The application of cut-off grade principles to enhance Mineral Resource profitability

(Orapa Mine case study)

Olefile Cisco Mashabila

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Abstract

The Application of Cut-off Grade Principles to Enhance Mineral Resource Profitability - Orapa Mine Case Study

Author: Olefile Cisco Mashabila, University of Witwatersrand, South Africa

Given the importance of optimizing exploitation of finite Mineral Resources, looking for opportunities to unlock value and increase profitability, previous researches have shown that the application of cut-off strategies improve profitability. Despite the vast research and application, the cut-off policy deployment is still under-researched and not fully exploited in diamond resources. Constant breakeven grades still prevail and inform the Life of Mine plans.

This study investigates the impact of the application of cut-off policy in diamond resources. For this purpose, an Orapa Mine case study was adopted, research objectives accomplished through qualitative and quantitative data collection and analysis. The main hypothesis proposes that the application of the cut-off policy increases profitability while the second research determines the optimum cut-off grade (COG) to inform strategic stockpiling and mining optimisation.

The research reveals that there is an unexplored/missed opportunity of applying cut-off strategy to drive Orapa Mine resource profitability. The breakeven COG for Orapa Mine is 15.83 cpht while the breakeven cut-over grade is 38.27 cpht. These assume a weighted recovery efficiency of the existing processing plants. The optimum COG lands at 31.34 cpht. Overall, the current conceptualization further reveals that the optimizing strategy results in 77% higher Net Present Value (NPV) and 11% increase on profits relative to the original constant breakeven grades. The declining cut-off grade calculated with depreciation, minimum profit and General and Administration costs further improves the NPV and the undiscounted profits. It further reveals that the cut-over grades for optimum stockpiling philosophy and processing for the Orapa plants will increase value. The study recommends the adoption of cut-off strategies and a cut-over criterion to enhance profitability.

Keywords: Optimization, cut-off policy, breakeven, NPV, opportunity cost, strategic stockpiles.

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Table of Contents

List of Figures

List of Tables

List of acronyms

COG	Cut-off Grade
cpht	carats per hundred tonnes
EDA	Exploratory Data Analysis
LoM	Life of Mine
LOMP	Life of Mine Plan
M	Million
Mtpa	Million tonnes per annum
MRM	Mineral Resources Management
NPV	Net Present Value
OKC	Orapa Kimberlite Cluster
OLDM	Orapa, Letlhakane and Damtshaa Mines
OREP	Orapa Resource Evaluation Project
RPEEE	Reasonable Prospects for Eventual Economic Extraction
SAMREC	South African Mineral Resources Committee

1.0 INTRODUCTION

1.1 Research overview

The Orapa, Letlhakane and Damtshaa Mines (OLDM) own a healthy inventory of developed and undeveloped Mineral Resources. It is however, important that the OLDM operations maintain an optimum mining balance to ensure short-term and long-term profitability. Large, easy to access, high-grade deposits are not easy to come by, and most have already been found. Those that are currently in production, require an increasing level of innovative and entrepreneurial skill to maintain margins while new prospects at lower grades, carrying with them economic, technical and political risks are still being evaluated (Mol and Gillies, 1984).

The cut-off optimization concept has been known for many years, but it is still not widely practiced (Bascetin and Nieto, 2007). One of the most difficult problems in mining operations is how to determine optimum cut-off grade (COG) of ores at different periods over the lifespan of the mine at the same time maximizing the Net Present Value (NPV) of the mine (Dagdelin, 1992). To date, little research has been conducted on the COG policy within the diamond mining industry and none or very few guidelines exist to assist researchers on today's diamond - related challenges.

1.2 Location of Orapa Mine

Debswana Diamond Company operates Orapa Mine, which forms part of the OLDM, three operations clustered in a radius of under 40 km. Orapa Mine is a Joint Venture (50/50), between the Government of the Republic of Botswana and De Beers Company. Orapa Mine is located in the Central District of Botswana, approximately 200 km west of the city of Francistown (http://www.atlas.gov.bw). Figure 1 is a map of Botswana showing the location of Orapa.

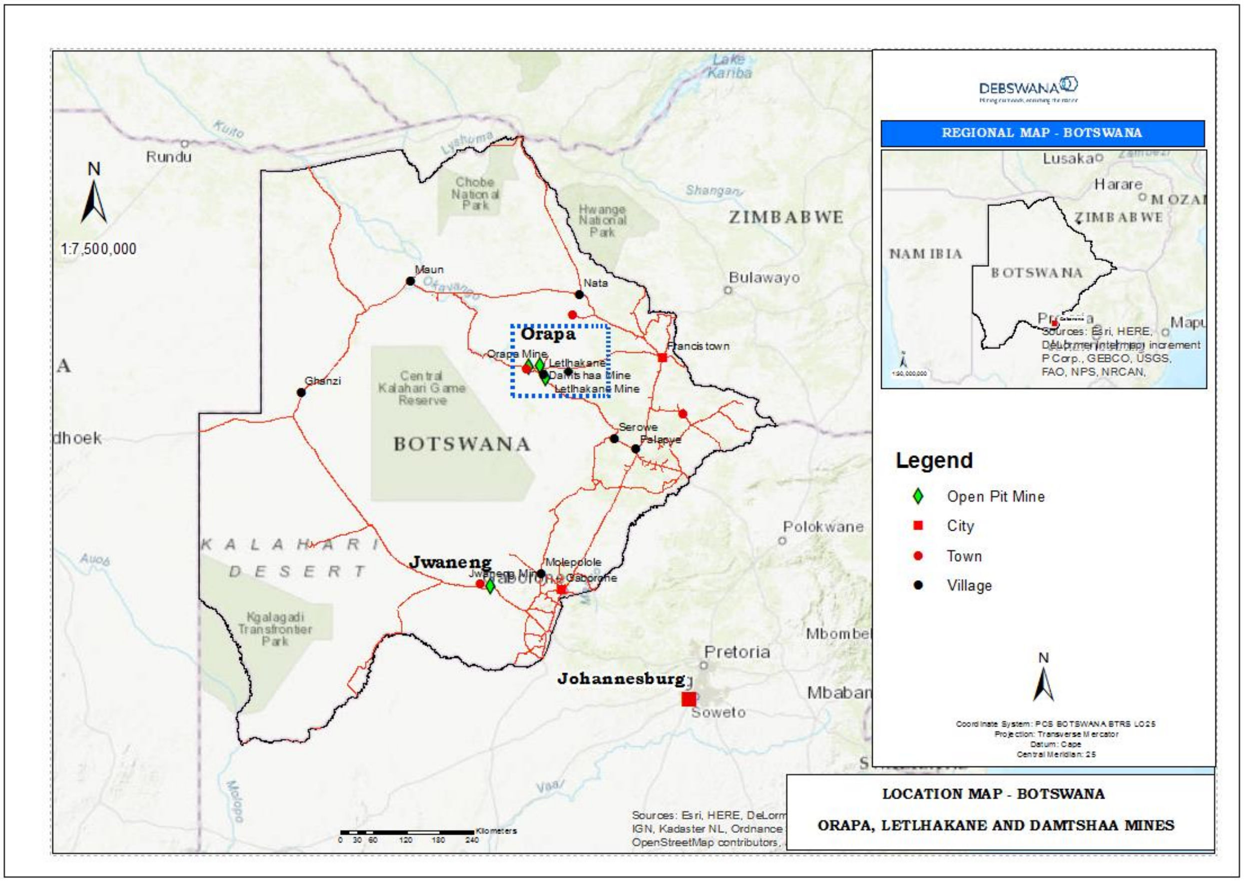


Figure 1: Map of Botswana (http://www.atlas.gov.bw)

The Orapa A/K1 Resource is mined by conventional open pit methods. Ore from the pit or stockpiles is treated through two processing plants (Plant 1 and Plant 2). The current processing capacity is 5.3 million tonnes per annum (Mtpa).

1.3 Geological setting

Regional geology

The Orapa-Letlhakane region is generally flat with a slight fall in altitude towards the north/northwest. Ground elevation ranges between 1000 m in the south/southeast and 950m further towards the northwest. Surface drainage is virtually non-existent, except for the dry Letlhakane River (fossil valley) which drains towards the Makgadikgadi pans. The flat landscape is altered by the presence of silcrete/ferricrete hillocks in the east, the numerous pans, especially to the west and northwest and man-made features of relatively high relief in the mining areas.

The Karoo Supergroup hosts the Orapa Kimberlite Cluster (OKC). The Archaean amphibolite bearing granite-gneiss and tonalite dominate the basement (Kiviets *et al.*, 1997). The Karoo Supergroup unconformably overlies the basement and its thickness extends to approximately 450m. A variably thick cover of Caenozoic to recent Kalahari Group sediments, calcrete and silcrete covers most of the area within the OKC. Many studies place the OKC on the southwest corner of the Zimbabwe craton supported by the chemistry of mantle xenoliths from Letlhakane Mine, indicating a relatively cool geothermal gradient at the time of volcanism (McCourt *et al.*, 2004). This is consistent with a cool, sub-cratonic lithospheric mantle.

Kimberlite geology

During the late Cretaceous period (93 Ma), kimberlites of the A/K1 North and South pipes at Orapa were intruded into highly deformed Archaean basement overlain by volcano-sedimentary rocks of the Karoo Supergroup (Carney *et al.*, 1994 and Field *et al.*, 1997). The Orapa A/K1 Kimberlite forms part of the extensive OKC that consists of more than eighty (80) kimberlite pipes (Gibson, 1984). The Orapa A/K1 provides seventy (70) to one hundred (100) metre thick section through the volcaniclastic deposits of the two coalescing kimberlite pipes.

Since the discovery of A/K1 in 1967, the geological understanding and modeling of the kimberlite has steadily evolved and improved over time. The previous geology work and models completed formed the basis of subsequent geological model updates. The first geological model for A/K1 was developed by Shaw (1991) based on Dobbs (1978, 1979, 1980). The original model was then updated with an extremely thorough review of the geology by Field (1997) later published by Field *et al.* (1997). Based on drilling and mapping data, a detailed lithofacies analysis of the various rock types present in A/K1 was completed i.e. subdividing lithofacies based on internal structure, composition (mineralogy) and texture (Field *et al.*, 1997). Additional pit and face mapping data necessitated the update of the geology model in 2007 (Maccelari and Farrow, 2007). Additional geological data from the Orapa Resource Evaluation Project (OREP) Phase 1 drilling campaign in 2006 - 2007 was used to update the A/K1 geology model (Letsatle, 2009), Tait (2010) and the recent update (Sejoe, 2012).

Previous reports have described A/K1 as a bi-lobate pipe, comprising a North and South Lobe. Field relationships, internal architecture and other features clearly demonstrate the North and South Lobes to be the deposits of discrete volcanic events and this should be considered as individual volcanic conduits (Stiefenhofer, 2009). The South Crater consists of layered volcaniclastic deposits that unconformably crosscut massive volcaniclastic kimberlite of diatreme facies in the North Pipe. As the distinction in geology becomes pronounced with depth, the potential for differences in Resource characteristics would also become greater (Tait, 2009). Each of these pipes represents a discrete batch of kimberlite magma that has resulted in a variation in the nature of the diamonds found within each pipe (Minter (1978) and Dobbs (1978)).

The upper portion of the crater contains a sequence of epiclastic kimberlite composed of shales, grits, sandstones and debris flows that formed in a crater-lake (Dobbs (1978) and Minter (1978)). Only the upper crater sediments contain a mix of material. The older north pipe contains crudely layered pyroclastic kimberlite, with avalanched basalt breccia lenses around the periphery (Sejoe (2012) and Maphane (2013)). The south pipe has a far more complex geology and three phases of kimberlite deposition have been modeled each separated by a sequence of basalt-rich breccias. Massive, steeply dipping basalt breccias and grain flow deposits are present around the periphery of the western and eastern margins of the pipe. Figure 2 shows the schematic geological cross section of A/K1 kimberlite pipe and the main lithofacies modeled.

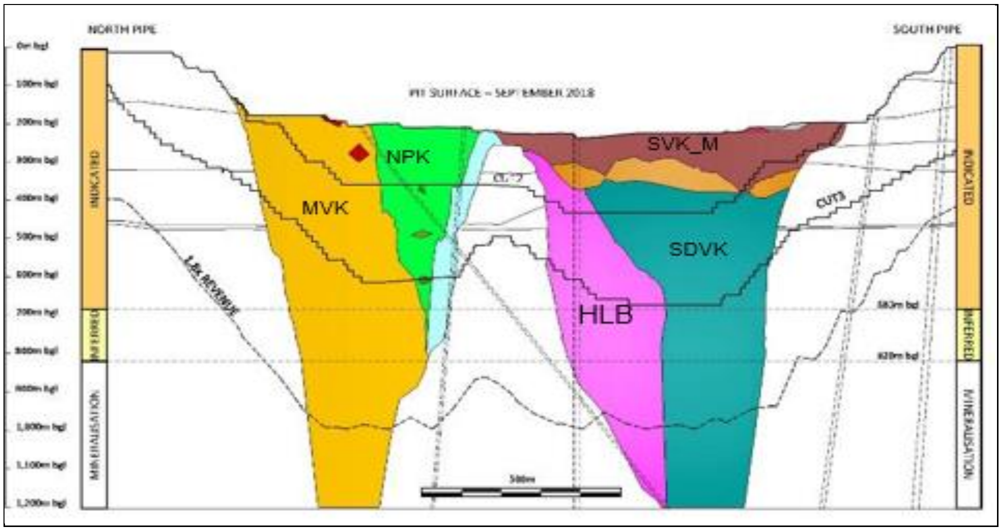


Figure 2: The A/K1 schematic geological N-S cross section

1.4 Exploration history

Diamonds exploration in Botswana started in April 1955 in the Tuli Block areas. As exploration progressed towards the sand covered west, soil sampling became necessary over increasingly greater areas. One of the first positive indications that a primary source of diamonds might exist in Botswana resulted from prospecting carried out in 1960 - 1961. Three small diamonds were found in samples taken on the Motloutse River. However, for various reasons (apparently largely financial) the discoveries were not followed-up (Gibson, 1984).

In 1962, De Beers secured the prospecting license and they were able to resample the Motloutse River once more, finding diamonds (Gibson, 1984). Therefore, attention focused on the source of the Motloutse River diamonds. Intensive prospecting of the Orapa area began in 1966 and this led to the discovery of the Orapa A/K1 kimberlite pipe in 1967. Figure 3 shows the inserts from early prospecting work during the discovery of Orapa A/K1 Kimberlite pipe in 1967.

Figure 3: Pictures of A/K1 early sampling work by Geologists (Brook, 2012).

Following initial discovery, sustained exploration efforts in the Orapa area by De Beers and other prospectors identified numerous additional Kimberlite pipes. By the end of 1968, it was evident that Orapa was a major Diamond deposit that warranted mining to go ahead (Gibson, 1998). This enabled township and plant construction to commence in 1969, as well as the road to link to the Francistown railhead, the diesel power station and the development of a water supply to the mine. Orapa Mine commenced production in 1971. The annual production call was approximately 2.4 million (M) carats and the total sampled reserve at the stage was just over 48 M carats (Gibson, 1984).

Orapa Mine holds mining license ML10/1971, covering an area of 16,575 hectares and mining lease area covering 26,874 hectares. The mining lease expires in 2029. Figure 4 shows the Orapa, Letlhakane and Damtshaa mining license and lease areas.

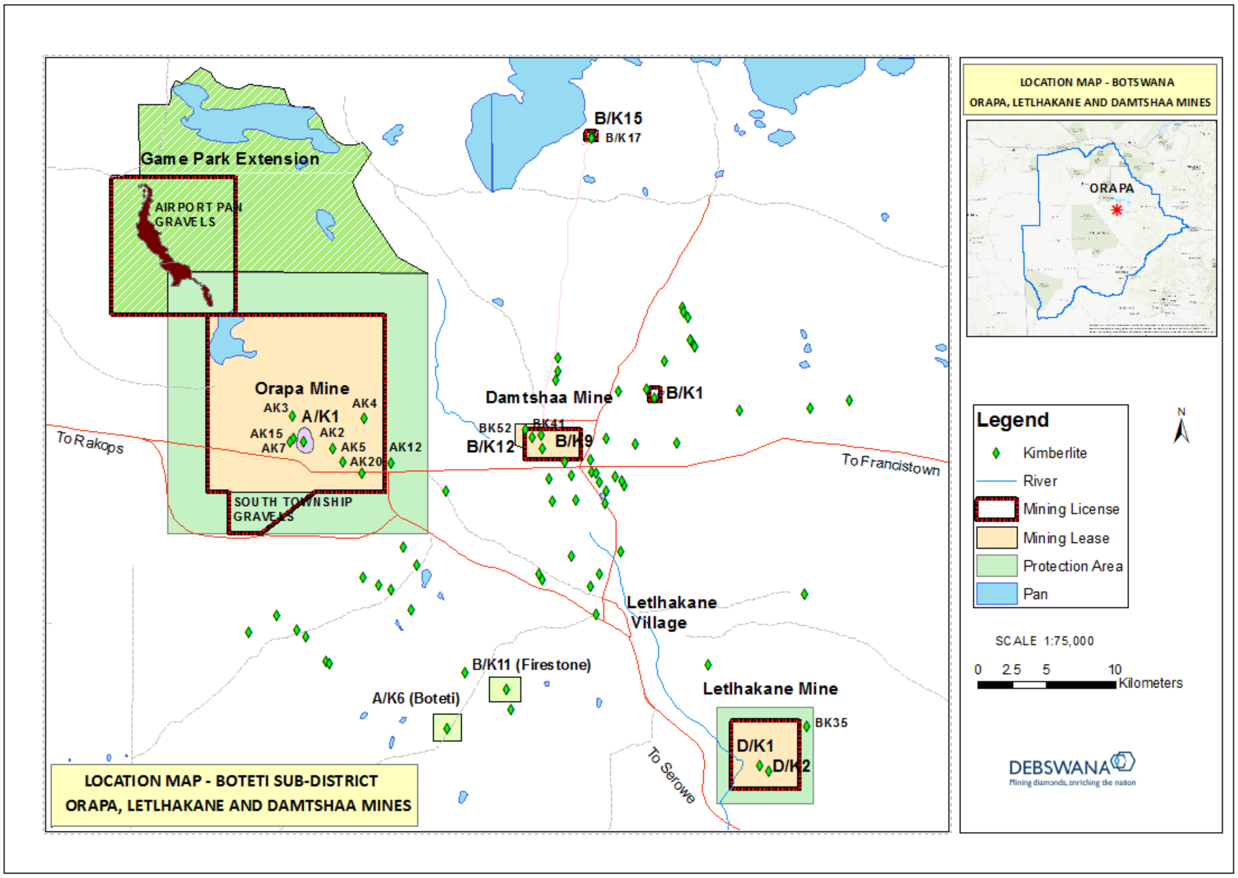


Figure 4: Plan showing Orapa mining license and lease area

1.5 OLDM business model

The total Life of Mine (LoM) Carats are 153,419 thousand carats consisting of 134,921 thousand carats in Reserve and estimated 18,498 thousand carats from Inferred Resource in plan (Oelofsen *et al.*, 2014). Figure 5 shows the OLDM 10-year historical production profile indicating the significant contribution of Orapa Mine towards the annual production. Figure 6 shows the Orapa LoM carats profile.

