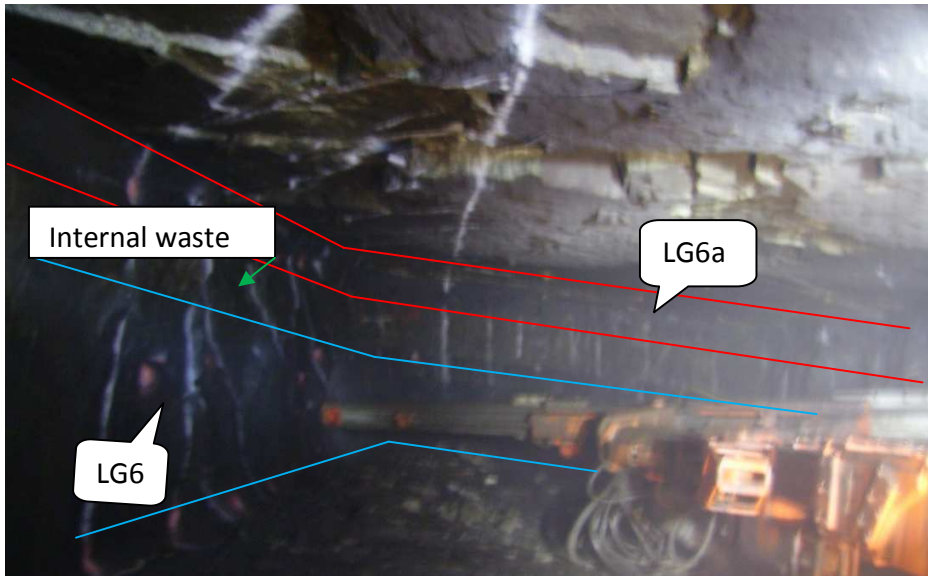
## **4.5 Millsell: Samancor - Case study 4**

### **4.5.1 Background**

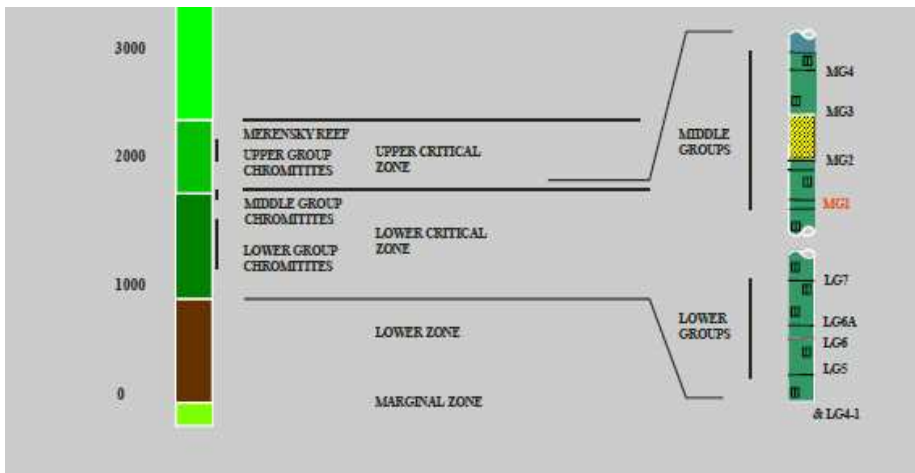
Chrome mines pioneered mine mechanisation in the BC where the geological environment was found to be suitable. The chrome mines use both conventional and mechanised mining in their production mix. This, in a way, indicates that not all ore bodies can be successfully mechanised. There is a limit on the level of technology and this is dictated to by the mining environment. Millsell Mine forms part of the Samancor`s western chrome mines. Samancor is a leading supplier of chromite ore and ferrochrome.

### **4.5.2 Location and geology**

The mine is situated in Rustenburg in the Western limb of the BC. The mine exploits the LG6 and LG6a chromite ores using the room and pillar mining method. The ore body dips at average of 9° and 11 ° at the most. The total reef width package is 1.74 m including internal waste. This condition makes the mining environment ideal for mechanisation. The stratigraphic column is shown in Figure 4.10 and it depicts the location of the lower group metals in the BC. The two reefs (LG6 and LG6a) are separated by internal waste as shown in Figure 4.11 The hanging and footwall are unique because they break at their parting planes in a more stable and smooth surface which is good for the trackless equipment tyres.



**Figure 4.10:** Mining channel with the two reefs



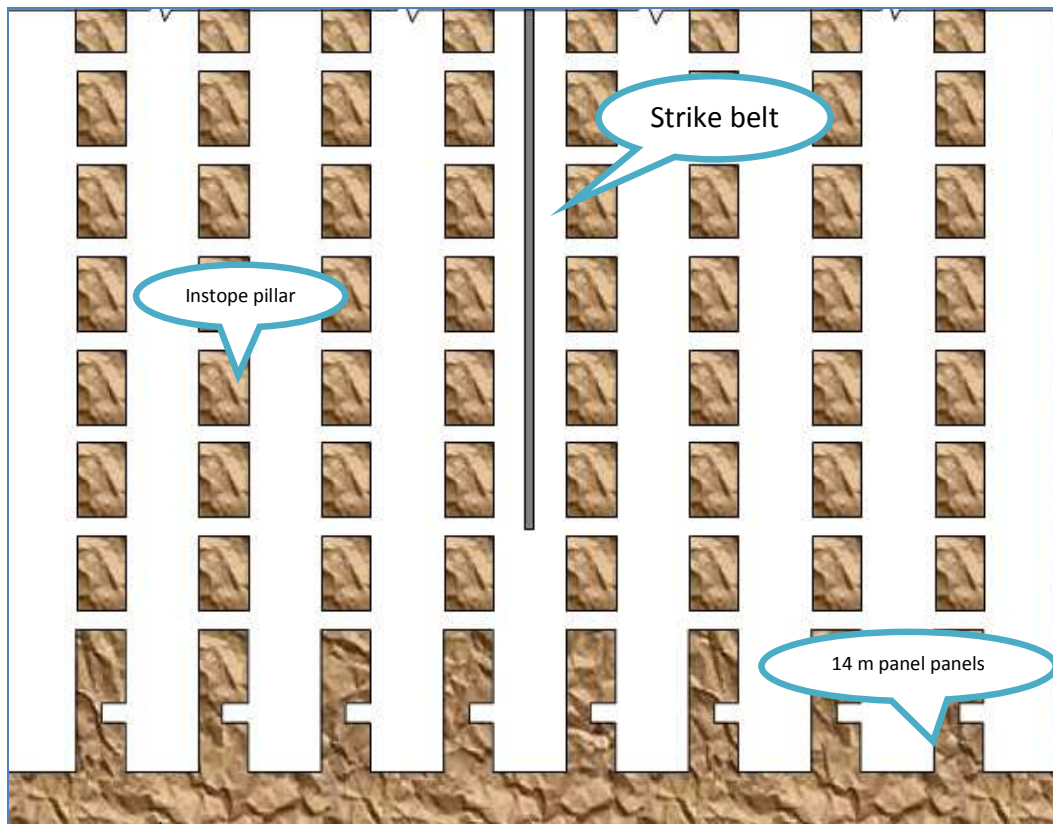
**Figure 4.11:** Typical stratigraphic column

#### **4.5.3 Access method**

Access is by means of a decline from surface. The mine is shallow and has a vertical distance that is less than 300 m from surface. Roadways are developed on strike to further access the mining areas. The main conveyor belt decline was mined on dip from surface. Strike conveyors discharge ore onto this belt.

#### **4.5.4 Mining method and layout**

Room and pillar mining is practised at this mine as indicated in Figure 4.12. The rooms are 14 m in length with the stoping height varying between 1.74 and 1.8 m depending on the local conditions. A section consists of 10 rooms. This is done to ensure that the mineable face length is adequate for equipment utilisation and to ensure that in the case of geological complications, production and productivity are maintained. The pillar sizes around the decline are 6 m x 9m (width x length) and in-stope crush pillars are designed at 5m x 5m. Millsell practices smart blasting technique underground where frequency of drill holes is reduced on the internal waste so that it breaks in large fragments for stowing underground. This is a very proficient way of ensuring that dilution is minimised underground.



