ECONOMIC EVALUATION OF AWONSU OPEN PIT MINE: A CASE STUDY OF NEWMONT GHANA GOLD LIMITED

By

NELSON NSIAH-AFRIYIE

B.Sc. (HONS) MINING ENGINEERING

A thesis submitted to the Department of Finance, Kwame Nkrumah University of Science and Technology in partial fulfillment of the requirement for the degree of

MASTER OF BUSINESS ADMINISTRATION (FINANCE)

School of Business

College of Humanities and Social Sciences

September, 2015

DECLARATION PAGE

I hereby declare that this submission is my own work towards the Masters of Business Administration degree and that, to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

Nelson Nsiah-Afriyie (PG9614413)	…………………… Signature	……………………. Date

Certified by:

Prof. J. M. Frimpong Supervisor	……………………… Signature	……………………. Date

Certified by:

Dr. K. O. Appiah Head of Department	…………………..… Signature	…………………..… Date

ABSTRACT

The Awonsu mining open pit deposit is one of several projects being evaluated by Newmont Mining Corporation. The phase one of the deposit has been mined out with some portion being backfilled with waste. Management of Newmont Ghana Gold Limited would like to know if there is any potential layback of the existing pit under the current economic conditions. In other to be able to determine the value or economic feasibility of the project, a pit optimisation process has to be performed on the geologic model by considering the gold price, mining cost, processing cost, selling cost, the geologic model and the geotechnical slopes. In line with this, this research seeks to evaluate the economic profitability of the Awonsu deposit through the pit optimisation process by the use of the Gemcom Whittle 4x ,determine a suitable pit design for the deposit using the Mintech Minesight design tools and use Discounted cash Flow method to determine the viability of the deposit. Results from this research show that the Awonsu phase two design is financially profitable at the evaluation price of $1200. The pit designed out of the selected pit shell produces an ore tonnes of 26 million at an average grade of 1.6g/t and recovered ounces of 1.2 million. The free cashflow of the project is $171 million and when discounted at 8% for six years, results in a Net Present value (NPV) of $60 million. The Internal Rate of Return (IRR) of the project is 14.6% and total cost per recovered ounce is $1053. The Return on Capital Employed (ROCE) is 14% which means for every $1 invested in the project will yield a return of 14 cents. The project breaks even at a gold price of $1129/Oz.

DEDICATION

This work is dedicated to my lovely wife Grace.

ACKNOWLEDGEMENT

I thank God for his guardians, strength and travelling mercies throughout the course of this study. Without Him I would have achieved nothing.

I am very grateful to my Supervisor, Prof. J. M. Frimpong for his patience and efficiency in supervising the thesis. His support and advice has made this work a success.

My sincere gratitude goes to the Management and Staff of Newmont Ghana Gold Limited for providing the necessary data for my work. Special thanks to Mr Justice Asare Fenteng (Technical Service Manager) for his guidance and Mr Matthew Hass (Regional Strategic Planning Manager) for his support and encouragement.

Special thanks also go to Mrs Afia Fima Baah Opoku of Newmont Ghana Limited for her support.

Finally, to all the Lecturers at the University of Mines and Technology (UMaT), Tarkwa, who lectured and guided me through my studies, I say thank you.

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

Table Page

CHAPTER ONE

GENERAL INTRODUCTION

1.0 Background information

The mining business is an industry that deals with the production of minerals which give huge financial and social advantages to the development and sustainability of a country. Minerals are the essential assets of most developed and industrialized nations such as the South Africa, Australia, Canada and U.S.A. It is also a significant contributor to the progress of most developing nations that are favored to have them. Ghana is no exemption of such nations. Ghana has a number of mining firms including Newmont Ghana Gold Limited, Keegan Resources, Damang Goldfields, Adamus Resources, Ghana Bauxite Company limited, Perseus Mine, Ghana Manganese Company limited and many others. A large portion of these mining organizations fundamentally extract gold. Since mineral resources are non-renewable, mining organizations continue to explore to add new deposits to their reserves.

Immense capital investment is required to have the capacity to execute any mining projects. New mineral deposits or laybacks of exiting projects need to be carefully evaluated to uncover any possible risk before committing resource into it.

As indicated by Whittle (2004) so as to add to a business methodology that makes positive undertaking esteem and meets risk hurdles over the short to longer term, a streamlining methodology must be assumed. Deposits for mining activities are for the most part assessed through pit optimisation. Pit advancement is clarified as the procedure utilized as a part of determining an optimal pit shell whiles considering every single conceivable uncertainty and requirements (Whittle, 1990).