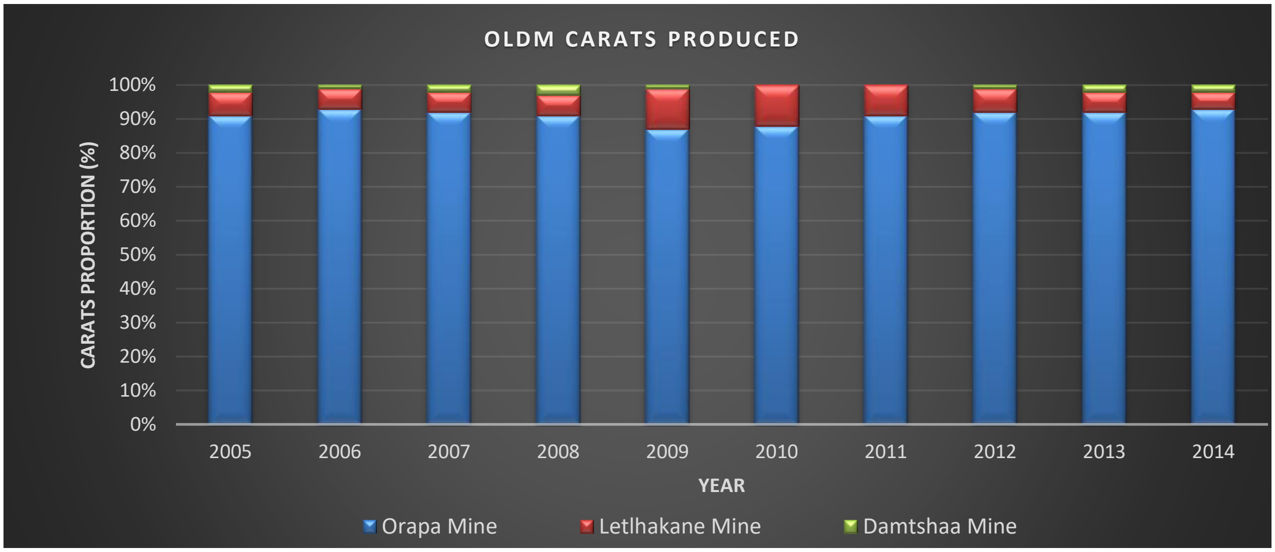


Figure 5: OLDM Carats Production Profile (Oelofsen *et al.*, 2014).

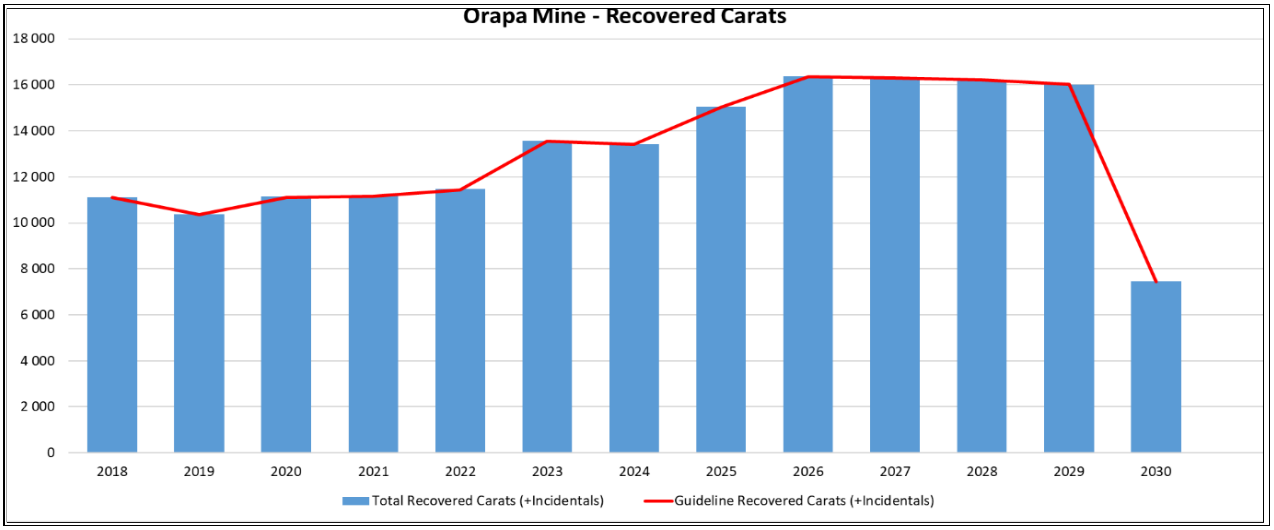


Figure 6: Orapa LoM carats profile (Oelofsen *et al.*, 2014)

The De Beers Strategy seeks to maximize a profitable carat that requires the parallel approach of optimizing the existing assets, as well as operating flexibly in order to better match supply and demand. The Debswana Leverage Areas and drivers target operational and functional excellence (Debswana Strategy, 2014). Table 1 shows the Debswana 2018 High Performance Organization Strategy Leverage Areas.

Table 1: Debswana Strategic Leverage Areas (Debswana Strategy, 2014)

Leverage area	Long-term strategic ambition	Outcomes
Agility and flexibility	Being a highly agile and flexible producer of rough Diamonds.	1. Aligned and lean business model supporting agility and flexibility. 2. Cut cycle time in half, ensure accountability, engaged workforce, culture of execution.
Deep Market understanding	Anticipating and understanding market dynamics ranging from demand to substitutes and consumer preferences.	1. Planning processes aligned between marketing and production.
Technological edge	Being an innovative driver for new technology in the Diamond mining space.	1. Being an influencer and partner with input into technology roadmaps of key suppliers.
Social license to operate	Trusted partner and active contributor to communities and our national stakeholder, with sound environmental management.	1. Strong brand synonymous with national development. 2. Trusted partner to the communities we operate in. 3. Sustainable environment legacy.
Superiority in HR	A superior employer attracting, training and retaining talent and facilitating world class performance.	1. Train and develop own talent to a level that we compete with global top-tier companies. 2. Provide an environment where performance enables individual growth.
Greater commercial attractiveness	A commercially driven player growing the value of the business continually.	1. Being an investment of choice for both shareholders (by having superior returns outperforming competition). 2. Business sense visible in what we do (by looking at input/output ratio).

2.0 PROBLEM DEFINITION

2.1 Background

The focus of this chapter is an overview of the research purpose and problem statement. It provides the research background, sets the scene and scope of the study. The COG optimization process is used to arrive at an operating strategy that maximizes the value of a mine i.e. exploitation and profitability. The Orapa Mine COG has been static throughout the LoM. A different view to Orapa Mine diamond resource mining through application of COG principles will bring a new dimension and life to existing mine operations and potential prospects.

Approximately, a third of Orapa Mine Resources contains low-grade material. The low-grade ore is currently being stockpiled for treatment towards the end of the LoM. An assessment for the criterion for stockpiling is necessary to validate the current practice taking into consideration the rough diamond price changes and the mining depth. Blending opportunities between high and low-grade ore imply that the determination of the optimum COG not only dominates mining economics, but is also a crucial decision in the efficient and effective utilization of the Mineral Resources (Abdollahisharif, *et al.*, 2012).

The Orapa Mine case study seeks to assess the impact of application of COG principles during extraction planning and execution. A comparative economic evaluation of various options i.e. current LoM Plan (LOMP) versus the recommended dynamic COG policy assessment. The outcome of this research is:

- The development of the Cut-off strategy framework;
- The determination of COG criterion; and
- The determination of the stockpiling philosophy to deploy when treating material through Orapa processing plants.

2.2 The model for COG application in Orapa Mine

Khodayari and Jafarnejad (2012) suggests that under a dynamic and increasingly volatile economic system, the traditional concept of stagnant COGs could fail to optimize the profit for an open pit mine. To achieve Orapa Mine's true diamond resource profitability, the optimum COGs have to change through the operation period. This is due to responses to changes in mining grade, price fluctuations, changes in the revenue footprint with changing geology, the time value of money and price-cost ratio assessments. Deferring all (or majority of the) Orapa Mine low-grade ore could be eroding Resource value. A variation of the applied COG could suggest a different model i.e. treating a significant proportion of the low-grade material currently stockpiled.

For a constant price, the COG would vary with mining depth (Dimbungu pers.com). An assessment will be conducted using the unit costs e.g. cost/tonne mined and cost/tonne treated. The determination and testing of a model that requires a constant COG would be paramount. Figure 7 shows a graphical illustration of the perceived COG variation with mining depth.

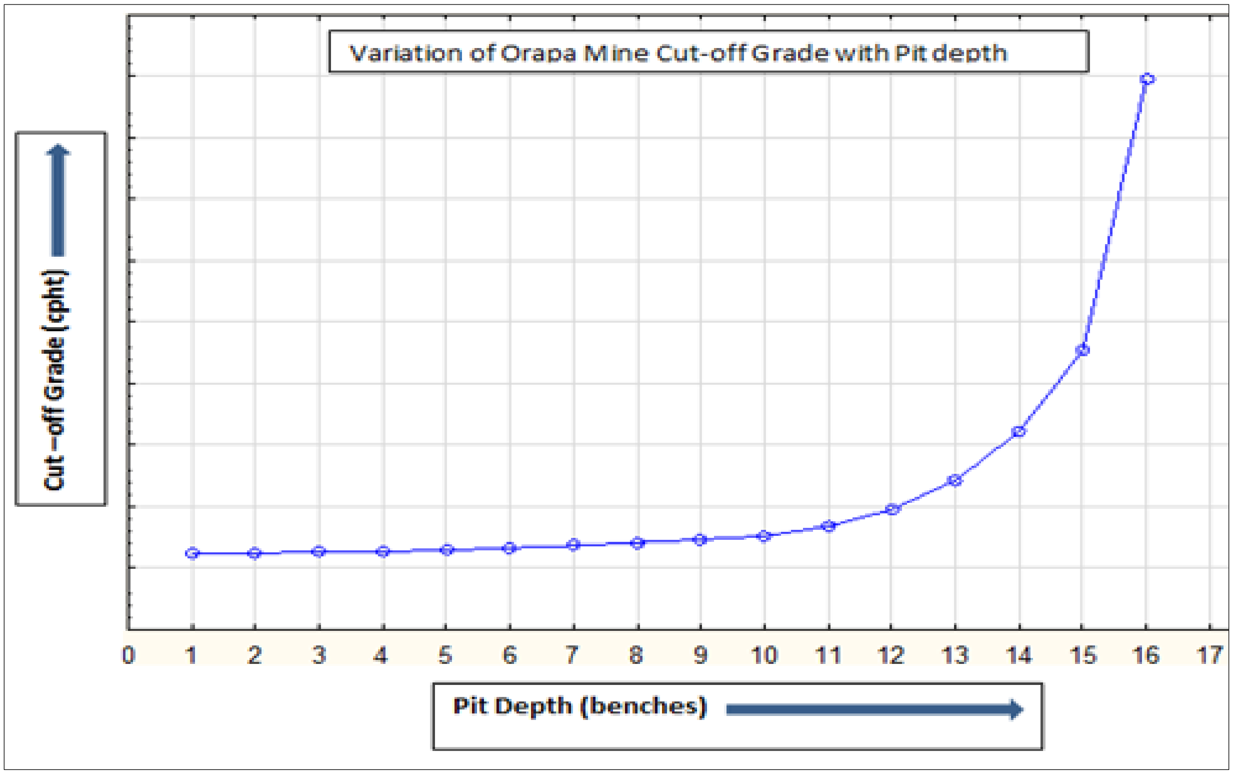


Figure 7: Illustration of the perceived Orapa Mine COG variation with pit depth

*(Cpht=carats per hundred tonnes. Each bench is 12 m, thus for example 3 benches equals 36 m from surface)

2.3 The research hypothesis

Over time, the depletion of quality deposits results in lower grades and higher risks that require creativity and inventiveness to stay profitable. It is time to re-look at the Orapa Mine strategic decision to defer treatment of low-grades material and systematically incorporate COG principles. For the purpose of this research study, the following hypothesis is tested using Orapa Mine as a case study.

Hypothesis 1:

The application of COG principles on diamond resources will increase profitability at Orapa Mine.

Hypothesis 2:

The Orapa Mine COG has to vary with mining depth.

Hypothesis 3:

A portion of the Orapa Mine low-grade material currently stockpiled should be treated now, profitably.

2.4 Research question

The study sought to build an informed understanding to answer the fundamental research question:

> *"What is the impact of the application of COG principles on Orapa Mine diamond resource profitability?"*

The following sub problems were critical in addressing the research fundamental question:

Sub-problem 1:

- Evaluation of the impact of application of COG principles in maximizing the profitability of A/K1 diamond resource.

Sub-problem 2:

- Determination of the optimum COG for Orapa Mine A/K1 diamond resource.

2.5 Objective of the research

The purpose of this research was to assess the impact of application of COG principles on Orapa Mine resource optimization and profitability.

The COG strategy developed in this study will serve as a blueprint for developing Debswana mining plans, which will in turn drive Mineral Resource profitability. The research objectives are:

- To assess the impact on NPV;
- To test different options for maximizing profitability and recommend the COG strategy for adoption; and
- To make recommendations for further research in this field.

2.6 Scope of the research

The scope of this research is assessing Orapa Mine diamond resource profitability by applying COG principles. Various options will be tested and the impact on resource profitability assessed. Opportunities for improving the LoM planning process that supports maximizing extraction for improved business performance will be identified. Although Orapa Mine is used as a case study, the recommendations from this research will also be implemented across all Debswana operations.

2.7 Assumptions of the research

The following assumptions are considered in this research study:

- While the diamond sales volume is fixed; mining and ore processing capacities can be changed during the optimization of the domain COG regimes;
- Assumptions made during feasibility study can be changed to align with COG regime optimization i.e. there is adequate capital to maintain full capacity;
- Geological uncertainty is well constrained and can be managed within reasonable risk boundaries; and
- The variability in grade is known and can be accounted for in the various lithological units at block scale i.e. local block estimates populated.

One of the key assumptions is that the Orapa ore processing plants have spare capacity to treat the currently stockpiled low-grade material. In this case, the plant capacity is measured as the Overall Plant Utilization (OPU). The average OPU achieved over five-year period is 50 – 60% relative to commissioning targets of 70-80%. Both the Orapa Mine ore processing plants are currently not achieving the design nameplate.

2.8 Limitations of the research

Several limitations were considered when proposing the COG driven strategy. The envisaged limitations are:

1. ***Limited data:*** Some of the required data for the research study is not readily available. Limited research has been conducted on application of COG principles in diamond resource mining;

2. ***Resource uncertainty*:** While some of the resource parameters (geology, grade, density & volume) are well defined, the aspects of revenue footprint and continuity with changing geology and geometallurgical aspects have not been constrained. Plant-based revenue and geometallurgical estimates deemed representative still inform the LoM plans;

3. ***Plant processing constraints:*** Due to treatability challenges associated with some rock types, it is impossible to treat certain ore types individually in significant quantities. The low-grade material, which has treatability challenges (hardness), are deferred for future treatment. Processing of such material will usually compromise the available plant capacity;

4. ***Capital constraints:*** The ability to modify certain plant components (e.g. primary crushers) is limited by capital funding constraints. Although it is desirable to fund any capital project which guarantees return on investment, it is not always possible because of the rigid capital structure and rationalization framework; and

5. ***Shareholder satisfaction:*** The COG study seeks to achieve some economic or financial goal, such as ensuring profitability and maximizing value. A company is required to

operate in the best interests of shareholders i.e. the operation model must boost cash returns. Achieving various societal goals will nevertheless also be important for obtaining the social license to operate.

2.9 Summary of this chapter

The goal of this chapter was to outline the background and rationale behind the research study. To facilitate the research, a fundamental research question was formulated and solved. The chapter also highlighted areas that the study focused on in order to answer the research fundamental question. The goal of the next chapter (Chapter 3) is review of the literature and assess applicability to answer the research question discussed in Chapter 2.

3.0 LITERATURE REVIEW

3.1 The COG principle

The COG optimization process is used to arrive at an operating strategy that maximizes the value of a mine i.e. exploitation and profitability. The criteria for selection of the COG boils down to whether a cost-effective block should be processed or not (Johnson, *et al.* 2010). The focus of this chapter is completing the cut-off literature review relevant for the application to diamond resources and the applicability to an open pit scenario for the Orapa Mine case study.