**Figure 4.12: Room and pillar layout as practiced at Millsell**

#### **4.5.5 Mining equipment**

Mining equipment is the traditional LP equipment for drilling, LHDs for loading ore, conveyor belts and utility vehicles. Hand-held bolting is used to complement the TMM. No explanation was given as to why a mechanical rock bolter was not used. It might have been a matter of a lack of capital outlay at the beginning of the project.

#### **4.5.6 Findings**

The room and pillar mining method at Millsell supports the use of LP equipment. The problem of dilution is an issue for most mines in BC including chrome mines. However the chrome mines especially Millsell reduce waste underground at the source. As a result minimum waste is sent to the processing plant. Equipment management and philosophy is that the equipment must operate at all times except when in service or on break down or shift change over. The longer back length is done to ensure that the mining face length is adequate for equipment. No pre-development is done here as is the norm in any room and pillar mining method. It is prudent that geological interpretation is technically informative and can be used in planning for production. The use of equipment is effective, however use of hand-held bolting equipment was a concern. The majority of mechanised mining systems are motivated on the basis of improved safety, minimum human effort, improved production and higher productivity. However use of hand-held bolter in most mines visited is because the mechanical bolter was identified as a constraint and hand-held bolting crews were introduced as a measure to avoid production delays. In this case however, hand-held bolting was selected during the design stages. At the time of the visit maintenance was becoming a challenge due to the location of the nearest workshop. The workshops must be closer to the working place to ensure that equipment is maintained timeously. Efforts are made to minimise dilution underground which is one of the biggest disadvantages of mechanisation.

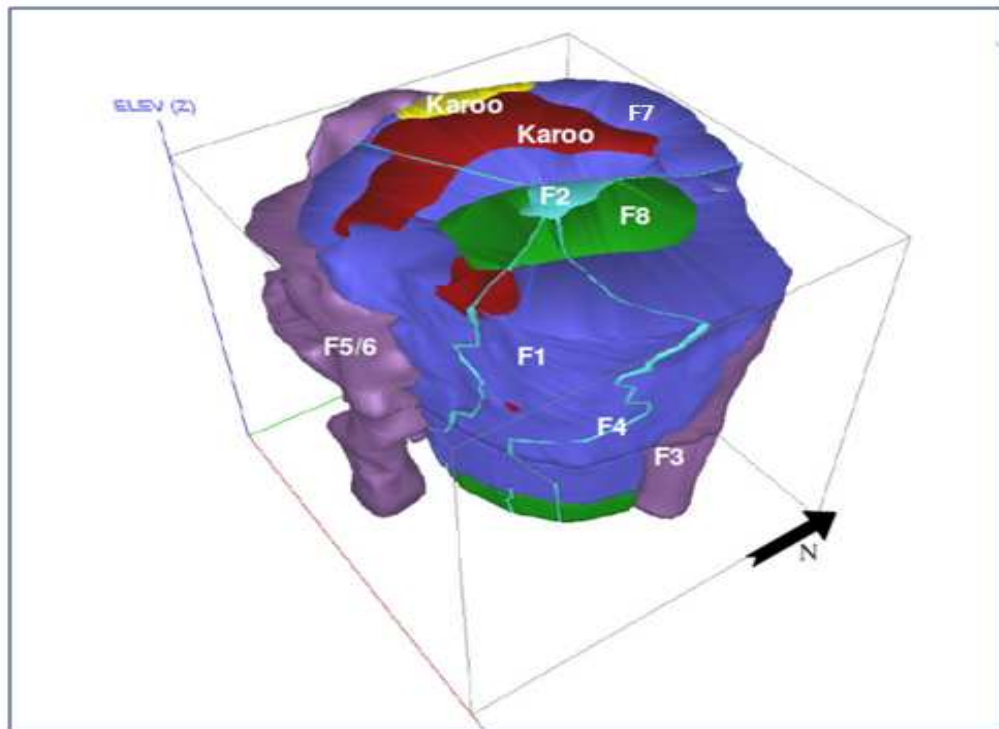
## **4.6 Finch: De Beers – Case study 5**

### **4.6.1 Background**

Finch Mine is one of the most technologically advanced mines in South Africa. The mine has been at the forefront of technology for many years. This is because, amongst other reasons, the ore body is different in deposition and orientation. While narrow ore bodies extend on strike and dip, the ore body is near vertical and massive. Development is done well in advance while in narrow tabular mines, development is a continuous process. The mine mechanisation strategy depends on the size of the ore body and quality of the ore body. Although De Beers championed the mechanised mining method on surface and underground, they still have some of their mines which are completely conventional with winches. This again shows that not all ore bodies can be mechanised. In Kimberley, Wesselton Mine used to be a complete conventional mine with track bound trains tramming ore. The conventional mining block was narrower in size. The conventional mining method was suitable and economical. Therefore it is important that technology application must be understood based on economical and geological factors

### **4.6.2 Location and geology**

Finch Mine is located 160 km north west of Kimberly in the Northern Cape Province. The Finch pipe consists of eight main Kimberlite types owing this to the way they were deposited. These Kimberlite types are named F1 to F8 as indicated in Figure 4.13. The Kimberlite is a unique massive ore body much different to ore bodies found in the BC which are much narrower and extend over a long strike length and dip.



**Figure 4.13: 3D image of Finsch Kimberlite pipe (Courtesy of De Beers)**

#### **4.6.3 Access method**

Access underground is through a vertical shaft. Further access is through flat end development towards the mining area referred to as the block cave area. The undercut is pre-developed to ensure initial block caving space. The undercut is linked to the production section by draw points. Draw points can be compared to the ore passes found in narrow conventional mines. The production level is the ore handling level. Ore is drawn from draw points by LHDs and dumped into trucks which transport ore to the central crusher system.

#### 4.6.4 Mining method and layout

Finsch Mine started as an open pit mine until the design limit was reached from surface. Currently the mine operates a block cave mining method. The mining method is different from the traditional mining method found on the BC. The block development is done and completed well ahead of production. The mine layout is shown in Figure 4.14. The development can be divided into two where the block cave is undercut to initiate the cave and secondly where production is going to take place. Although the mining method differs from the mining method found in the BC, the objectives are almost the same, namely: improved safety, higher productivity, improved production and higher efficiencies as the key performance indicators. The mining layout and development have been designed to be able to handle men, materials, equipment and ventilation. Block cave mining with mechanised mining has proven that technology can be applied successfully where the environment is conducive for equipment.

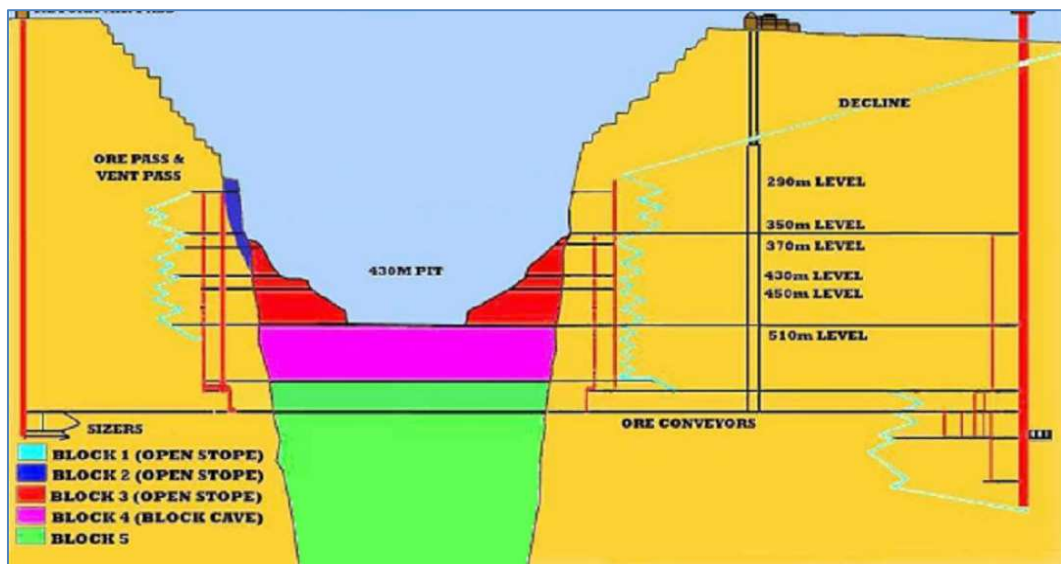


Figure 4.14: A schematic section of the Finch block cave layout (Courtesy of De Beers)