Once an optimisation process is carried out and the ultimate pit limit is defined then engineering and safety parameters can be applied to determine a suitable pit design. A suitable pit design is a design that ensures that the application of the engineering and safety parameters does not immensely impact on the project value or the Net Present Value (NPV) of the project. Annual scheduling targets can then be determined after the pit design has been finalised. A mine project that is taken through this process will be executed successfully without fear of risk or uncertainties.

After the pit optimisation processes, an optimal pit shell is chosen. A detailed pit is designed out of the selected pit shell. The design incorporates safety berms and ramps (roads) for access. The design is done to follow the optimal pit shell so that the Net Present Value of the design pit will be almost the same as the optimal pit shell selected.

1.1 Problem Statement

One tenet of investment is that if the risks of an investment are high, then the investor should be compensated for assuming the risks by a high potential return from the investment. Much exertion is added to guarantee that in building up a venture, a precise assessment of the task quality is resolved under an expected scope of conditions. The unpredictability of mining ventures is significant to the point that an assessment of the same essential undertaking can vary altogether taking into account the degree to which optimisation has been performed in assessing the project (Whittle, 2004). The Awonsu phase two pit is among the projects currently being examined by Newmont Ghana Gold Limited. The phase one of the deposit has been mined out with some portion being backfilled with waste. Management of Newmont Ghana Gold Limited would like to know if there is any potential layback of the existing pit under the current economic conditions. To determine the financial profitability of the Awonsu phase two deposit, pit optimisation needs to be run on the exploration gold model. In running the pit optimisation, factors such as gold price, mining cost, processing cost, selling cost, and ultimate pit slopes need to be determined. This study seeks to evaluate the financial profitability of the Awonsu phase two deposit using Whittle 4x for the optimisation work and Minesight 3D software for the pit design. The output data is extracted into Microsoft Excel to generate the cashflow and Net Present Value.

1.2 Objectives of the Research

The principal objective of the study is to determine the economic viability of the Awonsu phase two layback at a gold price of $1200 per ounce for management/investor decision. The specific objectives of the research are to:

1. determine the ultimate pit shell of the Awonsu phase two layback at an evaluating metal price of $1200/Oz.
2. design a suitable pit for the phase two layback of the Awonsu deposit based on the selected ultimate pit shell.
3. determine the NPV of the pit design and its sensitivity to changes in gold price, mining cost and processing and general and administrative (G&A) cost.

1.3 Research Questions

The research questions are as follows:

1. what is the optinal pit shell for Awonsu phase two layback at an evaluation metal price of $1200/Oz?
2. what pit design is appropriate for the selected optimal pit shell?
3. what is the net present value of the pit design and how sensitive is it to changes in gold price, mining cost and processing and general and administrative (G&A) cost?

1.4 Research Significance

The study can be important in varied ways to management of Newmont Ahafo Mine, the extracting industry and the scholarly world. The outcomes of this research will determining any potential economic layback of the Awonsu deposit and help management of the mine in deciding on committing resources into mining the phase two layback or not.

The strides and methodology in deciding and investigating the mineral deposit for investor decision can serve as a source of perspective to other mine planning and cost engineers in the mining business.

1.5 Scope of the Research

This study is limited to the Awonsu phase two layback at Newmont Ghana Gold Limited.

1.6 Research Limitations

The study is limited to the current exploration block model, metal price mining and processing cost and royalties as at April 2015. It is also limited to the use of Whittle optimisation software and Minesight pit designing tool.

1.7 Organisation of Research

This research work is organised in five chapters. Chapter one is the introduction and has the statement of the problem, objectives and research questions, scope and limitations of the research. Chapter two presents the relevant literature review of evaluating a mineral project and definition of some technical terms. Chapter three gives the information about Newmont Ghana Gold Limited which includes geological and geographical settings on the mine and also the research methodology. Chapter four presents the results from Whittle optimisation process and give interpretation of the findings while Chapter 5 has the conclusions and recommendations of the work.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This section shows an expansive survey of important writing concerning the subject understudy. It considers a brief review of an open pit mine, a definitive pit confine, the procedures included in pit optimization and the open pit design strategy and crucial financial parameters to be considered in the assessment of pit design.

2.1 The Open Pit Mine

Open pit mining is basically the extraction of material from the Earth's surface downwards with the made gap opened to the surface. Be that as it may, Dagdelene (2001) clarifies that an open pit mine is the customary cone-molded removal, despite the fact that the shape can be in different structures in view of the shape and size of the ore body, made at the surface of the ground with the point of mining the metal. Going before the extraction of metal, tremendous measures of waste rock are generally stripped to reveal the metal. The aim of any open pit mine design is to provide an optimal excavation configuration in the context of safety, ore recovery, and financial return. Investors and operators expect the slope design to establish walls that will be stable for the life of the open pit, which may extend beyond closure. At the very least, any instability must be manageable. This applies at every scale of the walls, from the individual benches to the overall slopes.