The COG policy is a planned sequence of cut-offs for an operation over time. It is rare for the best COG to be the same unchanged value over the LoM, even if such issues as costs and product were to remain unchanged (Hall, 2014). Cut-off specification is an integral part of optimizing the mining strategy. The more dimensions in the cut-off and strategy optimization model, the more parameters accounted for, the better the potential outcome (Hall, 2014). This is perhaps the least understood driver of value for a mining operation. Operations define different COGs for various purposes (Dagdelin, 1992). Any mine valuation must determine a COG that achieves the financial objectives of the company and maximizes the total profits. In Mol and Gillies (1984) publication, the COG theory would usually fall into two basic categories:

- The fixed COG assumes a static cut-off for the LoM; and
- The variable COG assumes a dynamic cut-off maximizing the NPV.

Naturally, a cut-off that delivers one goal will not necessarily deliver other goals. It is therefore imperative that the goals of the cut-off (and other strategic decisions) are stated before the derivation commences (Hall, 2014). The development and application of a dynamic COG policy drives long-term goals of the company by exploiting opportunities, which further enhance value (Osanloo and Ataei, 2003). An assessment will be conducted on the application of dynamic COGs i.e. impact on LoM and profitability.

Mol and Gillies (1984) define the requirements for determining the COG as follows:

- ***Reliable ore block estimates*:** Reliable ore block values are essential for any mining project and selection of an ore block size is an important factor in the determination of values;
- ***Grade-tonnage curves**:* The ore block grades, tonnages and COGs selected incrementally across a suitable range are used to calculate the total tonnages and the average grades of orebody Reserves above each COG point; and
- ***Marketing contract grade specifications**:* The direct-shipping grades of ore depend on the marketing contract specifications. The marketing grade specifications would normally include tolerance limits before penalties imposed.

Furthermore, Hall (2014) defines rules applied in cut-offs and strategy optimization to achieve corporate goals:

- *Boundary* cut-off*:* The rule is applied to delineate the ore-waste boundary of an orebody. It accounts only for the location of the specified COG in the rock mass. If the geological ore-waste boundary at the specified cut-off is regular, a practical mining boundary between ore and waste may be simply defined by following the geological contact or grade contour. However, if the cut-off is irregular, the boundary cut-off rule will determine where the practical boundary is to be placed. It may be that the mining boundary is entirely outside the geological boundary so that no above cut-off material is excluded. In this situation and extremes, there could be a number of rules specifying how the trade-off between ore-loss and waste inclusion are to be handled;
- *Volume* cut-off*:* The volume cut-off rule addresses the potential shortcomings of the boundary cut-off by accounting for the resulting average grade. It is firstly applied to generate an initial mining inventory, and volumes with average grades below the specified volume cut-off would then be deleted from the Reserve inventory. The volume and the boundary cut-offs need not to be the same, however operations that apply a volume cut-off typically use the same value as the boundary cut-off. The advantage of the volume cut-off is that it allows for factors not accounted for in the boundary cut-off particularly, the effect of ore recovery and dilution on tonnages and grades. This will then have an impact on the average grade of the material or the unit costs included in the cut-off derivation; and

- *Other rules:* Depending on the nature of mineralization, other rules may be applied to cull material above other cut-offs from the mining inventory or to include sub cut-off material in the inventory. An outlier rule may have to be applied to exclude small volumes of otherwise ore-grade material remote from the main zone(s) if including it in the inventory reduces value. Conversely, it may be that the operation needs to include unmined waste or low-grade areas within mined out areas.

Most mines operate with a number of cut-offs and the application of these would normally be for different purposes and for distinct circumstances. However, the criteria must be clearly defined and their application specified in the organization documentation. Typical generic definitions are discussed below for consistency:

- A *planning* cut-off is used in developing mine plans and designs as well as in long-term studies to distinguish between ore and waste. It sets the long-term big-picture cut-off strategy; and
- An *operational* cut-off used on day-to-day basis informs the tactical decision making process. Due to the inherent variability in ore bodies, it may be both necessary and legitimate to vary the cut-off from the long-term planning cut-off in the short term. An example of the application of operational cut-off will be keeping the mill supplied with lower grade but marginally profitable material below the planning cut-off when there is a shortfall of ore available above the planning cut-off. Since it is easier to fill the mill at the lower operational COG, the longer-term may be changed (Hall, 2014).

The reasons for the variation must be understood and part of the aim of short- to medium-term mine planning will be to return to the planning cut-off. The variations must be within the context and constraints of the overall plan, and that optimum long-term plan includes specifying the long-term cut-off. The operational cut-off must always be varying within the confines of the longer-term planning cut-off policy, aimed at achieving the corporate goals (Hall, 2014). Hall (2014) suggests the following Cut-off derivation methodologies and contrasting goals:

- ***Break-even analysis***: This is a one-dimensional process with the implicit goal of ensuring that every tonne classed as ore pays for itself;

- ***Mortimer's Definition***: A two-dimensional process, accounting for everything in the break-even as well as the geometry of mineralization shown by the grade-tonnage curves. The explicit goal seeks to ensure that every tonne classed as ore pays for itself and the average grade of ore treated delivers a minimum profit per tonne; and
- ***Lane's Methodology***: A three-dimensional process accounting for everything in Mortimer's definition plus the capacities of components of the overall production process. It has the explicit goal of maximizing NPV.

The cut-off is usually perceived as having to be accepted, driven by outside forces, in particular product prices, over which the company has no control. Hall (2014) contends that:

> "*There is common believe that* cut-offs *are outside the company's control which leads to situations where rather than actively selecting the best Cut-offs to weather the storms of change in economic conditions, companies allow themselves to be blown about uncontrollably by passive acceptance of inappropriate* cut-off *policies with potentially dire results."*

3.2 Application of COG strategies

The choice of the COG in mining influences the profitability, the life of individual mines and thereby the quantity of a resource that is available. Processing all material above the marginal COG will maximize cash flow over the life of the operation. Taking the time value of money into account, then a different strategy is warranted (Whittle and Whittle, 2007). Since the COG provides a basis for the determination of tonnes of ore and tonnes of waste, it directly affects the cash flows of a mine. A higher COG leads to higher grades per tonne of ore; hence, higher NPV realized depending upon the grade distribution of the Mineral Resource (Dagdelin, 1992).

Hall (2014) argues that the cut-off policy should be an outcome of the planning process that maximizes the marketable reserves, rather than a cut-off derived as a fixed input into the planning process. The cut-off determination process involves identifying a number of sets of potential Reserves at different cut-offs, one of which will ultimately form the basis for the mine plan that supports the publicly reported reserve. The economic optimum is the maximum tonnage of reserves with a mean grade above a given COG (Horsley, 2002).

The original algorithm introduced by Lane (1988) and usually applied frequently, is based on the maximization of NPV in which mining, processing plant and refinery capacities are considered constant. When the Cut-off is too low, the input capacity of the entire mining and mineral, processing operations is stretched, while revenues do not necessarily increase (Bascetin and Nieto, 2007).

Maximizing economic earnings is the most common goal in COG optimization of open pit mining operations (Khodayari and Jafarnejad, 2012). The COG distinguishes economical ore from non-economical ore, and these may vary according to domains or facies depending on geometallurgical parameters. The grade distribution is never uniform within a mineral deposit as high grade areas are often found intermixed with lower grade areas (Mol and Gillies, 1984). The presence of sub-economic levels of mineral concentration towards the boundaries of the deposit may also require selective mining in order to determine what to mine as ore, to stockpile and what to consider as waste. However, the material classified as waste today could become economical in future (Mol and Gillies, 1984).

COG optimization in open pit mining has been the subject of much research. More work is needed if it is to cover all essential practical mining considerations (Abdollahisharif, *et al.*, 2012). One important issue in mining is how the COG should change in response to changes in the price of the metal. The "rule of thumb" requires that the COG should decrease/increase when the rate of metal price increase is greater/smaller than the rate of discount (Taylor, 1972). Based on the volatility of Diamond Resource markets, this conversion principle needs improvement.

The problem of investigating the impact of the application of COG policy addresses two main objectives of maximizing total cash flow and NPV. If the former objective is the focus, then the time value for money is ignored i.e. time of cash flow realization is not important. In this case, the traditional relationship between COG and price becomes the prevailing factor in determining optimum COG. Both maximum total cash flow and maximum NPV always increase and decrease respectively when the price of product increases or decreases. Price fluctuations are a common feature in metals markets. Nwosu and Nwankwoala (2012) argue that the COG varies with varying price-cost ratios and irrespective of whatever value the price and total production cost may be, the COG will be the same provided the price-cost ratio does not change and the yield is constant. This assumption will be tested and/or affirmed during this research study using Orapa Mine as a case study.

3.3 Principles of MRM

Ore bodies with sufficient grade to make them “management-proof” are exceptionally rare. Since the Mineral Resource is the principal asset, its value must be optimised through each stage of the mining process (Macfarlane, 2006). The base for a strategic plan is determining the best strategy for exploitation in order to maximise the value while also addressing the uncertainties associated with mining the Mineral Resource (Hall and Harper, 2005). An understanding of how this impacts on the valuation of mining projects would also permit an objective approach to determining levels of gearing. SAMREC Code (2016) defines a Mineral Resource as a concentration or occurrence of material of economic interest in or on the earth’s crust in such form, quality and quantity that there are Reasonable and Prospects for Eventual Economic Extraction (RPEEE). This should be quoted at a cut-off related to the anticipated mining method likely to enable economic mining (JORC, 2012).

The principles of the JORC code are threefold; firstly, the public report should be presented clearly and unambiguously (i.e. transparency), the report should include all the information reasonably required and expected (materiality) and that it should be based on work undertaken by a Competent Person (Snowden, 1996). The Reserve is the economically mineable part of a measured or indicated Mineral Resource (SAMREC, 2016). Therefore, portions of a mineral deposit that do not have reasonable and realistic prospects for eventual economic extraction must not be included as part of a Mineral Resource (Noppe, 2014).

In SAMREC (2016), the RPEEE test is defined by a combination of the modifying factors, which include consideration of geological, mining, metallurgical, economic, marketing, legal, governmental, infrastructure, environmental, and socio-political factors:

- A mineral resource is a realistic inventory of mineralization that at the time of reporting and under assumed and justifiable technical and economic conditions, might become economically extractable;
- The modifying factors should be appropriate to the definition of Mineral Resources in terms of precision, accuracy, degree of confidence and variability; and
- The modifying factors used to test for RPEEE should be applied at an appropriate and reasonable scale. They may differ from those used for conversion of Mineral Resources to Reserves.

An assessment of the RPEEE is the responsibility of the Competent Person (CP), but may also require judgments based on inputs from specialists in different disciplines. The process implies judgment (albeit preliminary) by the CP in respect of technical and economic factors likely to influence the prospect of economic extraction, including appropriate mining parameters and processing methods (SAMREC, 2016). The RPEEE assessment must be based on the principle of reasonableness i.e. should be justifiable and defensible. The confidence in the Reserve estimate will depend on factors such as mining throughput, bench height, equipment selection and the ability of the model to represent the mining selectivity. The degree of confidence depends on mining approach (open pit versus underground, bulk versus selective, high or low cut-off) and the reporting period.

The Mineral Resource risk is not only related to the drillhole spacing, the nature and grade of the mineralization, it also depends on the COG dictated by relevant costs (Snowden, 1996). The COG allows making predictions about whether there are reasonable prospects for economic extraction in the near future or not, and serves therefore as decisive indicator for Resource classification (Winterstetter *et al.*, 2015). The reasonable prospects disclosure must include a discussion of the technical and economic support for the Cut-off assumptions applied. Therefore, the COG at which the Resource is reported, must relate to the likely mining scenario consistent with economic mining (Snowden, 1996). For open pit mining, the RPEEE test is completed through the generation of optimized pit shells using a commodity/product price higher than the long-term price used in the development of the current pit designs and mine plans supportive of the Reserves. However, for underground mining, the RPEEE requires application of a practical mining design (Snowden, 1996).

The RPEEE assessment implies a judgment in respect of technical and economic factors likely to influence the prospect of economic extraction as well as approximate mining parameters. An ideal situation will be defining the RPEEE in the current economic, social and political climate. Appropriate assessments must therefore be undertaken at some realistic specified cost/price structure and must take into account mining recovery factors, environmental and other considerations in order to demonstrate at the time of reporting that extraction could reasonably be justified (Snowden, 1996). Njowa *et al.*, (2011) defines this as a situation where an appropriate cut-off is split between payable and unpayable Mineral Resources i.e. established in view of the time value for money. The NPV and COG decline as the Mineral Resource is depleted. The application of COGs dictates phenomenal influence on the overall economics of the mining operation. The planning and scheduling of extraction is a complex process, which considers the presence of uncertainties such as the future metal prices and estimated ore grades.

3.4 Principles of Mine Planning

While the Mineral Resource is given, decisions regarding how it is exploited (delineation and extraction) have a significant impact on the types of decisions made. Whilst maximizing the total cash flow, the COG optimization ignores the time value of money. A business model with an NPV maximization objective would apply an opportunity cost concept. This involves lost opportunities due to postponing income realization for the material remains in the pit (unmined).

The current traditional and predominantly financial business leading indicators are becoming increasingly inadequate; hence, the need for alternative operating models with emphasis on long-term profitability. Maximizing the marketable reserves means a longer LoM life and a higher profitability level for the business. The marketable reserves and other factors such as the production rate, price of ore per tonne and the operating and fixed costs form the most important factors affecting the profitability of a mine (Mol and Gillies, 1984). Assuming production rate, price and costs are constant, the most important factor affecting profitability is its production life driven by the effective use of available reserves.

The practical requirement for maximization depends strongly on one condition that the rejected ore can be ultimately retrieved. The ore below the cut-off but of foreseeable positive residual value is stockpiled for treatment in the future (Ren and Sturgul, 1999). Under this condition, the cut-off should increase as price rises and decrease as price falls. During periods of depressed prices, processing and refining may have room to deal with the stockpiled low-grade ore, which no longer has mining cost at that time (Khodayari and Jafarnejad, 2012). The mine planning optimization process must identify the best combination of strategic decision parameters in order to achieve and deliver the desired corporate goal.

Strategic planning is not a once off event that is undertaken once or twice a year - the world does not stop changing hence the need to continuously search for better options to maximise value derived (Horsley, 2002). Without a suitable systematic and rigorous framework for current and future mining business entities, proper consideration, analysis and assessment of the planning process, current and future operating models will continue to imitate the existing mining operation’s practices. Tried and tested solutions perceived to have lower technical and financial risks, are chosen over more innovative resource conservation and optimization initiatives. An opportunity to make the plan better will always exist e.g. undertaking the value-adding research projects.

The mine planning process works in a hierarchy from long- to short-term. While long-term plans focus on delivering the corporate goal in the end, short-term plans detail how the operation in the near future will contribute to achieving long-term plans (Hall, 2014). Long-range production planning of an open pit is dependent upon several factors; however, the COG is the most significant aspect as it provides a basis for the determination of the quantity of ore and waste in a given period (Asad and Topal, 2011). As outlined in Hall (2014), the following key components define the mine planning process:

- ***Strategy Options Analysis (SOA)****:* First step in identifying the optimum LOMP adopted and followed by all detailed levels of the planning process. It evaluates at high level, the impacts on value, or a number of different measures of value of all the strategic decisions the organisation can make separately and together. Major updates of the SOA would be expected every three to five years triggered by significant changes in price forecasts and changes in corporate aspirations or strategic goals, discovery of substantial new Resources or identification of new options for processes, markets and mining strategies;

- ***Life of Mine Plan:*** This is the formally approved long-term plan of the business selected after conducting an SOA as the plan best delivering the corporate goal. A formal LOMP is required to establish the framework within which all other short-term plans are developed. Its seen as distinct from the SOA i.e. an outcome from the SOA and not the SOA itself;

- ***Five-year plan:*** it is an essential part of the planning process at operations with more than a few years of life remaining. It forms a critical medium-term link between strategies in LOMP and the detailed short-term plans. Production scheduled in the five-year plan (5YP) should be consistent with optimised schedules identified in the SOA and formalised in the approved LOMP;

- ***Two-year rolling plan:*** The two-year plan (2YP) like the 5YP is a critical link between the long-term plans and short-term execution plans and schedules. The 2YP provides a higher level of detail supported by detailed engineering work at the front end of the 5YP. The plan should be formally updated quarterly and reports activities on a monthly basis;

- ***Annual budget:*** If the SOA/LOMP/5YP/2YP process is in place and approved sequentially from long-term to short-term, then plans for all timeframes are continually evolving and considered realistic and achievable. The budget plan becomes the plan for the budget year in a version of the 2YP created three to six months before the start of the budget year; and

- ***Shorter-term operational plans:*** These are detailed operating plans, consistent with the 2YP and budget. They ensure that all activities required to implement the approved plans are scheduled with all the required inputs. The plans are on three-monthly periods, updated monthly with timeframes of weeks, daily and even shifts.

As discussed in the preceding sections, the cut-off and strategy option are the basis for conducting the SOA. The LOMP defines inputs for the ongoing cut-off derivation and identifies the immediate cut-offs. Cut-off specification is an ongoing process in the more detailed shorter-term planning process (Hall, 2014).

3.5 Risks and uncertainty in mining

The foundation for mining success is on exploring opportunities in the current environment and available Resources for efficiency and improvement, whilst managing the risks to prevent degradation (Macfarlane, 2006). It is the processes concerned with identifying, analyzing and responding to uncertainty throughout the project life cycle. It includes maximizing the results of positive events and minimizing the consequences of adverse events. A risk is a consequence of uncertainty and this would have internal and external sources in mining (Kazakidis and Scoble, 2003).