#### **4.6.5 Mining equipment**

Finsch is a highly mechanised mine where equipment used has system support of breakdown vehicles and equipped workshop. The mining equipment includes LHDs, drill rigs, utility vehicles and break down vehicles that have the capability to remove broken down equipment from the sections to the workshops. On surface there is a central control room where trucks in the autonomous loop are monitored and also controlled if necessary. The management system is active with all the equipment monitored at all times. The maintenance schedules are adhered to at all times. The workshops are large, well equipped and designed to be closer to the working place for support on breakdowns and scheduled maintenances. The control room forms part of the integral support system for the mine. It is a management tool that monitors all the mine activities with real time data. These include equipment performance and movement, ventilation systems, pumps and dams and the shafts. There is a maintenance contract with the suppliers. However the maintenance is not all entirely done by the suppliers, in house maintenance crews are also available. They too share the mine's maintenance responsibilities. This relationship ensures that there is continuous skills transfer for the mine in the long term.

#### **4.6.6 Findings**

Mechanisation at Finsch is more coordinated and is managed from a central point through a production management system. All equipment activities and tasks are measured on a daily basis. If any equipment stops at any time, the control room will pick it up immediately and ensure that the necessary support is rendered as required. Communication systems are advanced with leaky feeders underground. Communication between operators and the control room is immediate and unnecessary down times are avoided. The areas of concern are the dust levels in the

block cave which can be extremely high resulting in poor visibility. High dust levels are detrimental to mining equipment.

According to the mine management, road maintenance has a huge impact on operating costs. However it is necessary to ensure that investment in the roads is done to prolong the life of all mine equipment. Operators of equipment are selected on the basis of some literacy levels with a minimum of matric certificate. Finsch mine has proved that to mechanise the mine a lot of back up support must be provided to ensure the equipment can do the job they are employed to do.

#### **4.7 Conclusion**

The case studies indicate that mine mechanisation is being practised on the BC with some successes and failures. The major failures have resulted in the operations being converted to hybrid or conventional mining methods. This is as a result of poor productivity and high running costs. Dilution and maintenance are common issues in all the case studies in the BC. The use of XLP mining is done to minimise dilution on the mine. However on-reef development still brings a lot of waste material contributing to dilution. The average reef width is 60-70cm. The XLP stoping width requirement of 1.2 m still adds some amount of waste into the system and impacts on the head grade. Maintenance issues remain as one of the most threatening factor to successful mechanisation. Most of the findings indicated that new areas were started without workshops near the working place. This has resulted in delays and poor equipment availabilities. The lack of critical and general spares also contributed to the problem.

The XLP technology operates in small dimensions which contributed to the delay problems. This is because of poor blasting practices where excavations are made smaller, the equipment often got stuck between the hanging and footwall. The limited space also makes it difficult to attend to equipment on break-down at the stope face. In an LP environment, the excavations have adequate size required for services, men, material and ventilation.

The LP machinery has operated more successfully as compared to XLP equipment. This is attributed to the readily available equipment and their spares. XLP equipment is a new technology as compared to LP equipment. As a result there is more consistency and higher efficiencies with the LP equipment.

The mines visited that changed the mining system to hybrid mining method, retained mechanised development. The mechanised equipment has achieved development rates of up 60m per month. This results in quick access to reserves.

A strong mechanisation strategy requires a complete working system consisting of suitable mining environment and support system. A complete system will ensure that all human effort is minimised throughout the mining processes. However in the BC some areas have resorted to use of hand-held equipment for roof bolting due to delays resulting from the mechanical bolter failures and in certain cases under capitalisation was an issue. These issues undermine a complete working system for a mechanised mine.

The support system as observed in case study 5 is a good example which supports a successful mechanised mine. This is because there are adequate functional workshop close to the working place, a working communication system, control room for monitoring all mine activities including equipment through a production management system and a balanced maintenance contract which ensures skills transfer to the mine.

The notion of a support system is not fully entrenched in mechanised mines in the BC. This has led to termination of some mechanised mines on the BC. It is also worth noting that geology plays a huge role in mine mechanisation. All the case studies indicate that the geological environment in terms of dip, size, frequency of geological structures and ore body orientation is essential in implementing a mechanised mine especially on the BC.

A successful mining method should not destroy value, but should ensure that the system works efficiently with all the necessary support. In the BC, mechanisation strategy is used to ensure safe mining, productivity and efficiencies. However value creation is not mentioned in most of the strategies entrenched in the mines. The following chapter explores the mine mechanisation in the BC in terms of mining methods, value creation and suitability of the current mining technologies as applied in mechanised mines.

## **CHAPTER 5: ANALYSIS**

### **5.1 Introduction**

Mining companies resort to new technology in response to their operating environment. These include the following factors; legal framework, changing markets, currency fluctuations and metal prices. The companies do not have influence on the environmental factors, however they have to respond to these changes as they occur. As a result safety has been one of the driving factors for mine mechanisation in the BC. Other driving factors include improved efficiencies, improved productivity and better operating costs.

In the BC mine mechanisation is driven by company strategies which are informed by the needs of the company and the operating environment. To ensure that the business remains competitive, technology is seen as answer. Technology improvement is associated with benefits. The rationale and benefit for mine mechanisation is summarised in Table 5.1. Mine mechanisation strategies require thorough research and rigorous testing to ensure that the design results are realised. In the BC the technology trials done in some instances did not realise the value associated with mine mechanisation. The use of non-blasting technology did not achieve the intended purpose and as a result does not currently form part of the mining mix in BC. However the blasting technologies are being utilised on the BC as part of the mining mix. This includes hybrid and fully mechanised mining methods. However the conventional mining methods are still the most preferred over mechanised mining systems on BC. Most of the mines on BC still operate conventional mining methods.

**Table 5.1: Rational for Mine Mechanisation**

<b>Rational factors for mechanisation</b>	<b>Comments</b>
Improved efficiencies	The drilling efficiencies and advances are superior to conventional mining. The skills and literacy levels are usually higher with mechanisation
Productivity	Getting better production results and improved efficiencies.
Safety	Less people are exposed to dangerous working conditions.
Attract women in mining	In response to the statutory requirement, women can no longer be discriminated against in the mining industry. Use of TMM is not labour intensive hence women are finding it appealing.
Low operating cost	Improved efficiencies and productivity result in less wastage and improved working costs of the mine. This is a result of accurate drilling, efficient blasting and trained skillful employees.
Increased production	Increased productivity will ensure that life of mine plans and production targets are achieved.

The question to ask is whether the current technology investment in narrow tabular ore bodies is the correct one and if so, why is it that mechanisation does not spread and replace conventional mining methods? This is further explored in the sections 5.2 and 5.4. Mine mechanisation is not promoted on the fact that it can produce more tonnage output as compared to conventional mining method. The idea is to produce quality ore with high efficiencies, improved productivity and low operating costs. This ideal has been elusive in some of the operations visited.

## 5.2 Case studies

The case studies matrix was developed to measure performance of each of the factors considered important for mine mechanisation. The following factors have been selected based on the mechanisation philosophy observed from the case studies:

- Efficiency;
- Productivity;
- Safety;
- Operating costs; and
- Production.

The scale for measurement was based on information from the mines. The actual numbers are not used here because of the confidentiality agreement with the mines. The matrix consists of the following description for each factor deemed important in the advancement of mine mechanisation:

- Poor: this reflects poor results from using a mechanised system;
- Moderate: results are acceptable, but there is room for improvement; and
- Good: the benefit of mechanisation is fully realised.