It is essential that a degree of stability is ensured for the slopes in large open pit mines to minimise the risks related to the safety of operating personnel and equipment, and economic risks to the reserves. At the same time, to address the economic needs of the owners, ore recovery must be maximised and waste stripping kept to a minimum throughout the mine life. The resulting compromise is typically a balance between formulating designs that can be safely and practicably implemented in the operating environment and establishing slope angles that are as steep as possible.

The crucial operational strategies included in open pit mining start with boring and impacting the in-situ material, the following step is the burrowing and stacking of the broken material by the utilization of an excavator. The broken materials are stacked into a dump truck and transported to their chose destinations. The metal is sent to the crusher to be pulverized into littler sizes and thusly processed to uproot the gold whiles the waste is dumped at the waste dump. The procedure is cyclic in nature as demonstrated in Figure 2.1.

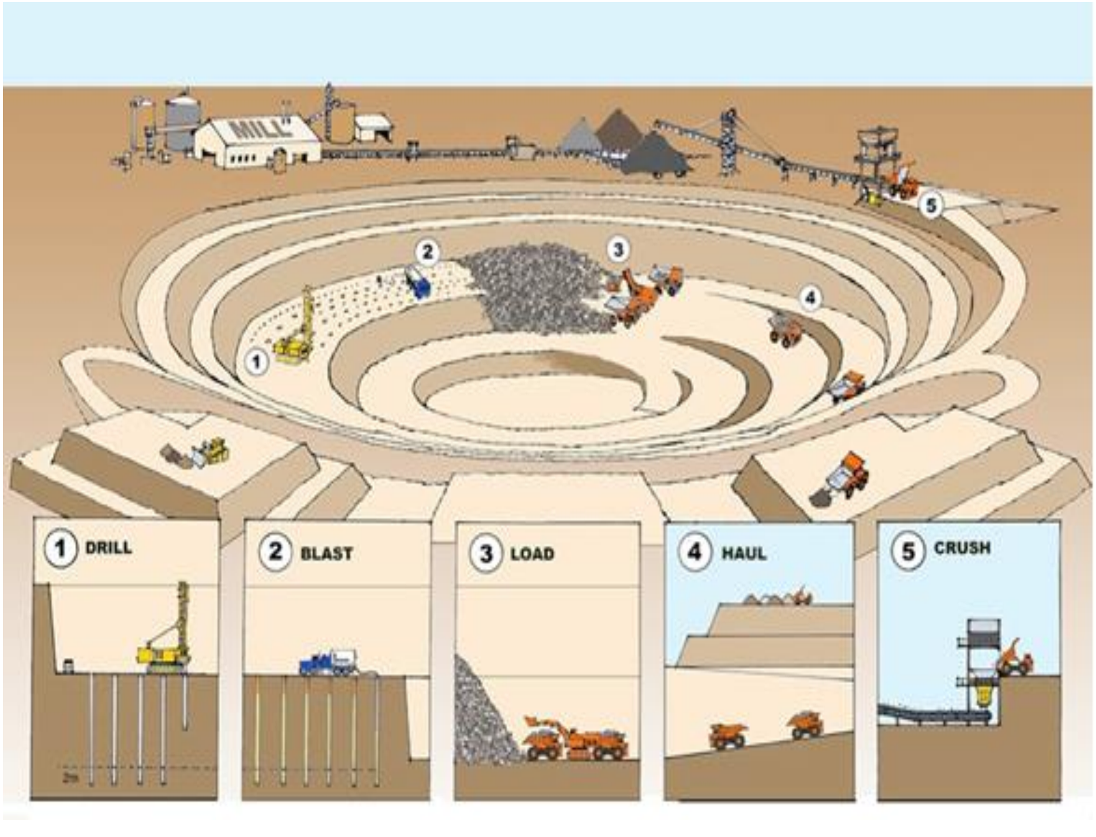

Figure 2.1: An Illustration of Typical Open Pit Mining Activities

(Source: Met-Chem, 2014)

2.2 Open Pit Optimisation

For any given deposit, there are several safe pit outlines that can be used to mine it. Among the several safe outlines, there exists an outline that is referred to as the optimal pit. There are probably as many ways of designing an optimal pit as there are engineers doing the design work. The methods differ by the size of the deposit, the quantity and quality of the data, the availability of computer assistance, and the assumptions of the engineer. As the first step for long or short-range planning, the limits of the open pit must be set. The limits define the amount of ore mineable, the metal content, and the associated amount of waste to be moved during the life of the operation. The size, geometry and location of the ultimate pit are important in planning tailings areas, waste dumps, access roads, concentrating plants and all other surface facilities. Knowledge gained from designing the ultimate pit also aids in guiding future exploration work.