Risks are differentiated into systematic and non-systematic risks. Systematic risks are associated with the behavior of financial and capital markets i.e. how they relate to market uncertainty, and the impact on the cost of capital (Macfarlane, 2006). Unsystematic risks are associated with the inputs to the business, understood and treated at source. Unsystematic risks are technical in nature, and a risk management strategy should be in existence to identify and manage such risks (Macfarlane, 2006).

In a world of widening competition and uncertainty, operating flexibility and strategic adaptability are increasingly recognized as critical to long-term corporate success (Kazakidis and Scoble, 2003). The mining business outlook requires operations to explore improvement opportunities by creating and planning for flexibility for the different Resources. Musingwini (2007) defines flexibility as the ability to cope with any change as a requisite to accommodate financial, technical and social changes that are a reality in the dynamic modern business operation environment.

The internal sources of uncertainties include the resource model/estimate confidence i.e. data inputs based on limited drilling and sampling, estimation confidence, etc. Operational challenges will include difficulty with extracting the reserve, treatability challenges, equipment availabilities and utilization. The external sources of uncertainty would predominantly be the market and economic factors in the operating environment e.g. the diamond volatile market conditions, metal prices and the impact of exchange rates and inflation. The political events present political risks while the government policy and legislation will have a negative impact on the trade policies, ownership and mining of the resource.

3.6 Diamond mining and market outlook

Today's business demands and the current market turbulence have increased the need to understand the interrelationship between technical and financial risk. In contrast with precious metals and other natural resources industries, which rely on multiple sources of demand, the diamond industry derives practically all its value from consumers' demand for diamond jewellery. A shortage of rough diamond supply is expected over the next ten years as demand continues to grow whilst global production remains constant (Statista Research Department, 2014). The outlook for the industry is thus intrinsically linked to the strength of consumer desire for diamonds.

Analysis suggests that even under the most pessimistic demand scenario and the most aggressive supply scenario, the fundamentals of the industry will likely be positive, with demand outpacing supply growth (Goodman *et al.*, 2014). Furthermore, the industry is set for rapid change under any scenario, such as the expected accelerated or further increase in mining costs, the pressure on the midstream to professionalize and the continued shift in demand to emerging markets (Goodman *et al.*, 2014). The review suggests seven fundamental trends facing the Diamond industry and most likely going to shape its future:

- Plateauing levels of production for the next ten years;
- Pressure from producing countries to extract more value;
- Increase in mining costs;
- Shift in demand to emerging markets;
- Changing consumer preferences;

- Increases in transparency and vertical integration; and
- Improvement of technical capabilities in synthetic gems.

Based on the above trends, Goodman *et al.*, (2014) then identified four uncertainties, which will likely have major implications for the future of the diamond industry, and assessed their potential impact on players across the value chain. These four uncertainties are:

- The global macroeconomic outlook;
- The future of retail consolidation and branding;
- Potential changes in consumer attitudes about diamonds; and
- Potential new sources of diamonds (including recycling).

In contrast with precious metals and other natural resources industries, which rely on multiple sources of demand, the diamond industry derives practically all its value from consumer's demand for diamond jewelry. Assuming there are no major hiccups in the global economic system, the demand growth for diamonds will almost certainly outstrip growth in carat production given the lack of major new discoveries in the last decade. Figure 8 shows the rough diamond demand-supply gap worldwide from 2014 to 2050 (Statista Research Department, 2014).

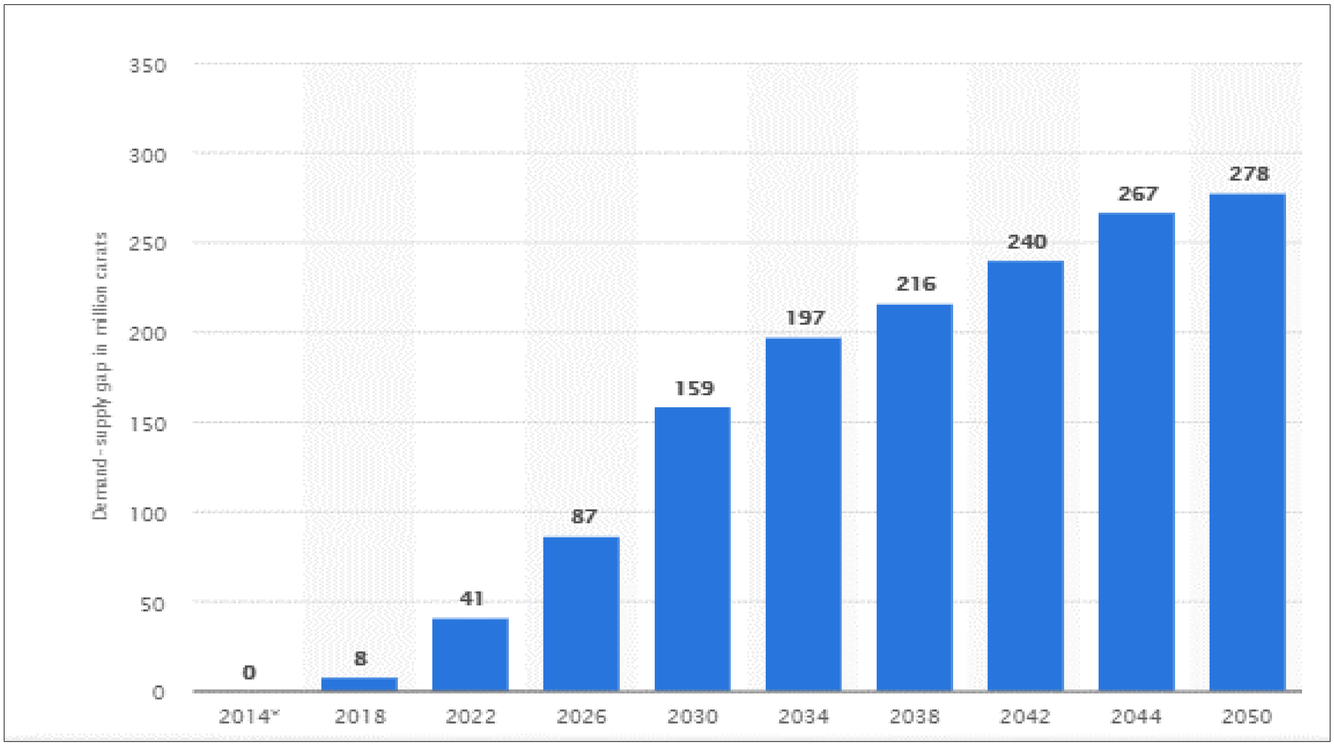


Figure 8: Worldwide rough diamond supply and demand gap forecast (in million carats)

Overall, companies must position themselves carefully to take advantage of growth opportunities. Best-positioned companies are those that are able to innovate and differentiate themselves to capture the opportunities created by the supply demand dynamics. OLDM has embarked on the journey towards excellence and remains prepared to change course quickly and decisively.

3.7 Summary of this chapter

The preceding chapter reviewed the available COG literature with emphasis on applicability to diamond resources in open pit mines. Various cut-off concepts and methodologies were tested on Diamond resources using the Orapa Mine case study. Concepts on mine planning, principles of MRM, profitability, risks and constraints were also reviewed. The review focused mainly on the current knowledge relevant to the scope of the research project. The chapter also discussed the global diamonds market outlook drawing in De Beers experience and forecasts.

4.0 RESEARCH METHODOLOGY

The study assesses the impact of application of COG policy on Orapa A/K1 Mineral Resources. Previous research has shown that the application of cut-off strategy maximizes the NPV. An assessment relevant to testing the model for varying COGs with depth was conducted and this was carried out in two parts. The first part included gathering data and information from the selected sources (e.g. LoM reports, Annual Resource and Reserve statements, etc.) whilst the second part included discussions with mine planning teams as well as analysis on the gathered data.

4.1 Methodology chosen

4.1.1 Sources of data

There are different methods and procedures used to gather data for quantitative researches and these include experimental research, survey method, historical method, descriptive method and case studies. Each of them has its own strength and weaknesses. To fulfill the objectives of the present study, the mixed method was adopted for generation of data. Saunders *et al.*, (2007) argues that this approach negates deficiencies of a single research method. It also provided opportunities for answering research questions as well as better evaluation of the extent to which the research findings can be trusted and inferences made (Carson and Coviello, 1996).

The data used in this study was obtained from the Orapa 2014 Annual Resource and Reserve Statement. The gathering of data specific to this study was made possible by analysis of various data sets that informed the resource and reserve statement. The data set would normally be highly summarized for declaration purposes for the annual statements. Interviewing mine-planning teams also produced insightful information and business view of the future.

4.1.2 Procedure for data generation and collection

Firstly, approval to use the company data was sought from OLDM Management. Once approval was given, the author started compiling data from the different sources.

The different methods and procedures used to gather data for quantitative researches included experimental research, survey method, historical method, descriptive method and case studies. Each of them has its own strength and weaknesses. To fulfill the objectives of the present study, all of the above approaches were used to generate data. This involves performing change impact analysis on selected COG scenarios and variations to determine impact on two ways: NPV response and impact on cash flow response.

The data collection procedures were prepared with qualitative analyses in mind that considered capabilities of various charting and statistical techniques. The analysis of the COG determination was completed from the existing dollar/tonne mined data and to a lesser extent on the limited dollar/tonne treated data. Functional leader's views were used to validate and provide assurance to conclusions and inferences thereafter.

The inputs into the Orapa 2014 Annual Resource and Reserve Statements were analyzed. A grade/tonnage assessment of the remaining Diamond Resource was completed. Furthermore, an analysis of the various COG incremental ranges with mining depth was completed. Relevant key stakeholders were engaged to test and validate the research assumptions and conclusions and subsequently recommending a suitable option. The Debswana MRM leadership, Long-Term planning leadership and the De Beers Group MRM have showed keen interest on the research outcomes.

4.2 Validity and reliability

The trustworthiness, validity and reliability of the qualitative research depends on what the researcher sees and what the analysis says as well as to what extent the inferences are made. Research credibility, transferability, dependability and confirmability are important in establishing trustworthiness. One way of ensuring credibility and transferability was ensuring that those interviewed have the experience to discuss the phenomenon the researcher seeks to explore. One way to establish confirmability is ensuring that the data interpretation is based on what the data and analysis tell without introducing any bias. Firstly, the data generated and collected was checked for obvious omissions and mistakes by establishing the effectiveness of the controls over the processes that produced the data. A systematic process provided the basis for making a preliminary assessment of the data reliability. Collecting known information, performing initial testing of the data and assessing risk related to the intended use of the data was covered. The process also included exploratory data analysis (EDA) tests.

The various datasets were analyzed for logical conclusions and inferences. Some of the current assumptions were tested to enhance the Resource planning process. For this process, various datasets were subjected to statistical tests for hypothesis testing, regression analysis as well as testing some of the inferences to test their basis and sound underpinning.

4.3 Limitations of the study

There is limited data and research pertaining to diamond COG application. The revenue footprint for Orapa Mine resource is not fully constrained per rock type; global kimberlite pipe and plant based revenue estimates still inform LoM plans. A low-grade diamond resource does not necessarily manifest itself into a low revenue Resource i.e. lower dollar/carat.

4.4 Summary of this chapter

The goal of this chapter was to outline the research method used to answer the fundamental research question and sub-problems formulated. A discussion of the procedure, data sources and collection process, analytical work completed and suggested views guided the research approach. Various existing sources of data were reviewed to generate the different data sets required for the research study. The multi-method research approach was preferred over the single method approach. The method enables triangulation to take place during analysis and different methods will be applied for different purposes. The goal of the next chapters (Chapter 4 and 5) is an overview of OLDM background information and the presentation of study results respectively to demonstrate application of the methodology described in Chapter 4.

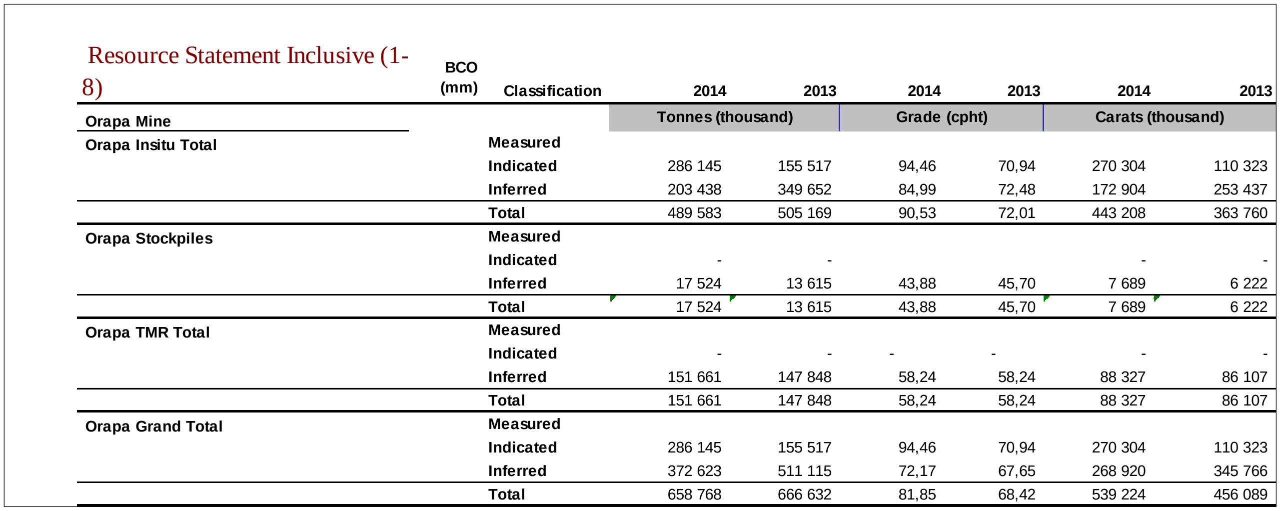
5.0 ORAPA MINE CASE STUDY

5.1 Orapa Mine resource endowment

The purpose of this chapter is the presentation of Orapa A/K1 Mineral Resource analysis and results for the different profiles in relation to this research study. As discussed in Chapter 4, Research Methodology, there was no sampling conducted to generate new data. However, the existing mine information and production data analysis, the author's personal work experience and maturity assessment on certain processes were used to form the basis of this chapter. The various validity and reliability tests completed on the data collated are also discussed.

The Orapa Mine A/K1 Mineral Resource classification complies with the South African Code for Reporting of Mineral Resources and Mineral Reserves (SAMREC, 2016). Table 2 and Table 3 show the 2014 Orapa Mine Mineral Resource and Reserve Statement respectively.

Table 2: Orapa A/K1 Mineral Resource Statement (modified from Oelofsen *et al.*, 2014)



Resource Statement Inclusive (1-8)	BCO (mm)	Classification	2014	2013	2014	2013	2014	2013
Orapa Mine			**Tonnes (thousand)**		**Grade (cpht)**		**Carats (thousand)**	
Orapa Insitu Total		**Measured**						
		Indicated	286 145	155 517	94,46	70,94	270 304	110 323
		Inferred	203 438	349 652	84,99	72,48	172 904	253 437
		Total	489 583	505 169	90,53	72,01	443 208	363 760
Orapa Stockpiles		**Measured**						
		Indicated	-	-			-	-
		Inferred	17 524	13 615	43,88	45,70	7 689	6 222
		Total	17 524	13 615	43,88	45,70	7 689	6 222
Orapa TMR Total		**Measured**						
		Indicated	-	-	-	-	-	-
		Inferred	151 661	147 848	58,24	58,24	88 327	86 107
		Total	151 661	147 848	58,24	58,24	88 327	86 107
Orapa Grand Total		**Measured**						
		Indicated	286 145	155 517	94,46	70,94	270 304	110 323
		Inferred	372 623	511 115	72,17	67,65	268 920	345 766
		Total	658 768	666 632	81,85	68,42	539 224	456 089

Table 3: Orapa A/K1 Mineral Reserve Statement (modified from Oelofsen *et al.*, 2014)

Reserve Statement (1-6)	BCO (mm)	Classification	2014	2013	2014	2013	2014	2013
Orapa Mine			**Tonnes (thousand)**		**Grade (cpht)**		**Carats (thousand)**	
Orapa OP		**Proven**						
		Probable	173 403	140 347	77,81	63,84	134 921	89 600
		Total	173 403	140 347	77,81	63,84	134 921	89 600
Orapa Grand Total		**Proven**						
		Probable	173 403	140 347	77,81	63,84	134 921	89 600
		Total	173 403	140 347	77,81	63,84	134 921	89 600

The Orapa Mine also hosts other diamond deposits namely Lease Area Gravels (LAGs) and Airport Pan Gravels (APGs) and various exploration datasets collated for comparison purposes (Noppe and Kleingeld, 1995). Table 4 depicts the 2014 Orapa Mine Deposit Statement.

Table 4: Orapa Mine 2014 Deposit Statement (modified from Oelofsen *et al.*, 2014).

Deposit Statement Inclusive				**Tonnes (thousand)**		**Grade (CPHT)**		**Carats (thousand)**		**USD/carat**		**Revenue (USD million)**	
Operation	**Insitu**	**BCO (mm)**	**Classification**	**2 014**	2 013	**2 014**	2 013	**2 014**	2 013	**2 014**	2 013	**2 014**	2 013
Orapa (OP)	Orapa Mine A/K20 insitu (0-260 mbgl)	1.65	Deposit	465	465	57.42	57.42	267	267	127.63	129.19	34.08	34.49
Orapa Stockpile	Orapa Mine A/K1 Stockpiles	1.65	Deposit	1 221	1 221	9.99	9.99	122	122	90.94	90.94	11.09	11.09
Orapa Deposit	Orapa Fines Tailings Deposit	1.47	Deposit	87 740	87 939	0	0	0	0	0	0	0	0
	Orapa Mine - Airport Pan Gravels (P)	1.50	Deposit	35 337	35 337	10.50	10.50	3 709	3 709	76.17	76.17	282.51	282.51
	Orapa Mine - Lease Area Gravels (P)	1.50	Deposit	36 621	36 621	17.67	17.67	6 470	6 470	90.94	90.94	588.38	588.38
	Orapa Mine - Old Recovery Tailings	1.47	Deposit	53	55	20 354.72	19 587.27	10 788	10 773	62.79	81.34	677.38	876.28

Notes:

1. The estimated tonnage and estimated number of carats contained in these deposits are conceptual in nature and do not conform to the definition of a "Diamond Resource" due to insufficient sampling. Further exploration will not necessarily provide the basis for determining a Diamond Resource.