The results are captured in an assessment matrix in Table 5.1. The purpose of the matrix is to show the case studies where mine mechanisation has been implemented successfully.

**Table 5.2: Mechanisation Matrix**

Case studies	Efficiencies	Productivity	Safety	Operating cost	Production	Comments
1	Poor	Poor	Good	Poor	Poor	Mechanisation benefits not fully realised
2	Moderate	Moderate	Good	Good	Moderate	Mechanisation benefits not fully realised
3	Moderate	Moderate	Good	Good	Moderate	Mechanisation benefits not fully realised
4	Good	Good	Good	Good	Good	Mechanisation benefits fully realised
5	Moderate	Moderate	Good	Good	Good	Mechanisation benefits fully realised

The case studies one to three have not fully realised the mine mechanisation benefit. The results are captured in Chapter 4. The poor to moderate results are due to the following:

- Lack of maintenance facilities and critical spares resulting in poor TMM maintenance. This comes with the ultimate consequence of high operating cost and poor production;
- Geological factors including faults, potholes and dykes. Their high frequency of occurrence will render TMM unsuitable due to dilution and operating gradients which may exceed 12 degrees; and
- Dilution as a result of on reef excavation which contributes to lower head grade. Lower head grade contributes to poor recoveries at the processing plant hence resulting in poor revenues.

In cases four and five, the mine mechanisation benefits are fully realised. The mine mechanisation strategy in both cases was to improve on the mining efficiencies and operating costs. In case study four, dilution is being managed underground and TMM are fully utilised underground. Although hand held equipment is still being used, this was done to save on the capital outlay during project planning. In case study five, mine mechanisation works as a complete system. The TMM consists of high support structure which includes workshops, control room and production management system. There is a continuous measurement of all mine activities to ensure smooth running of the mine. This support structure is non-existent in the Bushveld Complex. This is one of the reasons why mine mechanisation is failing on the BC.

### **5.3 Mining methods analysis**

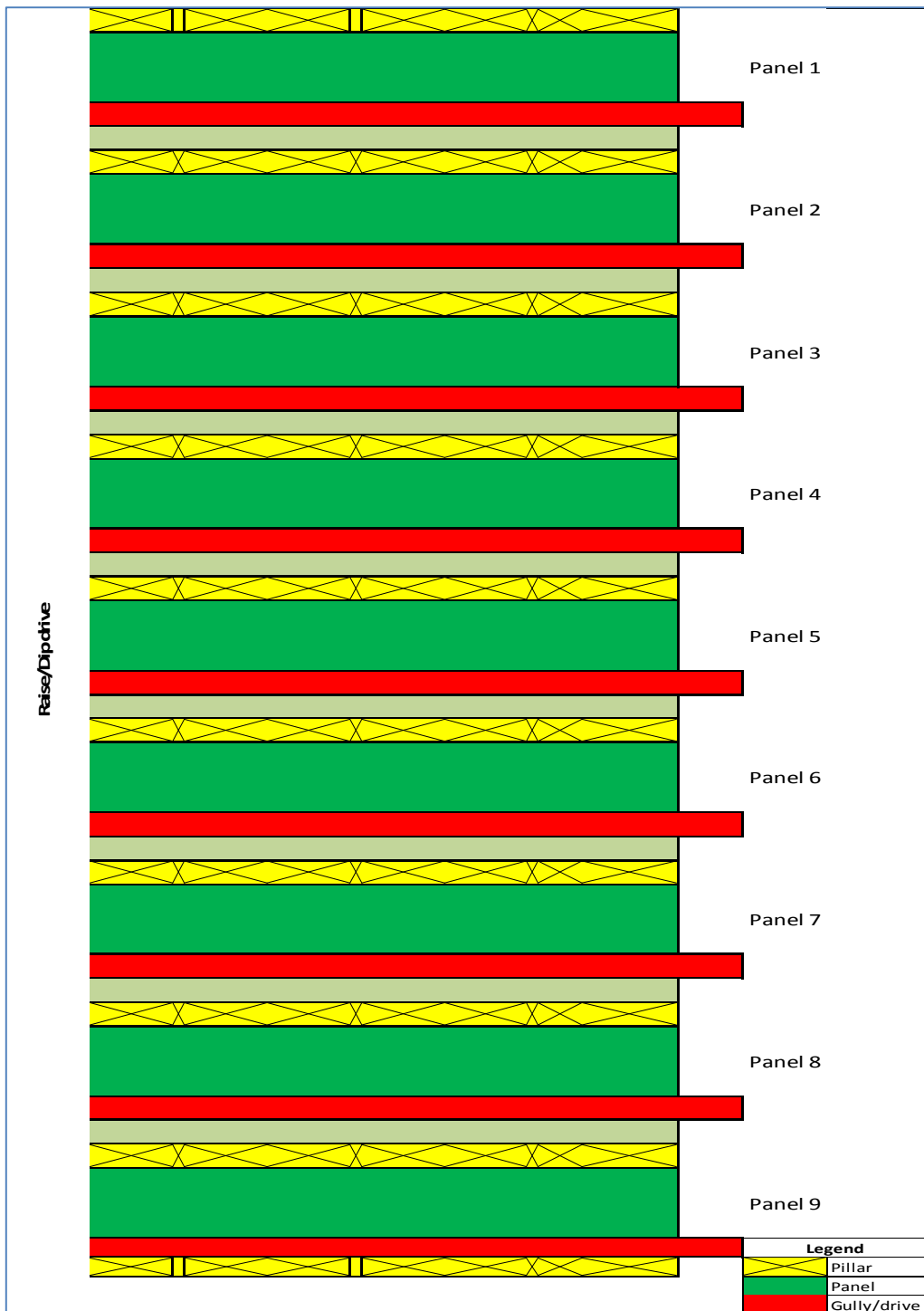
XLP and room and pillar mining methods are the most common systems using TMM. The mining method uses a series of on-reef development which is closer to the working panel but this extends into the footwall which carries waste. The reef is narrow and at the same time the mining width carries waste. On the other hand the conventional mining methods have better grades as compared to TMM operated mines. The typical panel lengths are the same for most mechanised and conventional mines. However the in-stope development and stoping height are lower on conventional mines. The Room and pillar mining contributes more waste as a result of large excavations on reef. Areas where in a stope there is a spilt of reefs with internal waste or wider reefs, the impact of grade is minimal and use of an XLP mining method is used to influence grade by mining narrower stopes at stoping heights of less than 1.2 m.

This mining method is compared with conventional mining method to analyze waste and the impact of dilution on the grade. This is done on the premise that room and pillar mining is a worse contributor of waste where reef conditions are the same.

The most common mining methods are shown in Appendices A1 to A3. Hybrid mining method is a compromise mining method which uses strong attributes of both fully mechanised and conventional mining methods. This method does not form part of the mining method analysis. The mining method analysis is best described by the following mining parameters as shown in Table 5.3. The mining parameters are used for comparing the two mining systems. The mining losses are the same for both systems. The losses include pillar, geological structures and quality of mining driven by drilling efficiencies. In conventional mining methods the drilling efficiencies are low resulting in poor quality of mining. This is due to the hand-held drilling equipment. In the TMM mining quality is good. TMM equipment will have better drilling efficiencies resulting in good mining conditions. In Table 5.6, mining parameters indicate dilution and losses which have an impact on the head grade. The data used is based on real life projects for demonstration purposes. The design parameters are indicated in Table 5.3 which is driven by the development requirements on the reef horizon for mechanised layouts and on reef and footwall development for conventional layout. However, for demonstration and analysis purposes, just on reef-development will be considered in this exercise for both mining layouts. Total mining panels are nine per section per half level. The nine panel layout is shown in Figure 5.1.