The optimal pit for a given orebody is usually defined to be that contour which is the result of extracting the volume of material which provides the total maximum profit while satisfying the operational requirement of safe wall slopes. The ultimate pit limit gives the shape of the pit at the end of mine life. The premise is that every cubic meter of rock in a geological resource has an intrinsic value. If the block is of a sufficiently high grade, then the value is the price obtainable for the metal/mineral which can be extracted from it, less the costs of mining and processing it. If the rock is waste, then the value is negative and numerically equal to the cost of mining it (Howard, 2006).

Computer programmes for open pit optimisation have become popular in recent years as computing costs have decreased considerably and software performance has improved. This growth of computer usage has allowed engineers to handle greater amounts of data and to examine more pit alternatives than with manual methods. The computer has proved to be an excellent tool for storing, retrieving, processing, and displaying data for mining projects. The most popular of these programmes are based on Lerchs-Grossmann algorithms almost exclusively. The pit optimising programmes have greatly improved mine design, making the task much quicker and more reliable. Mining engineers can use pit optimisers to examine the economics of the resource, looking at varying costs, product prices, recoveries and pit slopes and at different mining, processing and selling rates (Tucker, 2000).

The concept of optimal pit outline may be illustrated by the following simple hypothetical example. Let Fig. 2.2 represent an orebody. Assume that it is of infinite length, so that the end effects can be ignored. In this circumstance, consider a section through this orebody. From the quantities in Fig. 2.2, the tonnages for the eight possible pit outlines can be calculated. The results are shown in Table 2.1.

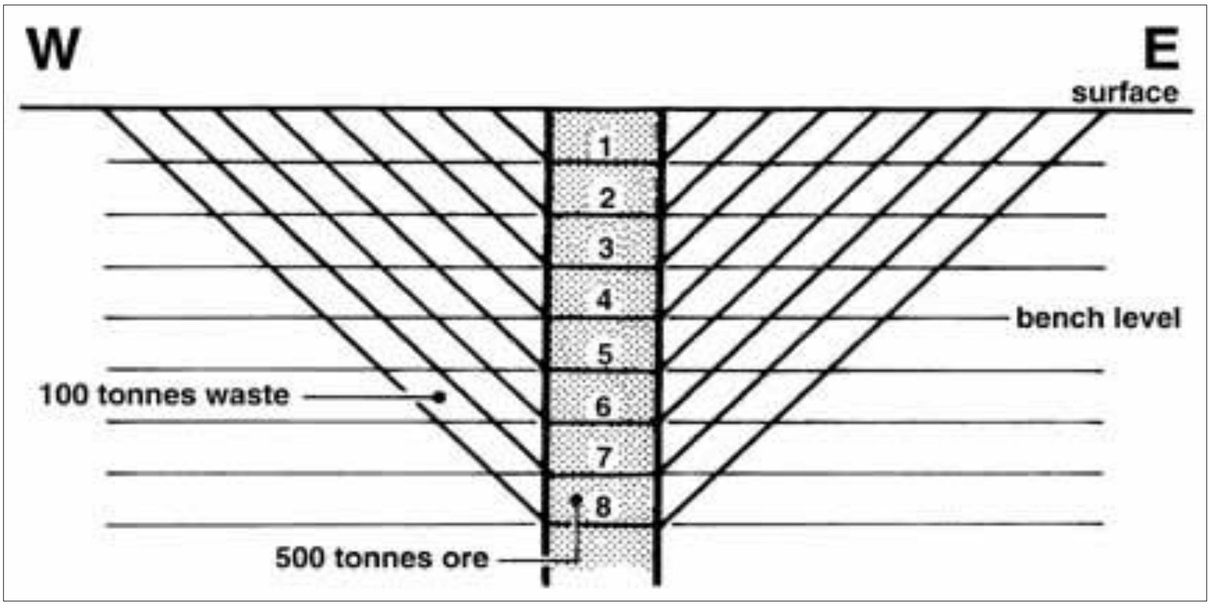

Fig. 2.2 Illustration of Open Outlines of Pits (Source: Whittle, 1990)

Pit No.	Ore (t)	Waste (t)	Total (t)
1	500	100	600
2	1,000	400	1,400
3	1,500	900	2,400
4	2,000	1,600	3,600
5	2,500	2,500	5,000
6	3,000	3,600	6,600
7	3,500	4,900	8,400
8	4,000	6,400	10,400

Table 2.1 Tonnages for Possible Pit Outlines

Assuming that the ore is worth $2.00 per tonne after all mining and processing costs have been paid, and that waste costs $1.00 per tonne to remove, then the values shown in Table 2.2 are obtained for the possible pit outlines.