2. Tonnage quoted as dry metric tonnes (t).

3. Grade quoted as carats per hundred metric tonnes (cpht).

In addition to the A/K1 insitu Resources and satellite deposits within the lease area, Orapa Mine maintains various stockpiles and tailings residue. The ore stockpiles are Old Recovery Tailings (ORT), Orapa Coarse Tailings Mineral Resource (OCTMR), Strategic Run of Mine (ROM) stockpiles and the low-grade stockpile. The stockpiling philosophy is guided by rock type and by grade range. Orapa Mine has been in operation for just over forty-five (>45) years, and throughout this period various ore mixes have been treated at different rates. Throughout the mining life, the low-grade material stockpiled and only small proportions treated to satisfy blending requirements.

5.2 Reasonable Prospects for Eventual Economic Extraction

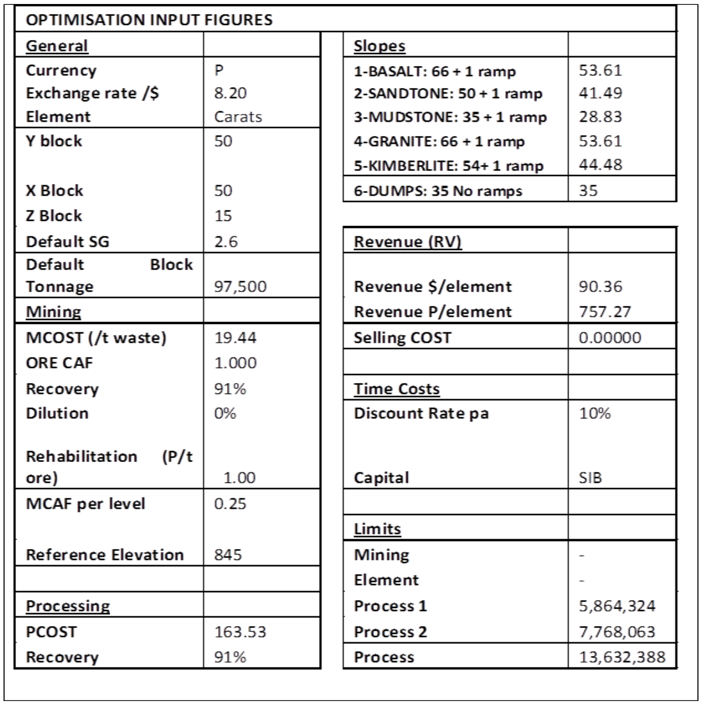
The purpose of this sub-section is an overview of the RPEEE process, the application of the test in other commodities, key assumptions for open pit mining versus underground operations as well as similarities and differences of the test between different commodities. Orapa Mine will in future transition to underground mining operation i.e. post Cut 3 mining.

For Orapa Mine, all Mineral Resources at Inferred level of confidence or higher are evaluated to test their potential economic viability. The Debswana RPEEE framework assumes a revenue factor of 1.8 x current revenue, on mine costs, and is derived by an independent Whittle run in order to define the potential pit limit at a strict bottom cut-off (Mompati, 2014). The RPEEE test assumes the following:

- Costs, exchange rates, prices and throughput are based on current year indices but the revenue used assumes a long-term price change view;
- The weighted realized value revenue (USD/Carat) including incidentals is used. Since Orapa A/K1 Resource is processed through two production plants, the weighted average realized revenue calculation is based on the annual throughput of the plant and the estimated revenue estimate per plant;
- A revenue factor of 1.8 x $/Carat is used as Resource Cut-off criteria; and
- The revenues used are as per the current year mid-year forecast. This is the forecast plan normally put in place to get back to budget using actual production for the first four months of the year. However, it can also be a response to market volatility and changes i.e. decrease/increase in demand for rough Diamonds.

The 2014 Orapa A/K1 Insitu Resource passed the RPEEE test and was included in the 2014 Resource Statement. Table 5 shows the Whittle optimization inputs used in the Orapa Resource RPEEE assessment for the 2014 Strategic Business Plan (SBP).

Table 5: 2014 Orapa A/K1 RPEEE Whittle optimization inputs (Mompati, 2014)



OPTIMISATION INPUT FIGURES

General	
Currency	P
Exchange rate /$	8.20
Element	Carats
Y block	50
X Block	50
Z Block	15
Default SG	2.6
Default Block Tonnage	97,500
Mining	
MCOST (/t waste)	19.44
ORE CAF	1.000
Recovery	91%
Dilution	0%
Rehabilitation (P/t ore)	1.00
MCAF per level	0.25
Reference Elevation	845
Processing	
PCOST	163.53
Recovery	91%

Slopes	
1-BASALT: 66 + 1 ramp	53.61
2-SANDTONE: 50 + 1 ramp	41.49
3-MUDSTONE: 35 + 1 ramp	28.83
4-GRANITE: 66 + 1 ramp	53.61
5-KIMBERLITE: 54+ 1 ramp	44.48
6-DUMPS: 35 No ramps	35
Revenue (RV)	
Revenue $/element	90.36
Revenue P/element	757.27
Selling COST	0.00000
Time Costs	
Discount Rate pa	10%
Capital	SIB
Limits	
Mining	-
Element	-
Process 1	5,864,324
Process 2	7,768,063
Process	13,632,388

There are significant differences in Mineral Resource and Ore Reserve confidence between open pit and underground mining scenarios for different commodities. The obvious differences include:

- Consideration for COG in other commodities, while the current Diamond RPEEE settles for bulk mining;
- Even though the SAMREC code recommends adoption of a product price higher than the long-term price used in the development of current pit designs and mine plans supportive of Reserves, the RPEEE test for Diamonds has historically been using the relatively short-term forecast. However, the 2016 Strategic Business Plan assumed a long-term revenue base; and
- Another obvious difference will be the application of COGs with option to condemn to waste, stockpile or process now.

The current RPEEE assessment declares all the Mineral Resources for open pit mining option. However, the outcome will be different if underground options are evaluated. The evaluation of the current Debswana RPEEE assessment suggests that the criteria has not fully incorporated the impact of varying the COG. The RPEEE COG applied has remained static for years irrespective of the volatile market conditions for Diamonds and the dynamic price position in the rough

Diamond price curve. The RPEEE framework needs to review to ensure robustness and consistency when reporting the Mineral Resources economic viability.

5.3 Orapa A/K1 mineral resource profile

The Orapa A/K1 unmined diamond resource contains 1,069M tonnes of ore translating into 990M carats at an average grade of 91.18 cpht stated at a BCO of 1.65 mm. The Orapa A/K1 diamond resource is processed through Orapa Plant 1 and Plant 2. The main difference between the two plants is the availability of the re-crush facility for Orapa Plant 2. Re-crushing enhances liberation and hence relatively higher recoveries for Plant 2. Similarities of the plant configurations will include the plant screen aperture BCOs at +1.65 mm. Figure 9 shows the Orapa A/K1 diamond resource tonnage-grade curve (un-depleted resource) while Table 6 presents the grade and tonnage/carats distribution.

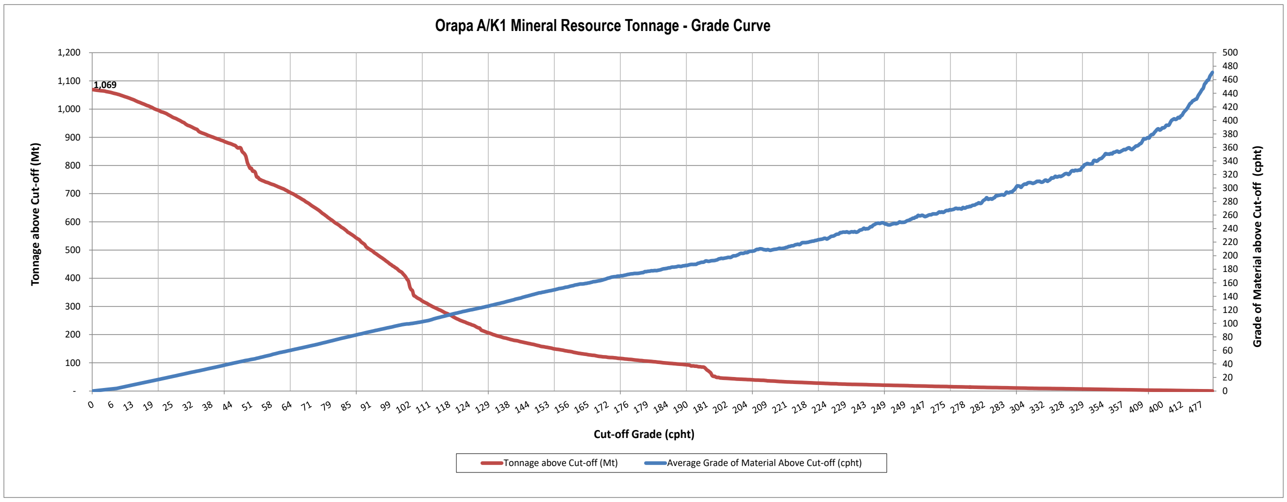


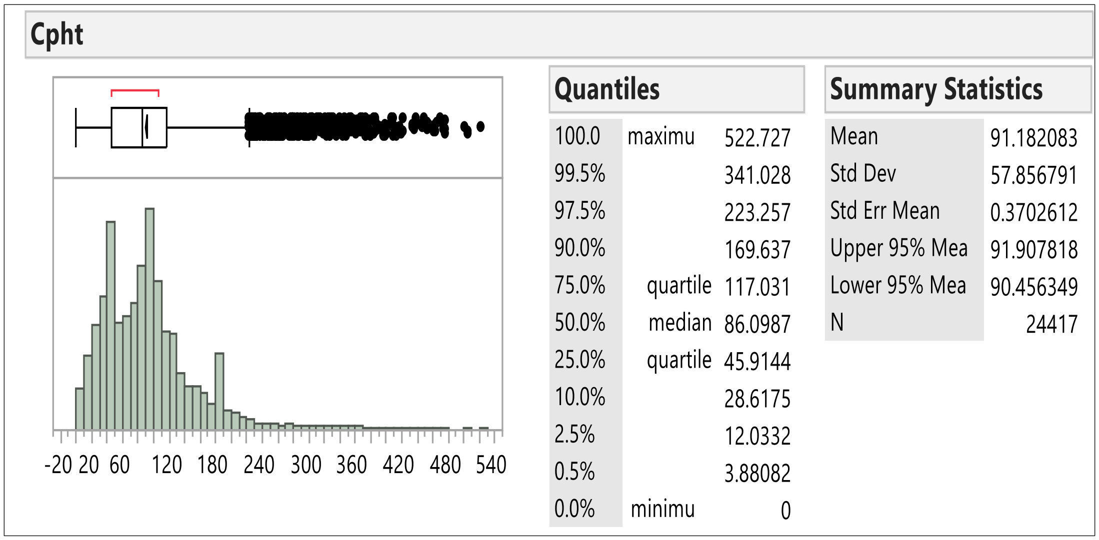
Figure 9: Orapa A/K1 unmined Mineral Resource tonnage - grade curve

Table 6: Orapa A/K1 grade tonnage and carats distribution

Grade (cpht)	Total Tonnes	Total Carats
<5	7,746,912	202,600
5 to < 10	15,366,466	1,175,679
10 to <15	21,788,597	2,725,856
15 to <20	24,236,361	4,227,038
20 to <25	24,995,382	5,652,287
25 to <30	33,130,755	9,259,210
30 to <40	59,920,134	20,471,270
40 to <50	124,475,430	56,811,531
50 to <60	45,356,621	24,902,286
60 to <70	55,630,846	36,271,817
>=70	669,223,040	833,172,455

*Grade and Carats Reported at BCO 1.65 mm, cpht = carats per hundred tonnes.

Figure 10 shows the Orapa A/K1 diamond resource local block grade distribution for the different rock types. The distribution shows the grade skewness to the left with a mean grade of 91.18 cpht within the 50 – 75% quartile and a long upper "tail" with relatively higher grades. The distribution also returns an average grade of 90.45 cpht and 91.90 cpht for the 95% Lower and Upper confidence limits respectively.



Quantiles

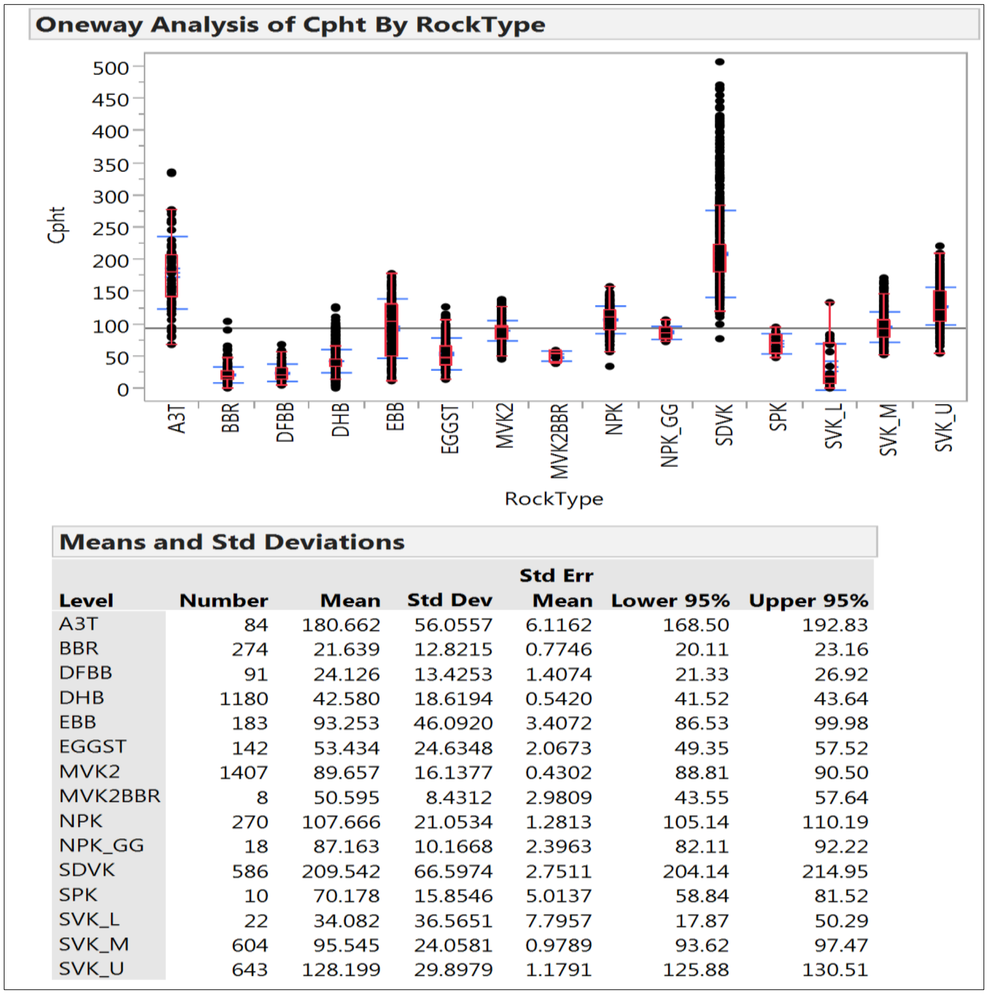
100.0	maximu	522.727
99.5%		341.028
97.5%		223.257
90.0%		169.637
75.0%	quartile	117.031
50.0%	median	86.0987
25.0%	quartile	45.9144
10.0%		28.6175
2.5%		12.0332
0.5%		3.88082
0.0%	minimu	0

Summary Statistics

Mean	91.182083
Std Dev	57.856791
Std Err Mean	0.3702612
Upper 95% Mea	91.907818
Lower 95% Mea	90.456349
N	24417

Figure 10: Orapa A/K1 grade profile for all rock types (block estimates at BCO 1.65 mm)

Figure 11 depicts the grade profile for blocks populated with approximately 100% single rock type i.e. Volume > 37,000 m^3 for any rock type.



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
A3T	84	180.662	56.0557	6.1162	168.50	192.83
BBR	274	21.639	12.8215	0.7746	20.11	23.16
DFBB	91	24.126	13.4253	1.4074	21.33	26.92
DHB	1180	42.580	18.6194	0.5420	41.52	43.64
EBB	183	93.253	46.0920	3.4072	86.53	99.98
EGGST	142	53.434	24.6348	2.0673	49.35	57.52
MVK2	1407	89.657	16.1377	0.4302	88.81	90.50
MVK2BBR	8	50.595	8.4312	2.9809	43.55	57.64
NPK	270	107.666	21.0534	1.2813	105.14	110.19
NPK_GG	18	87.163	10.1668	2.3963	82.11	92.22
SDVK	586	209.542	66.5974	2.7511	204.14	214.95
SPK	10	70.178	15.8546	5.0137	58.84	81.52
SVK_L	22	34.082	36.5651	7.7957	17.87	50.29
SVK_M	604	95.545	24.0581	0.9789	93.62	97.47
SVK_U	643	128.199	29.8979	1.1791	125.88	130.51

Figure 11: Orapa A/K1 Grade profile per main rock type at BCO 1.65 mm

There are three relatively lower grade lithofacies namely Basalt Breccia (BBR), Deep Heterolithic Breccia (DHB) and Lower Southern Volcaniclastic Kimberlite (SVK_L). The rock type BBR occurs on the upper portions, comprising more than 80% basalt clasts and mostly appearing on the pipe margins. The DHB dominates the northern half of the South Pipe and percentage proportion increasing with depth. The SVK-L is a basal unit marking the base of the South Pipe Crater facies. It comprises interbedded sequence of relatively undiluted kimberlite and heterolithic breccias of basalt, sandstone, mudstone and minor basement clasts. Dilution ranges from 20% to 40%. The mined out rock types include A3T, DFBB, EGST, EBB and SVK-U while rock types DHB, SVK_L and SDVK will be mined in future.