**Table 5.3: Mine design parameters**

<b>MINE DESIGN PARAMETERS</b>		
<b>In stope infrastructure</b>	<b>Mechanised</b>	<b>Conventional</b>
In-stope pillar	2.5m x 6m (w x l)	2.5m x 4m(w x l)
Panel length	26.5m(l)	26.5m(l)
Strike gully/drive	3.5(w)	1.4(w)
Raise/dip drive	4.5(w)	1.4(w)
Back length	292.5m(l)	282.6(l)



**Figure 5.1:** Typical mining section with nine panels (half level)

The impact of dilution is shown in Tables 5.4 and 5.5. Conventional mining methods have less waste as compared to the mechanised mining methods. The impact on mine head grade is demonstrated in Table 5.6 and 5.7. The resulting grades from the model indicate that the mining cut and additional waste by on reef development has an impact on grade. As a result, conventional mining methods have higher grade when compared to mechanised mining methods. This is one of the primary reasons as to why mining companies prefer conventional mining methods.

**Table 5.4: Mining waste – mechanised mining**

Dilution - Mechanised mining					
Reef		Volume (m3)	Length (m)	Width (m)	H(m)
Area of influence	100%	31,590	90.00	292.50	1.20
Dilution - On reef development					
Dip development	4.00%	1,264	312.00	4.50	0.90
Strike conveyor and service	2.85%	900	90.00	5.00	1.00
Strike development	7.98%	2,520	90.00	3.50	1.00
Holings: conv and service drives	0.03%	11	3.00	3.50	1.00
Electrical cubbies	0.22%	68	1.20	3.00	2.10
Tipping area	0.13%	40	3.85	4.00	1.30
Sumps	0.01%	2	1.50	1.50	0.80
<b>Total Dilution</b>	<b>15.21%</b>				

**Table 5.5: Mining Waste: Conventional mining**

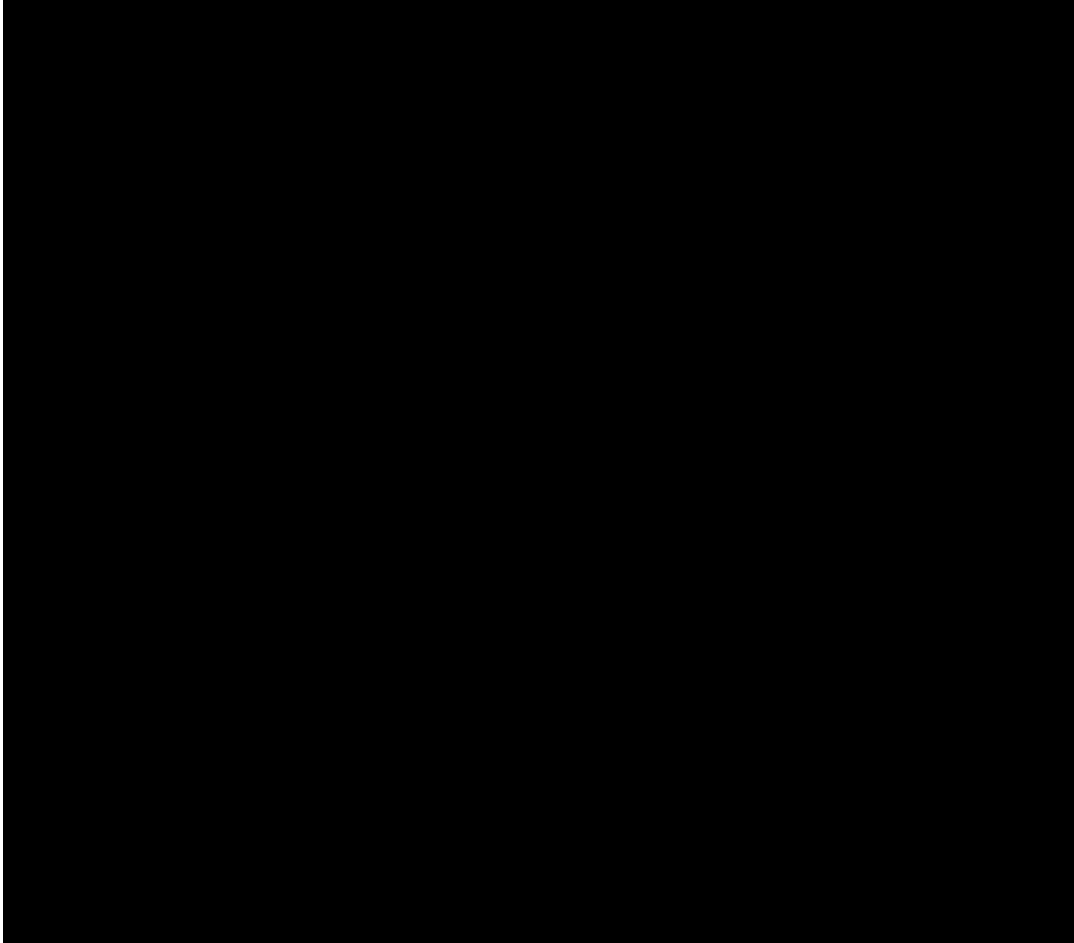
<b>Dilution - Conventional mining</b>					
	<b>%</b>	<b>Volume (m<sup>3</sup>)</b>	<b>Length (m)</b>	<b>Width (m)</b>	<b>H(m)</b>
<b>Area of influence</b>	<b>100</b>	<b>30,521</b>	<b>90</b>	<b>282.6</b>	<b>1.2</b>
<b>Waste: On Reef Development</b>					
Raise	1.11%	338	302.00	1.40	0.80
Strike development	2.97%	907	90.00	1.40	0.80
Electrical cubbies	0.22%	68	1.20	3.00	2.10
Tipping area	0.10%	30	3.85	3.00	1.30
Sumps	0.01%	2	2.00	1.00	0.80
<b>Total Dilution</b>	<b>4.41%</b>				

The waste ingress from the mechanised mine is high compared to the conventional mining method. The on reef development adds 4.41% in conventional layout and 15.21% in a mechanised layout. The results are shown in Table 5.4 for mechanised mining and Table 5.5 for conventional mining method. Using these results the grade calculations are then derived using the following factors:

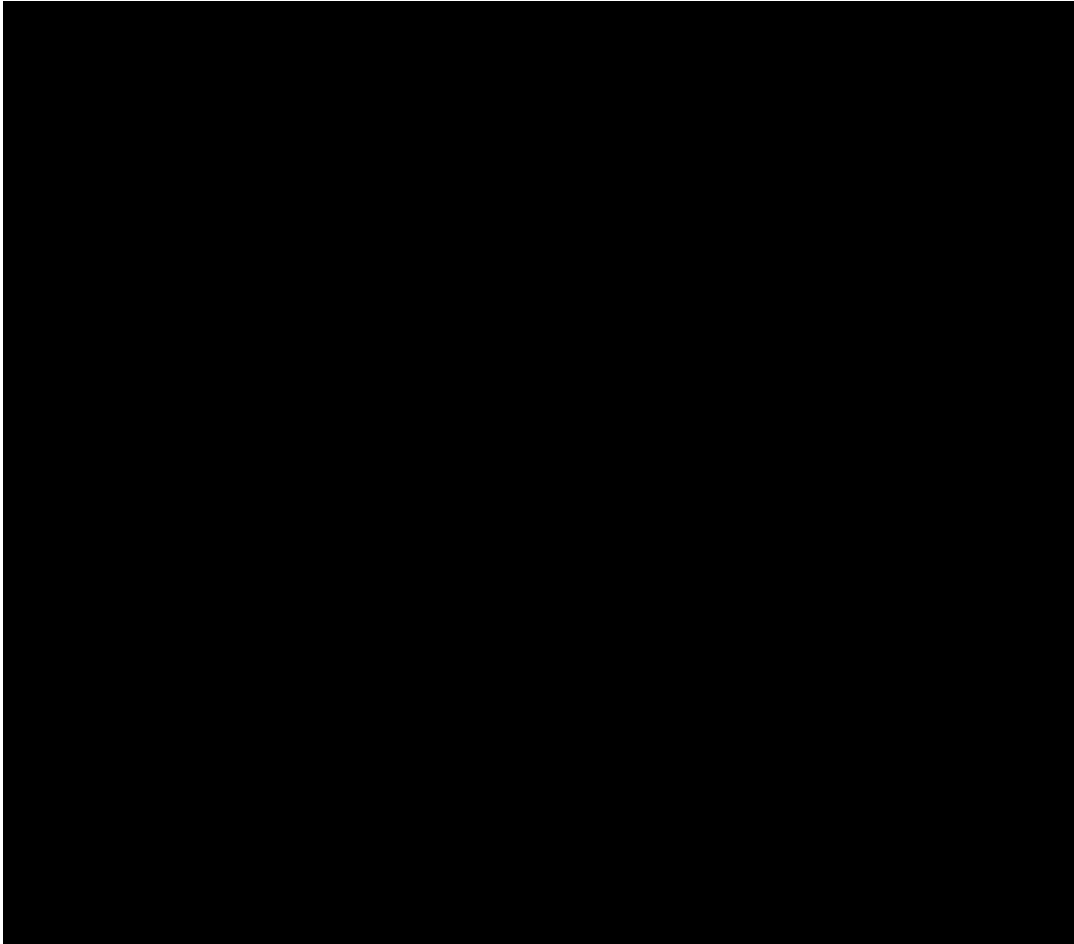
- Geology and resources;
- Grades and densities;
- Dilution factors; and
- Losses.