Pit	1	2	3	4	5	6	7	8
Value (US$)	900	1,600	2,100	2,400	2,500	2,400	2,100	1,600

Table 2.2 Pit Values for Ore at $2.00/t and Waste at $1.00/t

When plotted against pit tonnages, the results are shown in Fig. 3.3.Pit 5 is assumed to give the outline with the highest value. There are other things that can be learned from the curve in Fig. 2.3 (Whittle, 1990).

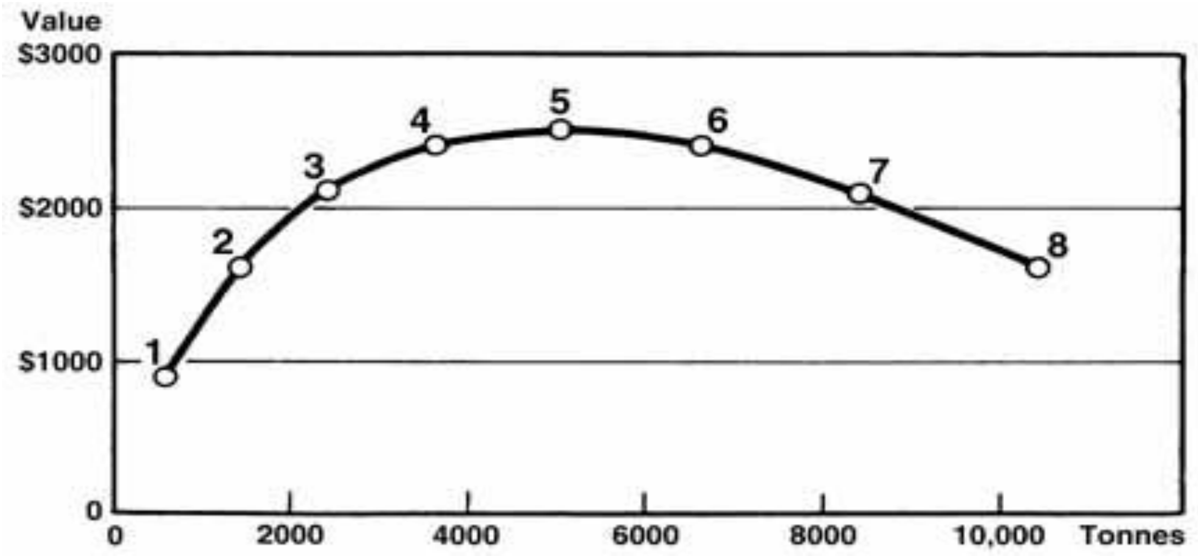

Fig. 2.3 Graph of Economic Values vs. Tonnages (Source: Whittle, 1990)

Firstly, outlines four and six have values which are close to that of outline five. For any continuous orebody, as the pit is expanded towards optimality, the last shell which is added will have only a small positive value. If it had a large one, there would probably be another positive shell to follow. This means that in the vast majority of real orebodies, the curve of value against tonnage is smooth and surprisingly flat at the peak. It is common to find that a 10% range of pit tonnage covers only a 1% range of pit value. The trick is to find the peak, and good optimisers guarantee to do this (Mohadini-Yahaya, 2006).

Secondly, consider Fig. 2.4, if one is working without an optimiser and doing a detailed design for a realistically complex orebody, then he/she might be working away from the peak at 'A', where changes in pit tonnage can have a significant effect on the value of the pit. In fact, generations of mining engineers have learned that a series of small adjustments, involving a great deal of work, can significantly affect the profitability of the mine. Contrasting this with starting from an optimised outline at 'B'. From this point, providing that ore and waste are kept in step with each other, it is difficult to go wrong.

Certainly there is no need to experiment with small adjustments. Since, with modern software, one can plot this graph for real orebodies, it can actually be found out how much freedom of movement is available before the detailed design is started. In other words, designs based on optimised outlines are much easier to do.