5.4 Orapa Mine production

Orapa mining commenced in 1971 with only Plant 1 processing the ore. In 2002, Plant 2 commissioned and production ramped up to over 15 M tonnes treated. Throughout the production history (1971 – 2015), ore tonnes mined were in most instances more than ore treated and this is due to the stockpiling of low-grade ores for treatment towards end of LoM and relatively lower Plant 1 throughput before Plant 2 commissioning. Where ore tonnes treated are more than tonnes mined, the balance would come from the stockpiles (i.e. stockpile material treated) and this would be accounted for on total tonnes moved. For periods 1996, 2007 and 2013, the recovered carats are more than tonnes mined due to additional carats from stockpile material treated and to an extent, the higher-grade material treated. Figure 12 shows the production profile for the years 1995 to 2015.

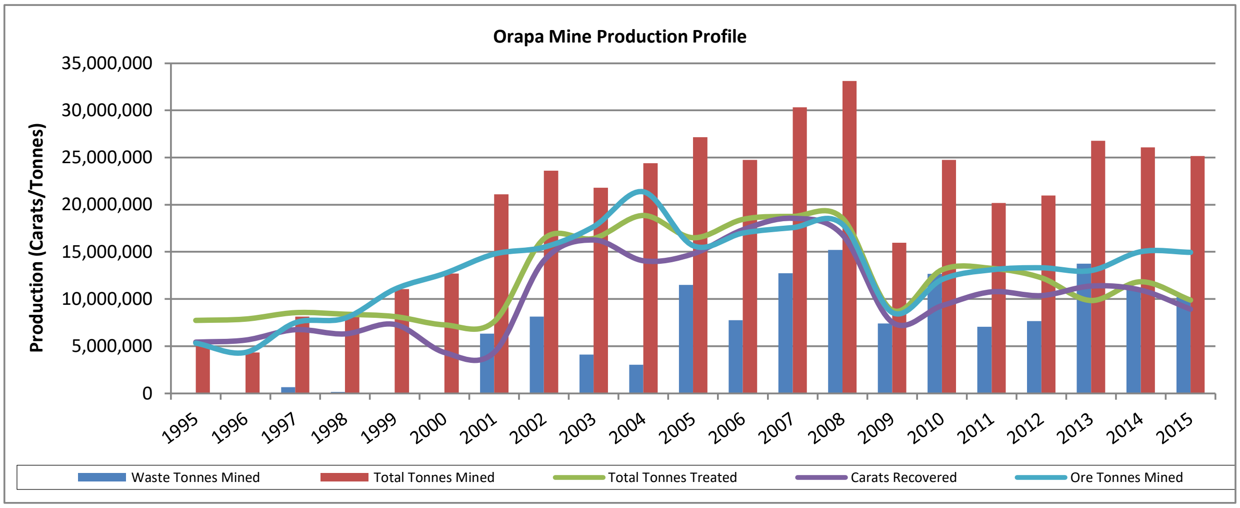


Figure 12: Orapa Mine production history for years 1995 to 2015

Figure 13 depicts the Orapa Mine Revenue produced profile. A comparison of tonnes treated (Figure 12) with the revenue produced shows that the revenue produced is driven by the grade depleted. While the depleted grade remains relatively static, the tonnes treated drops in 2009 in line with the economic downturn i.e. low demand for rough Diamonds. In 2009 - 2010, the revenue remained low while the depleted grade was relatively higher i.e. Diamonds mined but not sold due to suppressed market demand.

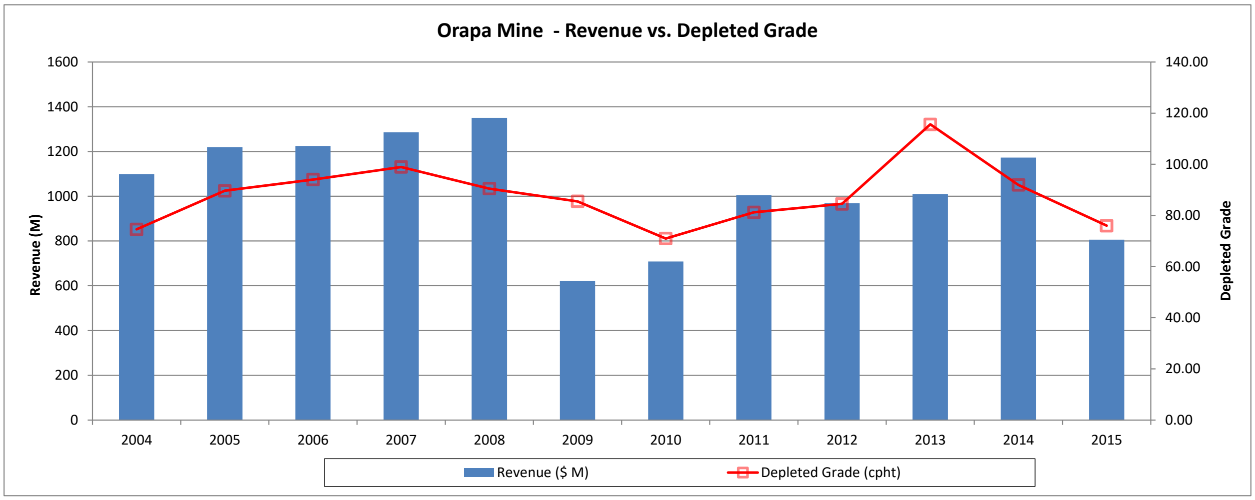


Figure 13: Orapa Mine Revenue plot versus Depleted Grade

5.5 Validity and reliability of results

Internal validity and reliability

The intent of this study was to assess the impact of the application of COG principles on the Orapa A/K1 diamond resources. In order for the research data to be of value and of use, they must be both reliable and valid. It is common to see the terms quality, rigor or trustworthiness instead of validity and reliability in qualitative studies (Seale, 1999). While reliability is concerned with the accuracy of the actual measuring instrument or procedure, in this case application of COG approach, validity would be concerned with the study's success at measuring what the study sets out to assess. The study relies on the results showing support or a lack of support for the study hypothesis and if the data used or generated is erroneous, the results will be erroneous.

The study approach involved investigative and analytical processes where the existing mining and production datasets, mine plans and associated limiting capacities were reviewed. Firstly, all the production data and information was verified from different sources e.g. end users, peer and expert reviews. Basic statistical analysis was completed as part of the exploratory data analysis (EDA) e.g. grade – tonnage plots, scatter plots, linear relationships, and dispersion trends, etc. The focus was on identifying patterns and explanations thereof by searching to confirm and disconfirm evidence. It is also worth mentioning that almost all the data used has previously informed Resource and Reserve Statements have also been subjected to various levels of reviews before publication.

External validity and reliability

External validity refers to the extent to which the results of this study are generalizable. For this study, most of the inferences and conclusions would also apply to commodities other than diamond resources. However, there are parameters which would be specific to diamond resources such as the Size Frequency Distribution (SFD), the bottom cut-off (BCO) sizes as well as the revenue e.g. $/carat per sieve class. For instance, a relatively lower grade Mineral Resource does not imply a lower $/carat hence a recommendation from this study to further investigate the grade-revenue equivalence for diamond resources or a cut-over ratio for consideration in decision making.

5.6 Summary of this chapter

The chapter presented analysis and results of Orapa A/K1 diamond resource inventory. Different validity and reliability tests were employed on the different data sets. Firstly, the data was checked for duplicate errors and gaps prior to use in the analysis. All the production data and information sources was verified. Basic statistical analysis was completed as part of the exploratory data analysis. The focus was on identifying patterns and explanations thereof i.e. searching for evidence. Since the data informs the past Resource and Reserve Statement declarations, it has also gone through external due diligence reviews. The chapter also presented the Orapa A/K1 Diamond Resource Tonnage-Grade curve based on the 2014 Annual Resource and Reserve Statement and the production profile discussed.

6.0 ANALYSIS AND INTERPRETATION OF RESULTS

The focus of the chapter is to analyze the data generated in order to test the research hypothesis and answer the fundamental research question.

6.1 Study findings

The fundamental elements of COG optimization and the effect on NPV was assessed for the different scenarios. The first case was determination of the breakeven COG and subsequently the determination of the optimum COG for the Orapa A/K1 diamond resource. An option to stockpile the low-grade as well as the various possible blending requirements and treatability constraints for the two Orapa plant streams was investigated. Plant 1 and Plant 2 cut-over grades were also determined.

6.2 Orapa A/K1 diamond resource COG determination

The economic definition of ore dictates that every increment of mineralized material has to contain a sufficient concentration of the commodity to pay for the cost of mining, processing and all related costs of access (Dagdelen and Mohammed, 1997). Algorithms for determining COG policy that maximizes the NPV for yearly cash flows are also available. For this study, the 2014 Whittle optimization assessment outcome for an optimum pit was adopted, the total LoM at forty one (41) years mining 4,778 M tonnes of waste and 616 M tonnes of ore to deliver the 584 M Carats (Mompati, 2014). This translated to a stripping Ratio of 6.75:1. The Revenue Factor was 1.8 and only Stay in Business capital considered for the RPEEE assessment.

Table 7 shows the adopted Orapa plant’s capacities from the 2014 Strategic Business Plan and mining costs incurred for the treatment of Orapa A/K1 diamond resource through Orapa Plant 1 and Plant 2.

Table 7: Economic parameters for the Orapa Mine case study

Item	Value	Unit
Price (P) – Realised Value	90.36	\$/ct
Sales Cost (s)	0.00	\$/ct
Fixed Cost (f_a)	194	\$M
Mining Cost (M)	2.37	\$/Tonne mined
Orapa Recovery (y)	91	%
Processing Cost (c)	15.39	\$/ Tonne treated
Processing Capacity (C)	13.63	M
Mining Capacity (M)	Unlimited	M
Discount Rate(d)	10	%

*the sales and marketing costs are discounted off in the price i.e. Realized Value.

6.2.1 Calculation of Orapa A/K1 Breakeven COG

The breakeven COG ($G_{b/even}$) is the minimum grade at which the ore generates just enough revenue to pay for the costs based on financial parameters only (Hall, 2014). Firstly, Equation 1 (Dagdelen (1992), Dagdelen and Mohammed (1997) and Hall, (2014)) calculates the A/K1 diamond resource breakeven COG. This determines the grade at which the revenue obtained is equal to the cost of producing that revenue. This breakeven COG maximizes the un-discounted profit function per annum. Whenever there is spare capacity in the plants, the marginal ore has the opportunity for processing.

$$\mathbf{G_{b/even} = \text{Processing Cost} - \text{Mining Cost} / ((\text{Price} - \text{Sales Cost} + \text{Marketing Cost})*\text{Recovery})} \qquad \mathbf{(1)}$$

$$\mathbf{G}_{b/even} = (15.39 - 2.37) / (90.36*0.91)$$
$$\mathbf{G}_{b/even} = 0.1583 \text{ Carats/Tonne}$$
$$\mathbf{G_{b/even} = 15.83\ cpht}$$

For the breakeven COG calculations above, the Realized Value (RV) price include sales and marketing costs. For this study, it was assumed that the material whose grade is much higher than the established breakeven COG pays all costs, including fixed costs. Since the decision to mine with open pit method to an optimum pit has already been made, the variable costs of mining (e.g. drilling and blasting, loading and hauling) has no bearing on the breakeven COG calculation. Therefore, the depreciation costs, general and administrative costs as well as opportunity costs were not included in the calculation of breakeven COG above. The only breakeven costs considered were total mining costs and total processing costs.

The breakeven COG calculated above is constant and maximizes the undiscounted profits unless the product price and costs significantly change during LoM. The major shortcoming in this assumption is that it does not account for the grade distribution of the resource and the capacities of mining and processing plants. The distribution of diamonds within the host rock is also not uniform and that different types of kimberlites have unique diamonds characteristics (e.g. assortment) which have a bearing on the price and revenues produced.

For this study, the breakeven COG calculation assumed a combined/weighted recovery efficiency of 91%, made up of the specific plant recovery efficiencies at 74% and 120% for Orapa Plant 1 and Orapa Plant 2 respectively. Orapa Plant 2 has a re-crush facility that enhances liberation hence relatively higher recovery efficiency compared with Orapa Plant 1. The mining costs remain the same as the two plants process material from the same single feed split after primary crushing stage. Breakeven COG for the Orapa plants considered:

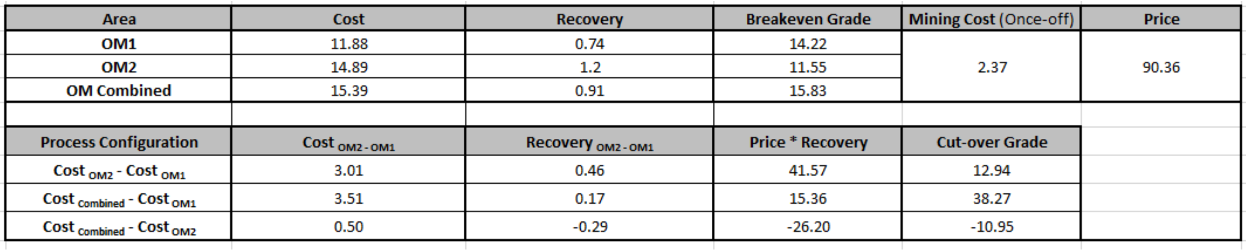
- Orapa Plant 1 has 74% recovery efficiency at \$11.88/Tonne of ore treated.
- Orapa Plant 2 has 120% recovery efficiency at \$14.89/Tonne of ore treated.

By substituting the above process parameters in Equation 1 above, the outcome is:

- Orapa Plant 1 $G_{b/even}$ = **14.22 cpht**
- Orapa Plant 2 $G_{b/even}$ = **11.55 cpht**

Table 8 shows the cut-over grade calculations for the various Orapa plant configurations i.e. calculation of cut-over grade when material is treated through Orapa Plant 2 as opposed to treating through Orapa Plant 1. Since Orapa Plant 2 has higher processing volume capacity and relatively higher recovery efficiency it makes business sense to fully utilize the facility and take the remainder to Orapa Plant 1. Orapa Plant 1 provides flexibility for extra material treatment capacity required in line with rough diamond demand as well as the processing swing philosophy by interchanging the different processing streams to optimize the maintenance tactics. The cut-over grade for material processed through both plants (Orapa Combined) versus processing through Orapa Plant 1 was also calculated.

Table 8: Breakeven cut-over grades for Orapa Plants



Area	Cost	Recovery	Breakeven Grade	Mining Cost (Once-off)	Price
OM1	11.88	0.74	14.22	2.37	90.36
OM2	14.89	1.2	11.55		
OM Combined	15.39	0.91	15.83		
Process Configuration	**Cost $_{OM2 - OM1}$**	**Recovery $_{OM2 - OM1}$**	**Price * Recovery**	**Cut-over Grade**	
Cost $_{OM2}$ - Cost $_{OM1}$	3.01	0.46	41.57	12.94	
Cost $_{combined}$ - Cost $_{OM1}$	3.51	0.17	15.36	38.27	
Cost $_{combined}$ - Cost $_{OM2}$	0.50	-0.29	-26.20	-10.95	

The breakeven cut-over ($G_{c/over}$) occurs when:

$$\text{Price*Grade*Recovery}_{\text{combined}} - \text{Cost}_{\text{combined}} = \text{Price*Grade*Recovery}_{\text{Plant 1}} - \text{Cost}_{\text{Plant 1}}$$

$$\mathbf{G_{c/over}} = (\text{Mining Cost} + \text{Cost}_{\text{combined}} - \text{Cost}_{\text{Plant 1}} / \text{Price}\ (\text{Recovery}_{\text{combined}} - \text{Recovery}_{\text{Plant 1}})$$

$$= ((2.37 + (15.39 - 11.88)) / (90.36*(0.91 - 0.74))$$

$$= 0.3827 \text{ Carats/Tonne}$$

$$= \mathbf{38.27\ cpht}$$

As shown above, the ore-waste breakeven grade for Orapa Plant 1 is 14.22 cpht. Applying the same calculation for Orapa Plant 2 generates an ore-waste breakeven grade of 11.55 cpht. Based on the cut-over grades calculated, the author concludes as follows:

- Due to its higher recovery efficiencies and throughput capacity, Plant 2 remains the processing facility of choice with the remainder coming from Plant 1;
- Any ore grade greater than 0 cpht but < 11.55 cpht should be stockpiled at the low-grade stockpile and treated at end of LoM;
    - ✓ Any material grade <= 0 cpht should be condemned to waste.
- Ore grade >= 11.55 cpht and < 12.94 cpht, should be stockpiled at the intermediate stockpile to allow for future technological advancements;
- Ore grade >= 12.94 cpht should be classified as ore and treated by Orapa Plant 2;
- Where Plant 1 is the only plant available, ore grade >= 14.22 cpht (breakeven) should be targeted; and
- For a combined processing scenario, the breakeven $G_{c/over}$ is 38.27 cpht. This is the point at which the scenario exists to increase the recovered grade and maximize cash flows especially in the initial years of the LOMP;

- ✓ In this case, ore grade >= 11.55 cpht and < 38.27 cpht should be classified as ore and taken to the intermediate ore stockpile.