In Table 5.6 and Table 5.7, the grade calculation indicates that the conventional mining methods have better head grades than mechanised mining methods. The higher grade can be associated with high recoveries. The high recoveries are also associated with high revenues.

**Table 5.6: Mining Grade Derivation – conventional mining**



**Table 5.7: Mining Grade Derivation – mechanised mining**



#### 5.4 Economic sense

Looking at the mining rates achieved using the mechanised and conventional mining method, the mechanised methods do not add value in the same way as the conventional mining methods. The revenues are associated with the ultimate recovery grade. The lower grades are associated with mechanised mining methods as it can be seen from the grade derivation in Tables 5.6 and 5.7. Therefore it is important to realise this fact. Financial indicators will tend to be higher with mining systems that can generate higher revenues. The drivers of the NPV and IRR for any project are driven by higher grades, tonnages and lower capital requirements. In order to mine the half level indicated in Figure 5.2, capital outlay required for mechanised equipment is about R62 million as shown in the Table 5.9 for a production target of 3600 m<sup>2</sup> per month using two suites of equipment producing 1800 m<sup>2</sup> each. The conventional mining method achieved the same square meters with six crews but for less than R2.3 million capital outlays as indicated in table 5.8. The production rate was slightly higher for the mechanised mining method due to the higher stoping width. However the conventional mining achieved less tonnes as related to the 1.0 m stoping width but the content is higher resulting in higher revenues.

**Table 5.8: Core equipment – conventional mining**

CORE EQUIPMENT			
Equipment	Quantity	Unit (R)	Total cost (R)
55 kw scraper winch	18	113,685	2,046,330
Mono winch	1	35,000	35,000
Rock drills	36	8,000	288,000
Grand Total			2,369,330

**Table 5.9: Core equipment - mechanised**

<b>CORE EQUIPMENT</b>			
<b>Equipment</b>	<b>Quantity</b>	<b>Unit (R)</b>	<b>Total cost (R)</b>
XLP double rig Merensky	2	3,736,133	7,472,266
XLP rock bolter	2	2,913,885	5,827,770
LHD 7 tonne	3	4,207,009	12,621,027
LP development rig	2	4,342,576	8,685,152
LP rig	2	4,820,148	9,640,296
LP access development bolter rig	2	5,005,990	10,011,980
Mobil bridge for XLP transport	1	642,000	642,000
Dozer	2	1,486,000	2,972,000
Multi-purpose vehicles (LP MPV)	1	1,432,000	1,432,000
LP emulsion utility vehicle	1	1,251,545	1,251,545
LP supervision vehicle	1	76,842	76,842
Scissor lift cassette	1	600,000	600,000
Lubrication cassettes	2	370,000	740,000
Flatbed Cassettes	2	42,000	84,000
<b>Grand total</b>			<b>62,056,878</b>

These results indicate that to realise value from TMM operated mines as they are currently, the extraction rate must be high to compete with conventional mining methods. This is at the expense of long life of a mine and huge capital outlay as expected from support infrastructure and equipment.

## 5.5 Opex

Mines operational costs are captured differently in most mines and this makes it difficult to compare operational expenditure (Opex). However, the typical cost curve in BC is indicated in the Figure 5.2 derived from communication with the industry players. On the higher end the cost of mining gets to be too high and it is not sustainable. The majority of mines operate in an average cost environment as shown in the Figure 5.2. Poor productivity, production and continuous breakdowns result in high mining costs.

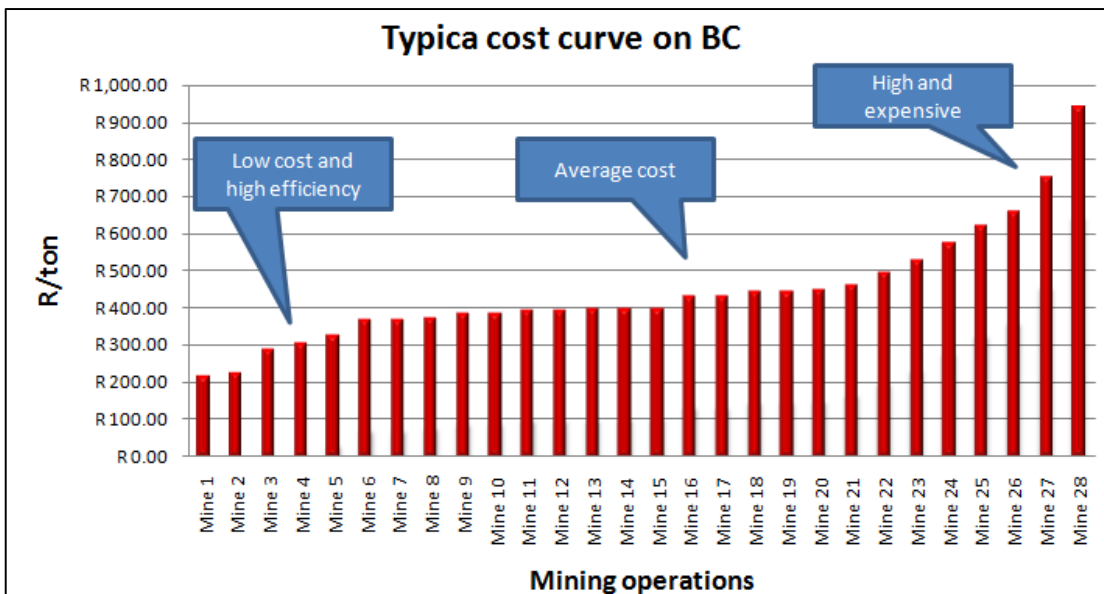


Figure 5.2: Typical Cost Curve on the BC - Escalated to 2010 money terms

## 5.6 Conclusion

Mechanised mining methods are motivated by benefits that include safety, higher productivity and higher efficiencies. However, this is proving to be difficult to realise in a majority of mechanised mines. Room and pillar mining utilises the LP equipment which are bigger and require large excavations. With the mines visited the average reef width was less than 70cm, this means the dilution incurred will be higher and affect the ultimate head grade. This is not an efficient way of mining if the revenue is compromised due to lower grades as a result of the mining method.

XLP mining methods are done to improve on the head grade. However mining at 1.2 m with the average reef width of 70 cm, the waste is still high resulting in dilution. In section 5.2, it was demonstrated that the grade associated with conventional mining method tends to be higher as the reef width could be reduced to about a 1m mining width which is closer to the in-stope *insitu* grade.

The capital requirement on a mining system does have an impact on the total revenues generated and the ultimate NPV and IRR which are ideal instruments for measuring the project viability over a long term. Use of mechanised equipment has high capital expenditure requirements as compared to conventional mining methods. However the conventional mining methods tend to have higher revenues due to higher mining head grade.

Capital and mining efficiencies are critical in determining the life of a mine plan that delivers the most value on the project. Therefore the conventional mining methods are the most efficient mining system for the narrow tabular ore body.

## CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusion

The successes and failures of mechanisation trials on the BC were not limited to the XLP and LP mining equipment. Other non blasting technologies were tried but did not prove to be convincing for implementation for various reasons that included ventilation limitation, mechanical failures and dynamics underground. The XLP and LP were found to be operating in mines visited. However the efficiencies were poor with one of the operations in the process of being converted to a conventional mining method.

XLP equipment was a relatively new technology on the BC. The technology was in the process of being proven in some areas. The typical problems included:

- In a narrow space, it was difficult to manage the equipment during breakdowns;
- Dilution was still high;
- Capital expenditure was high; and
- Maintenance issues.

Some limited success was realised with the LP mining equipment at the expense of the grade as demonstrated in case study three. In case study four, effort was being made to minimise the impact of dilution underground. In a LP mining environment, equipment operates in large excavation which makes it easy to manage. The LP proved to be popular with mine development. This technology is suitable for this type of mining operation where there is no restriction and the development is flat or operating within the design gradient.

The mechanised mining equipment requires maintenance support which was one of the most contributing factors of the failed projects in BC. Poor maintenance results in breakdowns which lead to longer downtime and poor production. Location of the workshops far from working places and availability of critical spares resulted in poor productivity and production which led to high operating costs in some areas. It is imperative to have a complete support system as observed in case study five. The workshops and control room offer support for a continuous and efficient process. The workshops are closer to the workings. Workshops are equipped and have equipment transporters which assist in loading and taking equipment to the workshops during breakdowns. In the BC most workshops were distant from the working areas and planned satellite workshops were under designed and not fully equipped.

The support equipment system must have a functional communication system to ensure that active management of production and productivity through a central control room. In case study five, use of a control room enhanced equipment management and other mine activities. In the BC, there was no control room in the areas visited. As a result equipment utilisation is low, equipment movement is not monitored. With the control room in place, equipment is monitored all the time to ensure that they perform duties according to the mine plan.

The operating environment is important for use of XLP and LP equipment. The frequency of potholes and rolling reef add to the operating problems as the equipment is not designed to negotiate strong changes on the dip of the reef. This puts a huge disadvantage on the mine mechanisation in the BC due to reef rolls. The BC consists of potholes, IRUPs and faults which can change the strike of the reef. The changes can increase the operating gradient to more than 12 degrees which is a limit for most TMM equipment on the BC. In addition, in the process of negotiating these structures a lot of waste is mined which contributes to dilution.

The mining method and exploitation strategy are important in any mining project. The decision to pursue conventional mining methods or mechanised mining methods is critical during the developmental stages. This is driven by the operating environments that include metal prices, exchange rates and statutory requirements which are beyond a miner's control. Other factors are local and include the ore body size, exploitation strategy, frequency of geological structures, dip and strike. This information which is used to determine the mining method is important. Conventional mining methods are more efficient as compared to mechanised mining method. This is mostly driven by the amount of dilution the mining methods produces which affects the head grade.

The XLP and LP mining methods are not considered efficient ways of mining the narrow tabular ore bodies found in the BC. This is because the compromises made reduce the ultimate value of the mine. In areas where wider and multiple reefs are encountered, use of LP mining method was found to be most suitable.

## **6.2 Recommendations**

The value adding principles are essential in making the decisions for mining projects which are long term in nature. Value adding principles will ensure that the exploitation strategy takes cognisance of the most suitable mining method which offers the greatest value for the life of a mine. Hence use of capital must be committed in the mining project that is viable for the life of a mine.

The conventional mining methods are associated lower operational efficiencies, but in terms of value creation they perform better than mechanised mining. This is due to the high grade that maximises revenue generation. The current mines where conventional mining methods are practiced or planned must invest in training programs that enhance safety and productivity.

The mining companies operating in the BC must invest in development of the technologies that will maximise value for the investors. These technologies must ensure that mining is done efficiently and without compromising value.

The use of activating disc cutting technology (non-blasting technology) and long hole stoping are found to be the most valuable in terms of safety and efficiency. These technologies are not yet proven but they can be the future of narrow tabular mining due to their mode of application and mining technique. Both technologies support safety. The traditional panels will be mined remotely from a safe area. They also maximise value. This is due to the fact that mining stoping width is even smaller than the traditional conventional mining stoping width. As a result, higher revenues will be realised due to improved grade.

Therefore it is recommend that the technologies and mining method associated with non- blasting technology and long hole stoping be investigated further.

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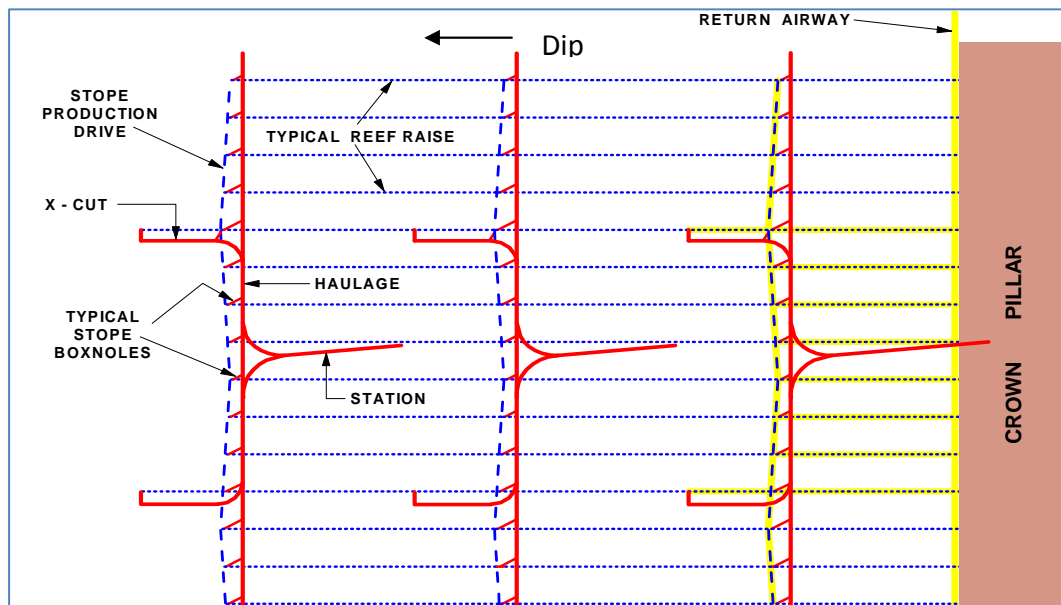
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## APPENDICES

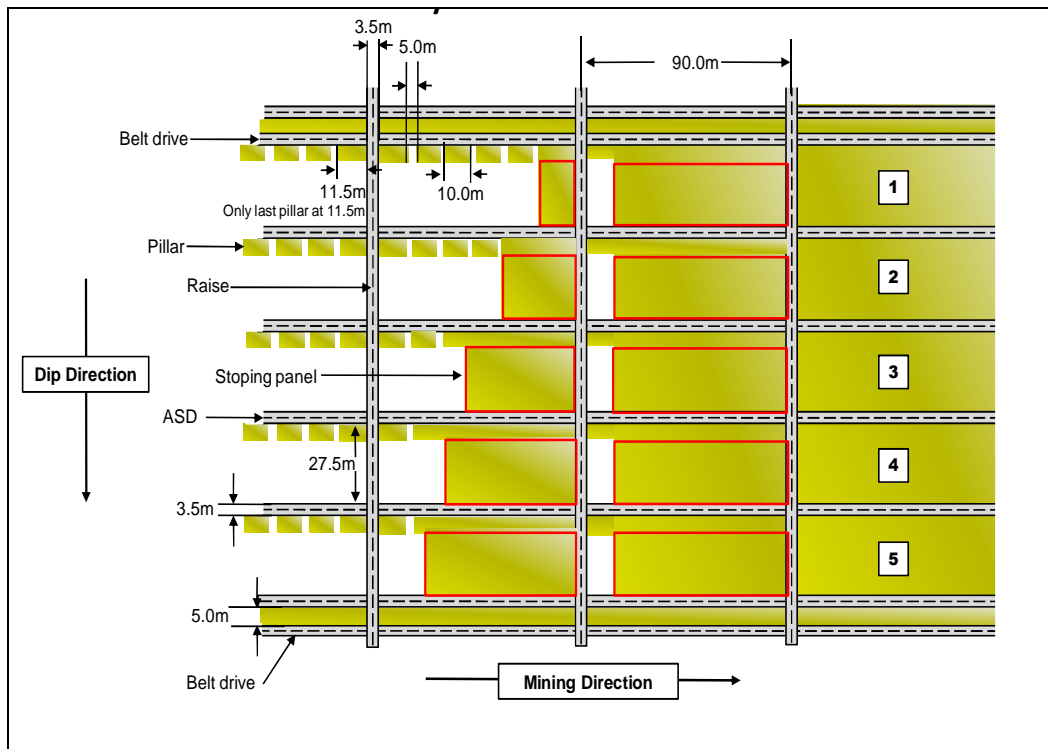
### APPENDIX A1: TYPICAL CONVENTIONAL MINING LAYOUT

Access infrastructure in the footwall. (Not to scale).