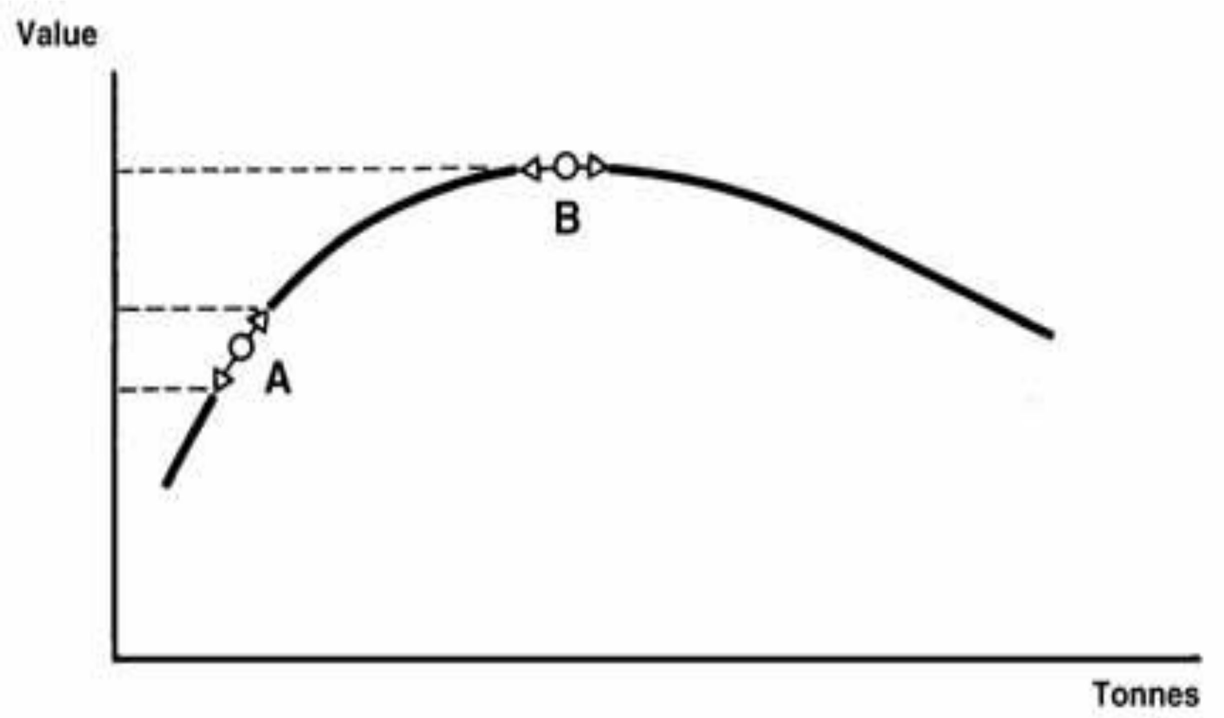

Fig. 2.4 Graph of Change of Pit Value with Deviation from the Optimal Outline (Source: Whittle, 1990)

2.2.1 Factors affecting the dimensions of the optimal pit

The choice in respect to what ought to be mined inside the optimal pit limit is a factor of time. It is hence imperative that all optimization software consider the information of to what extent one needs to strip the waste and when a given ore block will be uncovered for mining (Dagdelen, 2001). It is obliged that in examining shell with the highest Net Present Value, the time estimation of cash is considered to define the blocks that ought to be mined and those that should be left in the ground. In general, the size of the ultimate pit limit depends largely on the metal price, mining cost and processing cost. The higher the metal price, the bigger the pit limit and vice versa. Again, the higher the mining and processing cost, the smaller the ultimate pit limit and vice versa. The overall pit slopes also have an influence on the pit limit. The steeper the slopes the deeper the optimal pit limit and vice versa.

2.2.2 Economic Parameters and Open Pit Optimisation Model

In performing the optimisation process, relevant economic parameters are used as inputs for the calculation of the block value. The optimisation model uses these parameters to analyse and determine the ultimate pit limit.

2.2.2.1 Economic Elements

The economic elements impacting on an optimal pit are mostly cost estimates needed for determining the extraction sequence and can be broken down into mining cost per tonne, processing cost per tonne, rehabilitation cost per tonne, selling cost per unit of product produced, price per unit of commodity produced, time costs and royalties (Askari-Nasab,2010).

Mining cost per tonne

Mining cost per tonne is described as the amount of money spent to mine a tonne of material. This cost is the sum of the cost for several individual operational activities such as the following (Askari-Nasab, 2010):

- assaying and sampling
- clearing the site and topsoil removal
- pit dewatering
- drilling and blasting

- ground support for the pit walls to avoid failure
- loading and hauling
- mine services
- mobilization/demobilization
- stand by and miscellaneous machine hire maintenance.

Due to different equipment that may be used in mining, it is not uncommon for the cost per tonne of mining ore to be greater than the cost per tonne of stripping the waste. For Whittle Four-X optimisation purposes, this extra cost is added to the processing cost.

Processing cost per tonne

This is the cost incurred to process a tonne of ore. Processing costs include crushing and grinding, mill services, ore handling, stockpile management and treatment plant regents. These costs can be estimated fairly accurately with most mineral products due to the extensive experience within the mineral industry.

Rehabilitation cost per tonne

Rehabilitation costs are the costs associated with the rehabilitation of waste dumps. The rehabilitation is done to ensure that the impacted environment is reclaimed back to its original state.

Selling cost per unit of product produced

Selling costs include bullion transportation, insurance, marketing, refining, smelting, supervision and transportation.