Figure 14 shows graphically the benefits of classifying material as waste and ore treated by both Plant 1 and Plant 2. The benefit of waste is -$2.37 at all grades of material. The benefit of ore treated by Plant 1 increases linearly from -$11.88/tonne at zero grade. Similarly, the benefit of material treated by Plant 2 increases linearly from -$14.89/tonne at zero grade i.e. the total cost of mining and processing by Plant 2. The Orapa Combined process line crosses Orapa Plant 1 process line at 38.27 cpht. The ore-waste breakeven for Plant 1 does not enter into the specification of how the material is classified. In the absence of Plant 1, Plant 2 treats material of grade >= 11.55 cpht. Plant 1 provides better returns than Plant 2 for all grades up to the identified cut-over of 12.94 cpht.

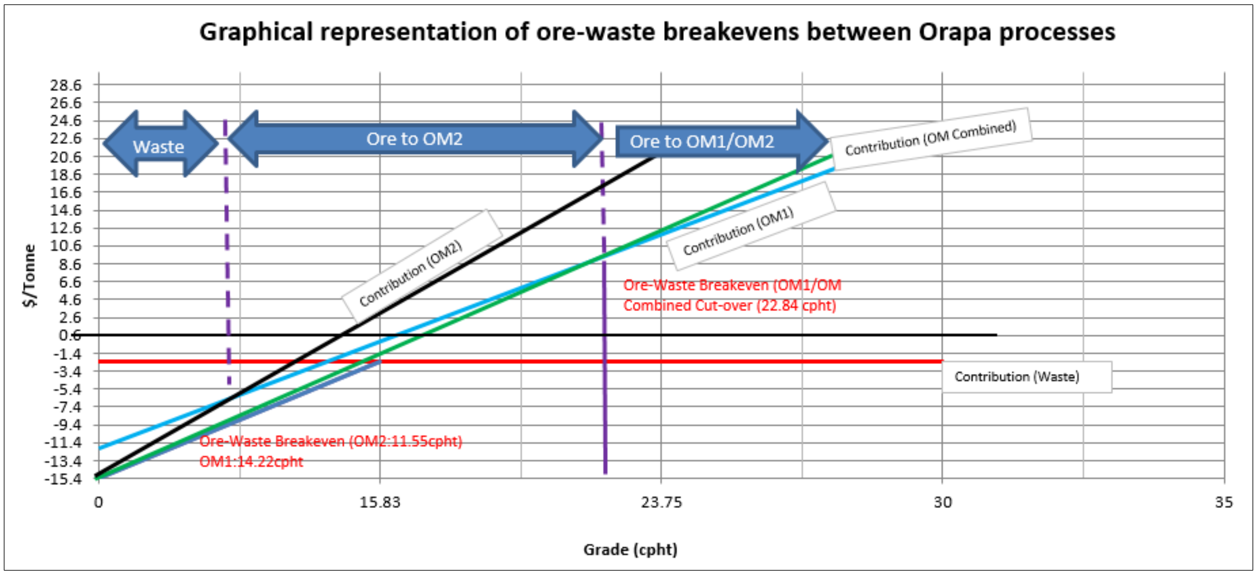


Figure 14: Graphical representation of ore-waste breakeven for Plant 1 and Plant 2

Table 9 illustrates the 10-year cash flow schedule. The annual cash flows given as profits in millions of dollars are determined using Equation 2 (Dagdelen and Mohammed, 1997).

$$\textbf{Profits (\$M)} = (P-s)*Q_r - c*Q_c - m*Q_m - f_a \qquad (2)$$

Where;

Q_m is total material mined (in Million tonnes).

Q_c is ore tonnage processed (in Million tonnes).

Q_r is recovered carats in a year (in thousands).

Table 9: Breakeven COGs for Orapa Plants Combined

Year	Breakeven Cut-off	Average Grade above Breakeven Cut-off	Q_m (M)	Q_c (M)	Q_r(M)	Profits ($M/Year)
1	15.83	96.64	5394	13.63	1199	95,123
2	15.83	96.64	5394	13.63	1199	95,123
3	15.83	96.64	5394	13.63	1199	95,123
4	15.83	96.64	5394	13.63	1199	95,123
5	15.83	96.64	5394	13.63	1199	95,123
6	15.83	96.64	5394	13.63	1199	95,123
7	15.83	96.64	5394	13.63	1199	95,123
8	15.83	96.64	5394	13.63	1199	95,123
9	15.83	96.64	5394	13.63	1199	95,123
10	15.83	96.64	5394	13.63	1199	95,123
Total				**136.30**	**11987**	**951,229**
					NPV ($M)	**366,740**

Profits ($M) = $(P-s)*Q_r - c*Q_c - m*Q_m - f_a$

The breakeven grade ($G_{b/even}$) ensures that any material that provides positive contribution beyond processing and recovery is processed. Mining the Orapa A/K1 Diamond Resource with the breakeven grade of 15.83 cpht at 13.63 M tonnes, processing capacity results in 25-year mining.

6.2.2 Calculation of Orapa A/K1 Optimum COG

The mining of the Mineral Resource in such a way that maximizes NPV at the end of LoM is a generally accepted objective of most mining companies. The use of simply calculated breakeven COGs during production in most instances leads to sub-optimum mining of the Mineral Resource (Dagdelin and Mohammed, 1997). Since it fluctuates with price changes, the operation may not actively control what is ore or waste, which may limit mining and flexibility options.

The calculation of the optimum COG also takes into consideration the Resource grade distribution, price and cost changes throughout LoM with the view to maximize the NPV. The basis of optimum COG considers Mortimer's definition of ore (Hall, 2014), which states that whatever makes it into the classification as ore must satisfy the following:

- The average grade must provide a certain minimum Profit per tonne treated; and

- The lowest grade of material must pay for itself.

Table 10 below shows the key financial inputs parameters considered in the calculation of the Orapa A/K1 Diamond Resource optimum COG (G_{opt}) i.e. defining the lower bound of options that deliver the minimum profit. The analysis also covered various scenarios i.e. fixed costs excluded from the calculation and vice versa.

Table 10: Orapa financial input parameters

Fixed Cost ($)M	Fixed Cost/Tonne Treated ($)M	Capital Cost ($)M	Depreciation Cost/Year ($/Year)M	Depreciation Cost/Tonne ($/Tonne)M	Minimum Profit Estimate ($/Tonne)
141.4	10.37	88.65	8,87	0.65	5

While the preceding sub section (6.2.2) has satisfied the second criteria by determining the breakeven COG at which each tonne pays for itself, this does not guarantee achieving a certain level of profitability. The average grade of ore that delivers the required profit was determined and used to distinguish ore/waste. However, it is itself not the COG but the average grade of ore. Various costs were included in the COG calculation to ensure that the average grade of material provides a minimum profit per tonne.

For this sub section, the general expenses costs, depreciation and amortization as well as the minimum profit per tonne are required for a specified period to obtain higher COG during the early years. At the end of this period, exclusion of the minimum profit is necessary to lower the COGs further until the payoff of the capital investment with exclusion of depreciation charges. The case study considered a 10-year period for the purpose of change impact analysis.

Table 11 shows a total of $88.65 M plant capital cost depreciated over a ten-year period by straight-line method:

Depreciation cost per year =

$88.65 M/10 years = **$8.87 M/year**

Depreciation cost per tonne =

$8.87 M/13.63 M tonnes = **$0.65/Tonne of ore**

A minimum profit of $5/tonne (Gorogodo pers.com, Finance Manager) imposed to increase the cash flows further during the first 5 years. The calculation of the processing Cut-off calculated in equation 4:

For years 1 -5

$$G_{process} = (\text{Processing Cost} + \text{Depreciation Cost} + \text{Minimum Profit}) / (\text{Price} * \text{Recovery}) \qquad \textbf{(4)}$$

$$G_{process} = (15.39 + 0.65+5) / (90.36*0.91)$$

$$G_{process} = 0.25587 \text{ Carats/Tonne}$$

$$G_{process} = \textbf{25.59 cpht}$$

Thereafter, the COG re-calculated without the minimum profit and the processing COG given by:

For years 6 -10

$$\mathbf{G_{process} = (Processing\ Cost + Depreciation\ Cost) / (Price * Recovery)}$$

$$G_{process} = (15.39 + 0.65) / (90.36*0.91)$$

$$G_{process} = 0.19506 \text{ Carats/Tonne}$$

$$G_{process} = \textbf{19.51 cpht}$$

Table 11 shows yearly tonnes and grade schedules resulting from the modification of the traditional breakeven to the COGs. In this scenario, COGs are elevated during the initial years.

Table 11: Calculation of Orapa A/K1 Declining COGs

Year	COG (cpht)	Average Grade of Resource above COG	Q_m (M)	Q_c (M)	Q_r(M)	Profits ($M/Year)
1	25.59	93.48	68.97	13.63	1,274	95,358
2	25.59	93.48	68.97	13.63	1,274	95,358
3	25.59	93.48	68.97	13.63	1,274	95,358
4	25.59	93.48	68.97	13.63	1,274	95,358
5	25.59	93.48	68.97	13.63	1,274	95,358
6	19.51	98.17	78.51	13.63	1,338	194,240
7	19.51	98.17	78.51	13.63	1,338	194,240
8	19.51	98.17	78.51	13.63	1,338	194,240
9	19.51	98.17	78.51	13.63	1,338	194,240
10	19.51	98.17	78.51	13.63	1,338	194,240
Total				**136.30**	**13061**	**1,447,990**
NPV ($M)						**1,332,864**

Profits ($M) = $(P-s)*Q_r - c*Q_c - m*Q_m - f_a$

The COG policy includes depreciation costs as part of the Cut-off and the profit calculation. The policy of declining COGs calculated with depreciation and minimum profit further improved the NPV of the Diamond Resource by 263% ($366,740 versus $1,332,864) while the overall undiscounted profits also increased by 52% ($951,229 versus $1,447,990). The COG strategy results in relatively higher and improved NPV.

In the preceding sections, the General and Administration (G and A) costs were not included. The Cut-off that ensures that each turn pays for itself is determined by considering the direct variable costs associated with classifying material as ore. Using the $8.35 M/year fixed costs (Table 11), the resultant profits and NPVs are calculated using the equation below:

For years 1 -5

$G_{process}$ = (Processing Cost + Depreciation Cost +Minimum Profit + Fixed Cost)/ (Price * Recovery)

$G_{process}$= (15.39 + 0.65 + 5 + 141.40) / (90.36*0.91)

$G_{process}$= 1.97552 Carats/Tonne

$G_{process}$= **197.55 cpht**

Thereafter, the COG re-calculated without the minimum profit. The COG is given by:

For years 6 -10

G_{proces}= (Processing Cost + Depreciation Cost+ Fixed Cost)/ (Price * Recovery)

$G_{process}$= (15.39 + 0.65 + 141.40) / (90.36*0.91)

$G_{process}$= 1.91471 Carats/Tonne

$G_{process}$= **191.47 cpht**

Table 12 gives yearly tonnes and grade schedules resulting from the COG policy that includes fixed costs on the profit calculation for the 10-year period.

Table 12: Orapa A/K1 diamond resource Declining COGs with fixed costs

Year	COG (cpht)	Average Grade of Resource above COG	Q_m (M)	Q_c (M)	Q_r(M)	Profits ($M/Year)
1	197.55	224.81	68.97	13.63	3,064	229,415
2	197.55	224.81	68.97	13.63	3,064	229,415
3	197.55	224.81	68.97	13.63	3,064	229,415
4	197.55	224.81	68.97	13.63	3,064	229,415
5	197.55	224.81	68.97	13.63	3,064	229,415
6	191.47	221.65	78.51	13.63	3,021	194,240
7	191.47	221.65	78.51	13.63	3,021	194,240
8	191.47	221.65	78.51	13.63	3,021	194,240
9	191.47	221.65	78.51	13.63	3,021	194,240
10	191.47	221.65	78.51	13.63	3,021	194,240
Total				**136.30**	**30,426**	**2,118,275**
NPV ($M)						**1,970,617**

The policy of declining COGs calculated with depreciation, minimum profit and the G andA costs further improved the NPV of the A/K1 Mineral Resource by 446% ($360,740 M versus $1,970,617 M) while the overall undiscounted profits increased by 123% (from 951,617 M to $2,118,275 M).

The last step is to calculate the Cut-off that gives the highest NPV possible i.e. optimum COG (G_{opt}). Lane (1988) demonstrated that the COG that maximize NPV have to include fixed costs associated with not receiving the future cash flows quicker due to the COG approach taken now. Since every Mineral Resource has a given NPV associated with it at a given point in time, the opportunity cost is included in the calculation. The opportunity cost provides opportunity to process the low-grade now when higher grades are still available. The calculation of G_{opt} is:

G_{opt}= (Processing Cost + Fixed Cost + Opportunity cost)/ ((Price – Sales Cost) * Recovery)

G_{opt}= (c + f + F_i)/ ((P-s) *y)

Where:

(F_i) = d*NPV_i/C

f= f_a/C where f_a is the annual fixed costs.

d is the discount rate; NPV_i is the NPV of the future cash flows of the years (i) to end of mine life N; and the C is the total processing capacity in Year i.

For the calculation of F_i, an NPV of $1 M was assumed and a 10% discount Rate (Table 8)

F_i = 0.10*1/13.63

= $**0.01/Tonne** of ore processed

f= 141.40/13.63

f= **\$10.37/Tonne** of ore processed

Therefore, G_{opt} is given by:

$G_{opt} = (c + f + F_i)/ ((P-s) *y)$

$= (15.39 + 10.37 + 0.01) / ((90.36 - 0) *0.91)$

= 0.3134 Carats/Tonne

= 31.34 cpht

Table 13 gives yearly tons and grade schedules resulting from the declining G_{opt}. The optimizing strategy gives 77% higher NPV and 11% increase on profits relative to the original constant breakeven grades. Figure 15 below shows a plot A/K1 G_{opt} impact on NPV.

Table 13: Orapa A/K1 Optimum COGs

Year	COG (cpht)	Average Grade of Resource above COG	Q_m (M)	Q_c (M)	Q_r(M)	Profits (\$M/Year)	Discount Factorised	NPV (\$M)
1	31.34	103.10	68.97	13.63	1,405	105,047	0.91	95,497
2	29.34	102.09	68.97	13.63	1,391	105,259	0.83	86,991
3	27.04	101.17	68.97	13.63	1,379	105,452	0.75	79,228
4	24.64	100.08	68.97	13.63	1,364	105,680	0.68	72,181
5	21.54	98.97	68.97	13.63	1,349	105,913	0.62	65,764
6	18.84	97.94	68.97	13.63	1,335	106,129	0.56	59,907
7	15.94	96.87	68.97	13.63	1,320	106,354	0.51	54,576
8	12.93	95.61	68.97	13.63	1,303	106,618	0.47	49,738
9	10.93	95.05	68.97	13.63	1,296	106,736	0.42	45,266
10	7.63	93.96	68.97	13.63	1,281	106,964	0.39	41,239
Total				**136.30**	**13,423**	**1,060,152**		
NPV (\$M)						**650,388**		

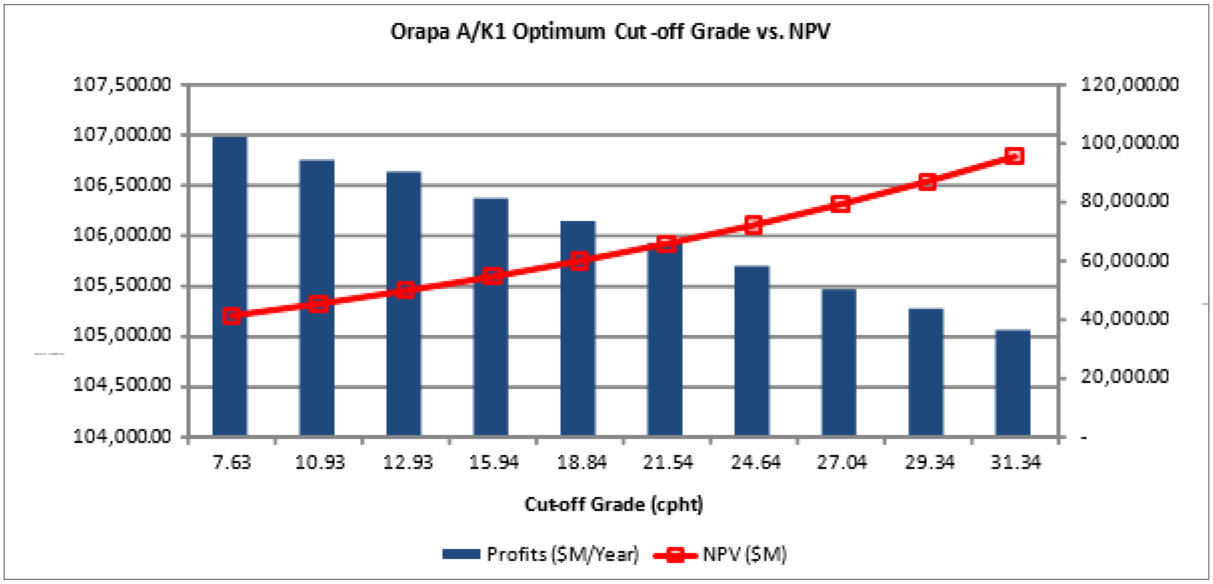


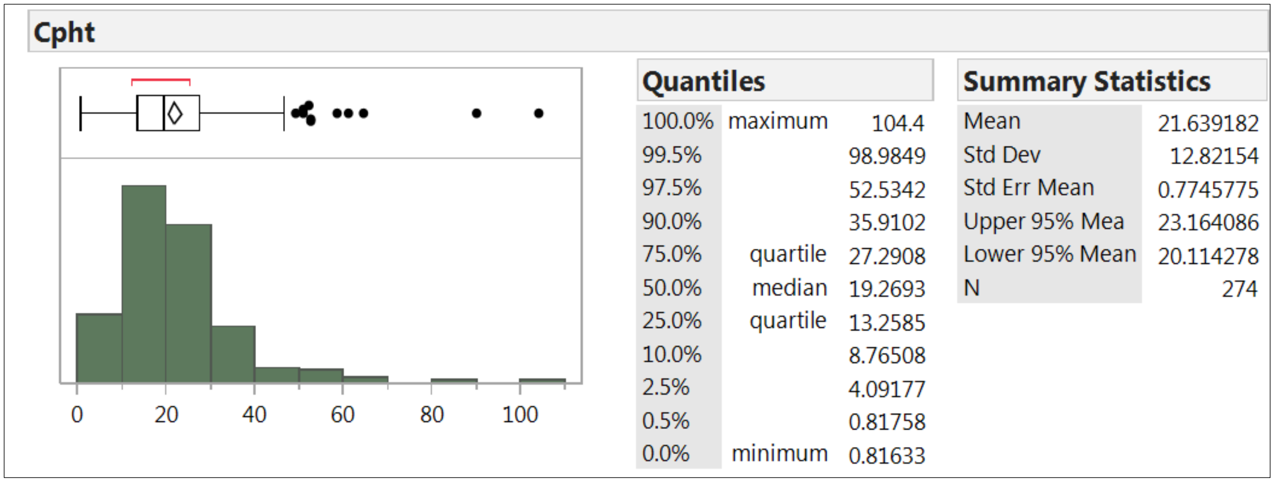
Figure 15: Plot of Orapa A/K1 optimum COGs versus NPV

Relatively higher COGs lead to higher grades per tonne of ore, hence higher NPV realized especially for A/K1 with generally higher grades. The G_{opt} at 31.34 cpht achieves the highest NPV. At this point, the undiscounted cash flows are at the minimum (Figure 15). As the COG increases, the NPV also increases as the undiscounted cash flows decrease.