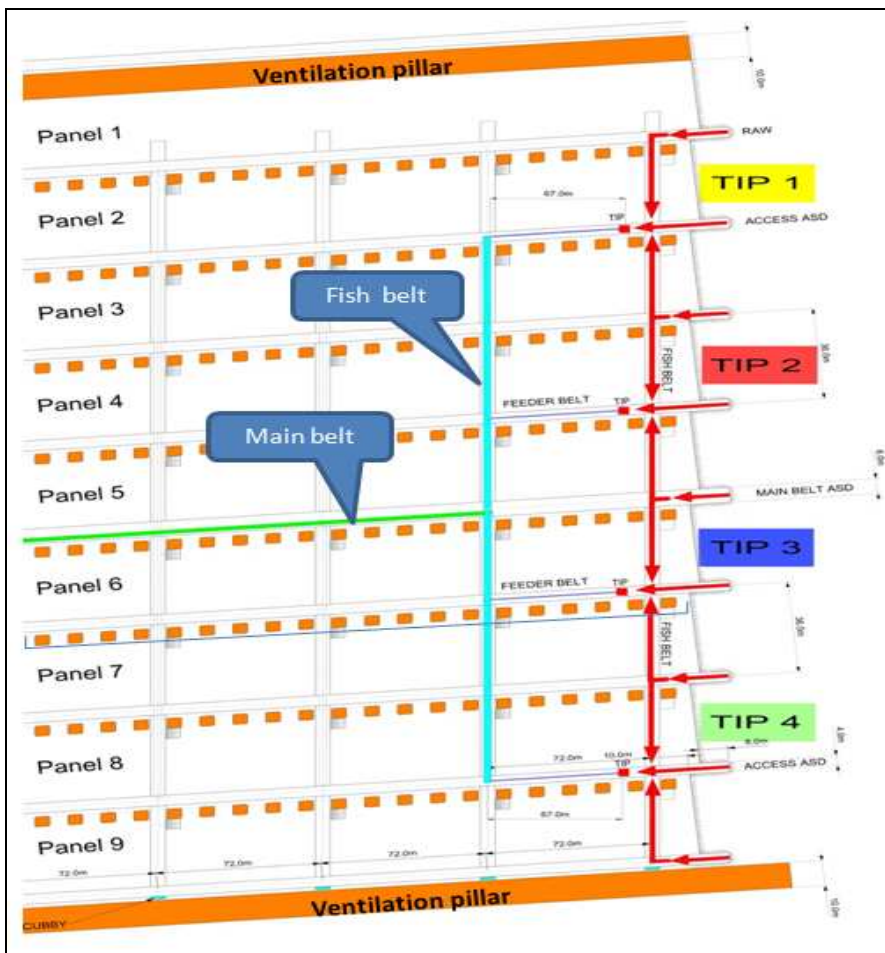
## APPENDIX A2: HYBRID MINING LAYOUT

Development mechanised and stoping hand help equipment and winches scrapers for cleaning the panel. (Not to scale).



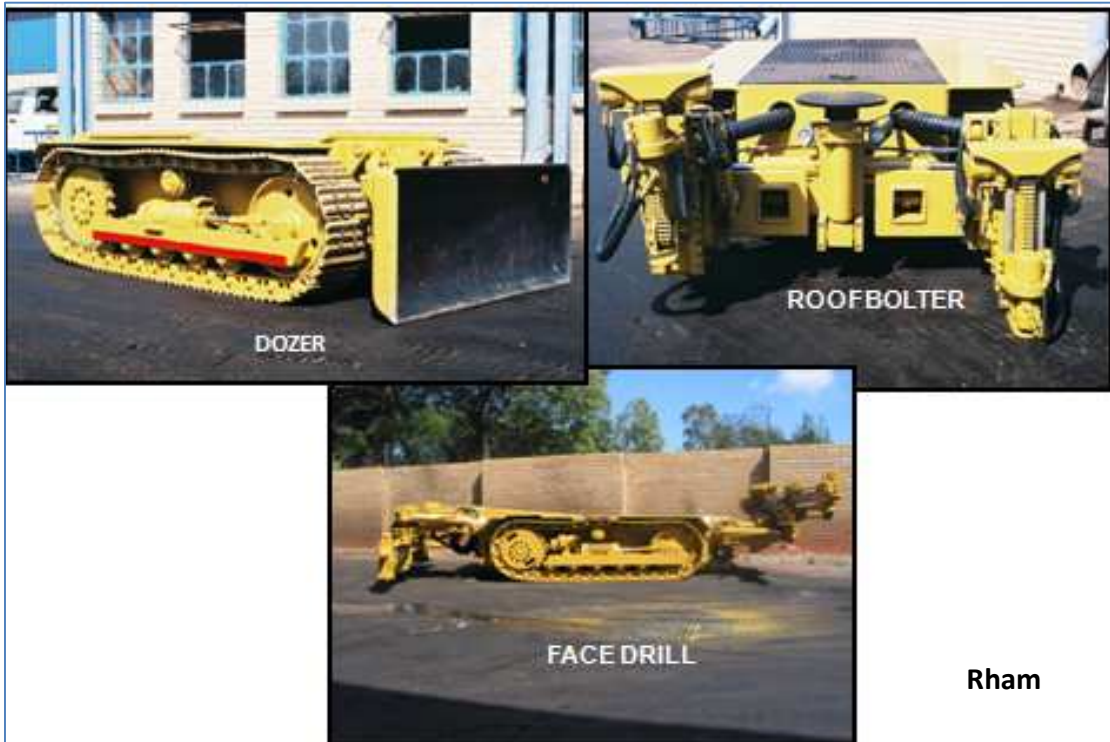
### APPENDIX A3: FULLY MECHANISED MINING LAYOUT

In-stope development all done by equipment. Cleaning by dozers on the panels, LHD's load in the on-reef development and belts support to the section ore pass systems. (Not to scale).



## APPENDIX B1: TYPICAL XLP EQUIPMENT

Rham and Sandvik



Drill rig - Sandvick



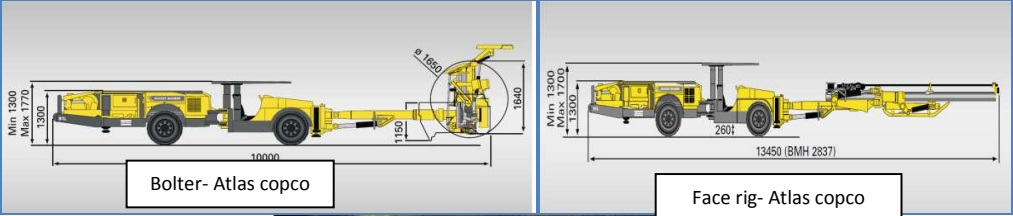
Bolter rig - Sandvick



Dozer - Sandvick

**APPENDIX B2: TYPICAL LP EQUIPMENT**

**Atlas Copco and Sandvik**



## APPENDIX B3: TYPICAL SUPPORT EQUIPMENT

### Utility vehicles: AME, Sandvik, GHH and Fermel



### Supervision vehicles: AME, Fermel and GHH