Price per unit of commodity produced

The revenue or income from the sale of minerals is a direct function of the market price minus certain costs and treatment fees. The estimation of future market prices for minerals is very challenging and frustrating task as it depends on complex factors. Nevertheless, market price is one of the most critical parameters in mine optimisation and design therefore a very good and well informed estimate must be done for a life of mine optimisation or design.

Time costs and Royalties

Time costs include accommodation, supplies and services for employees, administration salaries, communications, insurance, legal services, safety and training. Meanwhile the royalty is a percentage of the commodity price paid by a holder of a mining lease.

2.2.2.2 The Optimisation Model

Generally, all optimisation processes are done with the sole aim maximizing value. The following equations form the basis for most mine optimisation processes.

Equations (2.1) to (2.3) are used in open pit optimisation model using linear programming (Suglo, 2012):

The estimated cash flow is calculated as

$E\{CF_t\} = Rev_t - Cost_t$ ……………………………………………………………..Eqn 2.1

Where

$\mathrm{Rev_t}$= Revenue for period t

$\mathrm{Cost_t} =$ Cost for period t

$\mathrm{E\{CF_t\}} =$ Expected Cashflow for period t but

REV_{ijk} = g*To*P*Rec……………………………………………………………Eqn. 2.2

Where: Rev_{ijk} = Revenue for all blocks, ,g= ore grade; T =tonnage of ore; P= price;

Rec. = mill recovery

$$Cost_{ijk} = \sum_{UC_{W} \times TWB_{ijk}}^{UC_{O} \times TOB_{ijk}}$$ ………………………………………………………… Eqn. 2.2

Where: UC_o = unit cost of ore

UC_w = unit cost of waste.

TOB_{ijk} =tonnage of ore blocks

TWB_{ijk}=tonnage of waste blocks.

CO = Operating Cost

CI = Operating Cost

$UC_o=OC_{mine}+ OC_{mill}+OC_{admin}+ CI_{mine}+ CI_{mill}+CI_{infrl}$

$UC_w=OC_{mine}+ OC_{admin}+ CI_{mine}+ CI_{infrl}\pm \Delta OC$

2.3 Open Pit Design

Pit design is a dynamic and iterative process. The dynamic nature of pit design, results from the variability of the main groups of inputs that go into the pit design process. In an active mine, there is a continuous enhancement of the geological and geotechnical database as exploration and mining take place. The economic parameters, too, change continuously, so that the design engineer has to modify the technical parameters for the profit maximisation objectives to be accomplished. Thus, the emergence of new values for the vital pit design inputs continuously refine the design output, and send the engineer back and forth as the design is fine-tuned (Macrae, 2011).

There are a number of elements which are important in designing an open pit mine.

With the establishment of the basic design requirements, the geometric configuration of the pit design can be developed in one of the following ways depending on the size of the orebody, the degree of accuracy desired, time limits and availability of appropriate computer system and software (Macrae, 2011):

- Manual;
- Combined manual-computer;
- With a computer.

The precise method used in creating a detailed pit design from a particular pit outline depends upon the tools which are available. It may be done entirely by hand, or with varying degrees of computer assistance. Whatever the method, the aim is the same. It is to produce a detailed design which deviates as little as possible from the outline provided by optimisation.

2.3.1 Design Configuration

Certain items must be considered when designing a pit to make it feasible and safe to execute. These technical elements include the bench height, overall pit slope, bench with, total pit depth berm width among others. Figure 2.5 below shows a sectional view of an open pit.