The COG distinguish economical ore from non-economical ore. Where the ore grade is higher than the COG in use, the ore is processed. In a situation where the ore grade is lower than the G_{opt} in use and for this study lower than 12.94 cpht (Plant 2 – Plant 1 cut-over), it must be sent to the intermediate ore stockpile. The breakeven grade for Orapa Plant 2 is 11.55 cpht. The intermediate stockpile takes ore grade >= 11.55 cpht and < 12.94 cpht for future consideration and opportunistic blending requirements for Plant 2. Otherwise, where the preferred option is treating through both Orapa plants, the minimum ore grade must be 38.27 cpht i.e. the cut-over grade, or else the optimum grade takes over to maximize the NPV.

6.3 Orapa A/K1 low-grade rock type profiles

The rock type BBR has a relatively wider grade distribution as shown in Figure 16. The mean grade is 21.63 cpht. This attracts different handling scenarios i.e. treat now, keep as low-grade for processing at end of LoM or classify as intermediate ore for treating through Plant 2 and for opportunistic blending requirements.



Quantiles

100.0%	maximum	104.4
99.5%		98.9849
97.5%		52.5342
90.0%		35.9102
75.0%	quartile	27.2908
50.0%	median	19.2693
25.0%	quartile	13.2585
10.0%		8.76508
2.5%		4.09177
0.5%		0.81758
0.0%	minimum	0.81633

Summary Statistics

Mean	21.639182
Std Dev	12.82154
Std Err Mean	0.7745775
Upper 95% Mea	23.164086
Lower 95% Mean	20.114278
N	274

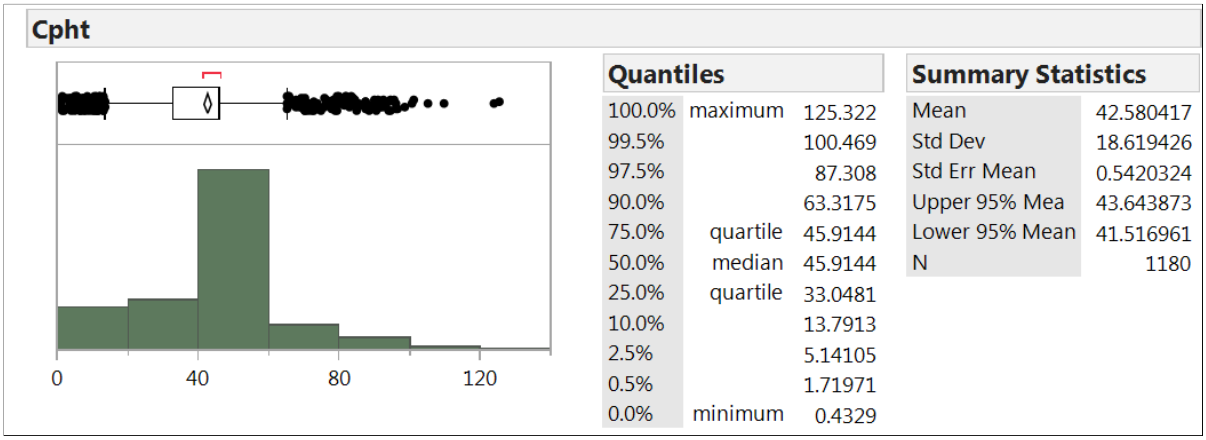
Figure 16: BBR Grade distribution (Block estimates at BCO 1.65 mm)

A comparison with the breakeven cut-off (15.83 cpht) and optimum COG (31.34 cpht) discussed in sub-section 6.2.1 above reveals that the breakeven Cut-off grade is lower than the BBR mean grade while optimum COG higher than the BBR mean grade. For this analysis, the optimum COG_{opt} is lower that the depletion grade for the first 29 years of mining where mining was entirely within ore i.e. no waste mining. The lower grade material was mined out to mixed stockpiles to access high grades without a defined cut-over grade to condemn some of the material to the waste dump or intermediate stockpile for blending purposes. However, there are portions of BBR with relatively lower grade. This is where the decision to stockpile at low-grade stockpile especially where they report in significant quantities and there is an opportunity to do selective mining.

Part of the lower grades (> 0 cpht to < 11.55 cpht) should be condemned to a low-low-grade stockpile by defining a dilution Cut-off. Since the hardness of BBR causes primary and secondary crushing constraints affecting throughput, material with dilution as high as 90% leading to lower grades (e.g. 0-5 cpht) is a candidate for low-grade stockpile category. Therefore, decisions and actions on how to handle BBR need further optimization.

A trade-off study for BBR grade distribution in view of cut-off optimization and blending requirements is required. Some of the high grade BBR currently stockpiled and mixed with relatively lower grades should be treated now. The operation incurs mining costs to move lower grade BBR to the mixed stockpile as well as introducing dilution. The preceding section discussed the opportunity cost for treating the low-grades whilst the higher grades are still available.

A similar grade distribution observed for the rock type DHB that is yet to be mined in significant quantities in future (Figure 17). A significant portion of the grade distribution is on the lower end. Similar trends appear for the mixed breccia SVK_L (Figure 18).



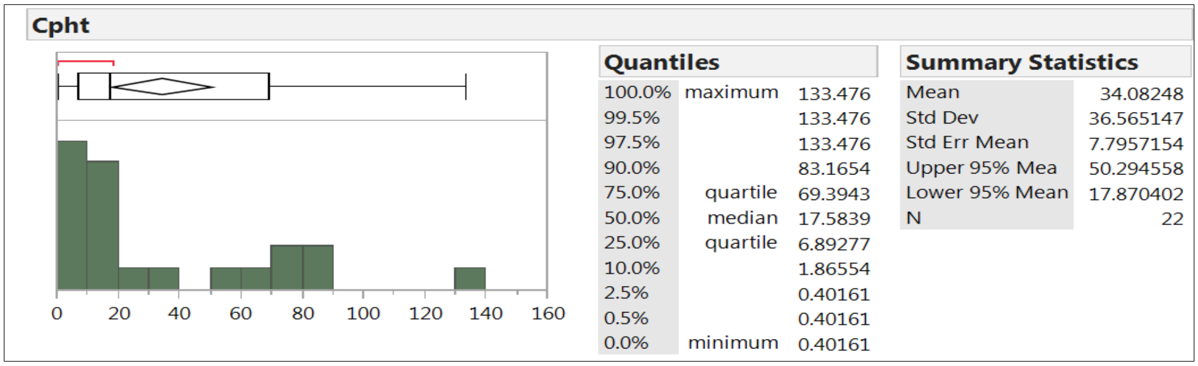
Quantiles

100.0%	maximum	125.322
99.5%		100.469
97.5%		87.308
90.0%		63.3175
75.0%	quartile	45.9144
50.0%	median	45.9144
25.0%	quartile	33.0481
10.0%		13.7913
2.5%		5.14105
0.5%		1.71971
0.0%	minimum	0.4329

Summary Statistics

Mean	42.580417
Std Dev	18.619426
Std Err Mean	0.5420324
Upper 95% Mea	43.643873
Lower 95% Mean	41.516961
N	1180

Figure 17: Orapa rock type DHB Grade distribution (Block estimates)



Quantiles

100.0%	maximum	133.476
99.5%		133.476
97.5%		133.476
90.0%		83.1654
75.0%	quartile	69.3943
50.0%	median	17.5839
25.0%	quartile	6.89277
10.0%		1.86554
2.5%		0.40161
0.5%		0.40161
0.0%	minimum	0.40161

Summary Statistics

Mean	34.08248
Std Dev	36.565147
Std Err Mean	7.7957154
Upper 95% Mea	50.294558
Lower 95% Mean	17.870402
N	22

Figure 18: Orapa rock type SVK_L Grade distribution (Block estimates)

6.4 Summary of this chapter

Following the discussion and presentation of results in Chapter 5, this chapter analyzes and interprets the results. Analysis was completed to determine the breakeven grade, optimum COG as well as the cut-over grades for the Orapa Processing Plants. In view of the different COGs, the discounted cash flows and NPVs for the different scenarios were determined.

7.0 CONCLUSION, DISCUSSION AND FUTURE WORK

In this chapter, the main findings about the fundamental research questions are summarized and general conclusions based on the findings of the studies presented. Furthermore, strengths, opportunities and limitations of this thesis are considered and recommendations for further research presented. The chapter concludes with recommendations for Orapa Mine to adopt the Cut-off policy with additional analysis and trade-offs.

7.1 Summary of the Study

The focus of this study was to assess the impact of applying COG principles to enhance Mineral Resource profitability using Orapa Mine as case study. This research used the objectives of the COG policy to establish the level of extent the economic potential or value of the Orapa Mine A/K1 Mineral Resource is. The background information of this study was achieved through literature review of the application of COG policy across different commodities and drawing learnings for use on Diamond resources that as indicated previously had limited attention and research. Chapter 2 covered the literature review focusing on existing research work and publications on the application of Cut-off policy. The background of the research problem covered the assessment of the impact of the application of COG principles using the Orapa Mine case study. Various implementation strategies were reviewed i.e. impact of firstly adopting the policy, varying the COGs with time and lastly determining the optimum COG. The approach adopted for this study is a multiple/mixed method of data collection and analysis. It has an advantage of being able to negate deficiencies of a single research method approach.

The analysis revealed that the application of COG policy have an impact on the profitability of Orapa A/K1 Mineral Resource. The observations are:

1. ***Sub-problem 1*** was aiming at evaluating the impact of application of COG principles in maximizing the profitability of Diamond resources at Orapa Mine. In the designed and optimized Orapa A/K1 Mine, the G_{opt} has an essential impact on the NPV. This study investigated the relationship between G_{opt}, undiscounted cash flows and NPV achieved. In order to visualize the impact on NPV and undiscounted cash flows, various COG iterations

were completed. The optimum COG returns a higher NPV compared to declining Cut-offs and traditional constant breakeven grades.

2. ***Sub-problem 2*** focused on determination of the A/K1 Resource optimum COG. When the optimization aims at maximizing NPV, one subjects the COG to two opposite forces. As the amount of material mined increases through the operation life, the opportunity cost decreases and the optimum COG drops. Therefore, to achieve true maximization of present value, the optimum COG must change with time and depth. Furthermore, as the Diamond prices increase, the optimum COG must be lowered and vice versa. The declining COGs calculated with depreciation and minimum profit further improved the NPV.

7.2 Conclusions of the study

The study reveals that there is an unexplored opportunity of applying Cut-off Strategy to drive Orapa Mine Resource profitability. Current conceptualization reveals that the optimizing strategy results in 77% higher NPV and 11% increase on profits relative to the original constant breakeven grades. The declining Cut-off grade calculated with depreciation and minimum profit further improves the NPV. It further reveals that the cut-over grades for optimum stockpiling philosophy and processing for the Orapa plants will increase value. The following section summarizes the conclusions into different categories:

<u>Mine profitability</u>

The application of COGs has a positive impact on the Orapa Mine profitability. However, if the objective is:

- Maximizing the undiscounted cash flows, the breakeven grade prevails;
- Maximizing NPV, a change in price of Diamonds would push the optimum COG up or down. In this study, the declining optimum COG improves the NPV realized by 446%; and
- The declining COGs calculated with depreciation and minimum profit further improves the NPV by 263% while the overall undiscounted profits also increase by 52%.

Mining grade/cut-over calculation

Relatively higher COGs lead to higher grades per tonne of ore, hence higher NPV realized. As the COG increases, the NPV also increases while the undiscounted cash flows decrease:

- The highest NPV is at optimum COG of 31.34 cpht;
- The optimizing strategy gives 77% higher NPV and 11% increase on profits relative to the original constant breakeven grades; and
- Relatively higher COGs lead to higher grades per tonne of ore, hence higher NPV realized especially for the A/K1 Mineral Resource with generally higher grades.

For a combined processing scenario, the breakeven $G_{c/over}$ is 38.27 cpht. This is the point at which the scenario increases the recovered grade and maximizes cash flows especially in the initial years of LOMP. The Orapa Combined cut-over grade of 38.27 cpht reveals that:

- Due to its higher recovery efficiencies and throughput capacity, Plant 2 remains the processing facility of choice with the remainder coming from Plant 1:
- Any ore grade greater than 0cpht but < 11.55 cpht should be stockpiled at the low-grade stockpile and treated at end of LoM;
    - ✓ Any material grade <= 0 cpht should be condemned to waste.
- Ore grade >= 11.55 cpht and < 12.94 cpht, should be stockpiled at the intermediate stockpile to allow for future technological advancements;
- Ore grade >= 12.94 cpht should be classified as ore and treated by Orapa Plant 2; and
- Where Plant 1 is the only plant available, ore grade >= 14.22 cpht (breakeven) should be targeted.

Government's strategic objective

A shortened LoM would have an impact on Government of Botswana's strategic objectives of providing sustainable cash flow and employment to citizens. Despite the higher NPV, the LoM is shortened by depleting at a grade higher than the average grade of the A/K1 Resource i.e. 197.55 cpht vs. 91.18 cpht average grade.

7.3 Recommendations for the application of COG policy

There are a number of gaps concerning the adoption and practice of the Cut-off theory that follow from the study findings and this would benefit further research, inclusive of realistic evaluation to extend and further test the Cut-off theory whose basis in Diamond resources has been confirmed:

- The application of Cut-off principles in Diamond Resource exploitation remains under researched, it would be helpful to further explore the application, practicality and its effectiveness for enhancing Diamond Resource's profitability;
- More methodological work is required in determining how to robustly assess and carry out a full cost-benefit analysis for Diamond Resource given generally wider profit margins through application of Cut-off principles for grade and Diamond revenue ($/Carat);
- Quantitatively capture the opportunity cost associated with determination of the optimum low-grade treated whilst the high grade is still available. Further research required to assess possibilities of exploiting the marginalized Diamond deposits seldom considered in the Debswana Strategic Business Plan given their size and low-grade profile; and
- Complete the detailed Orapa processing plant optimisation studies to determine the economic criterion to treat ore at both plants.

A final important question identified by this study is:

> "*What is the economic impact of treating ore at the two Orapa Mine plants with different configurations and efficiencies*?"

7.4 Recommendations for further research

Further research recommendations to:

- Firstly, investigate the possibilities of reviewing the business approach (cost benefit analysis) through definition and incorporation of optimum COG policy. Chapter 6 provided the assessment of the NPV impact on A/K1 Mineral Resource through application of the various COGs i.e. NPV at constant breakeven grades to NPV returned through application of declining optimum COGs;
- Secondly, the Diamond grade and revenue optimum ratio requires further research. As the COG seemed to be the most promising candidate for mine planning, its relationship with

Diamond grade is still paramount to the decision process as the prices are driven by Diamond assortment and associated revenue;

- Conduct detailed evaluation of the RPEEE framework and its effectiveness; and
- Investigation of the deployment philosophy of the two Orapa plants i.e. when do you treat ore at both plants. Define the decision criteria in view of all the organizational, economic and sustainability aspects.

7.5 Limitations of the study

Note the following significant limitations to this study:

- Non-availability of the historical documents to confirm some of the assumptions at mining inception i.e. the feasibility study report;
- Misalignment to the strategic objective of Debswana providing employment opportunities for the citizens. However, this is in line with government policies for Debswana to run the operations for a prolonged period of time i.e. marginal profits and long LoM; and
- Inadequate investigation of the grade-revenue assessment. Very often, the volume and grade are key drivers for business case and there is less attention on the price i.e. dollar per carat. A low-grade, low volume resource could turn out profitable if the revenue is promising.

7.6 Summary of this chapter

The objectives of this research have been achieved and the findings of the analysis discussed. It has been concluded that that the application of COG policy will enhance the Mineral Resource profitability for Orapa Mine and that it should be adopted with further research study, especially adoption of the declining COG and trade-off using grade-revenue equivalence ratio. The analysis has also revealed that the adoption of COG policies in Diamond resources remains complex and deserves further research to optimize its deployment.

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