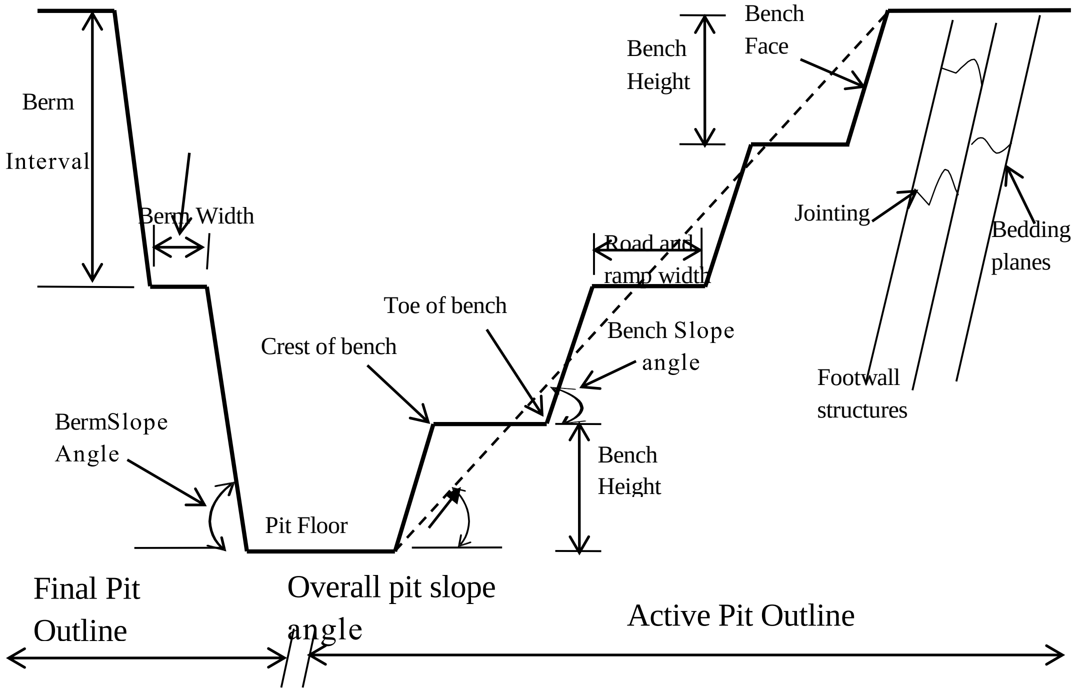

Figure 2.5: A Sectional View of an Open Pit Design

(Source: Fourie and Gerald, 1992)

2.3.1.1Overall pit slope

It the angle a straight line drawn from the crest of the upper bench to the bottom of the pit makes with the horizontal. It has a major influence on the depth of the pit. The steeper the overall angle, the deeper the pit and the flatter the overall angle, the shallower the pit. An optimal overall pit angle should be determined in order to extract the maximum ore without compromising safety.

2.3.1.2Bench height

It is the vertical distance between successive horizontal levels of the pit as shown in figure 2.5. Bench height are normally chosen base on the geological characteristics of the ore body and the size and type of mining equipment being used. Bench height selection can affect ore and waste selectivity. Higher bench heights result in high ore dilution and lower bench heights give low ore dilution.

2.3.1.3Bench face slope

Bench face slope is the angle of the face a bench height. It also depends on the physical characteristics of the ore body for safety purposes. Achieving the required face angle sometimes become very challenging as blasting holes around the pit walls need to be drilled at that angle.

2.3.1.4Berm width

Berm width is the distance between a toe and crest of a single bench. It is denoted on benches where the toe is different from the crest. In Ghana, berm with in the saprolite zone is always 10m. Berm width in the primary zones is defined by the geotechnical conditions of the rock for safety purposes.

2.3.1.5Pit ramp

It is the road to provide access to the pit for mining. Pit ramps are normally dual carriage for easy entrance and exit. The width of the pit ramp should be equal to 3.5 times the width of the largest mobile equipment in the mine. The gradient of pit ramps is general designed to be between 8% and 12%. Flatter ramp gradients result in a shallower and smaller pit whilst a steeper ramp gradients result in deep pits.

2.3.1.6Stripping ratio

The stripping ratio (SR) is the ratio of ore to waste. it represents the amount of waste needed to mine to get a unit tonne of ore

Break – even stripping ratio (BESR) is the ratio of waste tonnage to ore tonnage where the cost of the waste removal and mining of ore exactly equals the value of the mineral. This is an economic ratio and will change depending on grades, costs and revenue.

The BESR can be calculated using equations 2.2 and 2.3:

$$BESR = \frac{A-B}{C} \quad \text{..........} \mathbf{Eqn.\ 2.2}$$

Where: A=Revenue per tonne of ore;

B= Production cost per tonne of ore (including all cost excluding stripping); C =Stripping cost per tonne of waste.

In certain cases, a minimum profit requirement is included:

$$BESR = \frac{[A-(B+D)]}{C} \quad \text{..........} \mathbf{Eqn.\ 2.3}$$

Where

D = minimum profit per tonne of ore.

2.4 Mining Projects Investment Evaluation

There are several criteria for evaluating the economic attractiveness of an investment proposal. Of them, the most widely used in the economic evaluation of mining projects are the Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PBP). Simple rate of return is also used in some cases.

2.4.1 Mine Cash Flow Model

A pictorial model of the annual cash flow into and out of a mining project is shown in Figure 2.6. Before and often during the operation of the mine, capital costs are spent to construct infrastructure such as roads and power lines, the mine itself, the processing plant (mill), and ancillary facilities such as tailings ponds or water management systems. The source of the capital is some combination of equity and a loan. The equity is from the owner of the mining project, who may have the cash available or could issue shares to obtain cash, while the loan may come directly from a commercial bank or the company may issue bonds to obtain cash. During operation, revenue for the mineral product(s) is received, operating costs are incurred, and the principal and interest payments on any loans are paid. Taxes are another cost that must also be paid during mine operation.

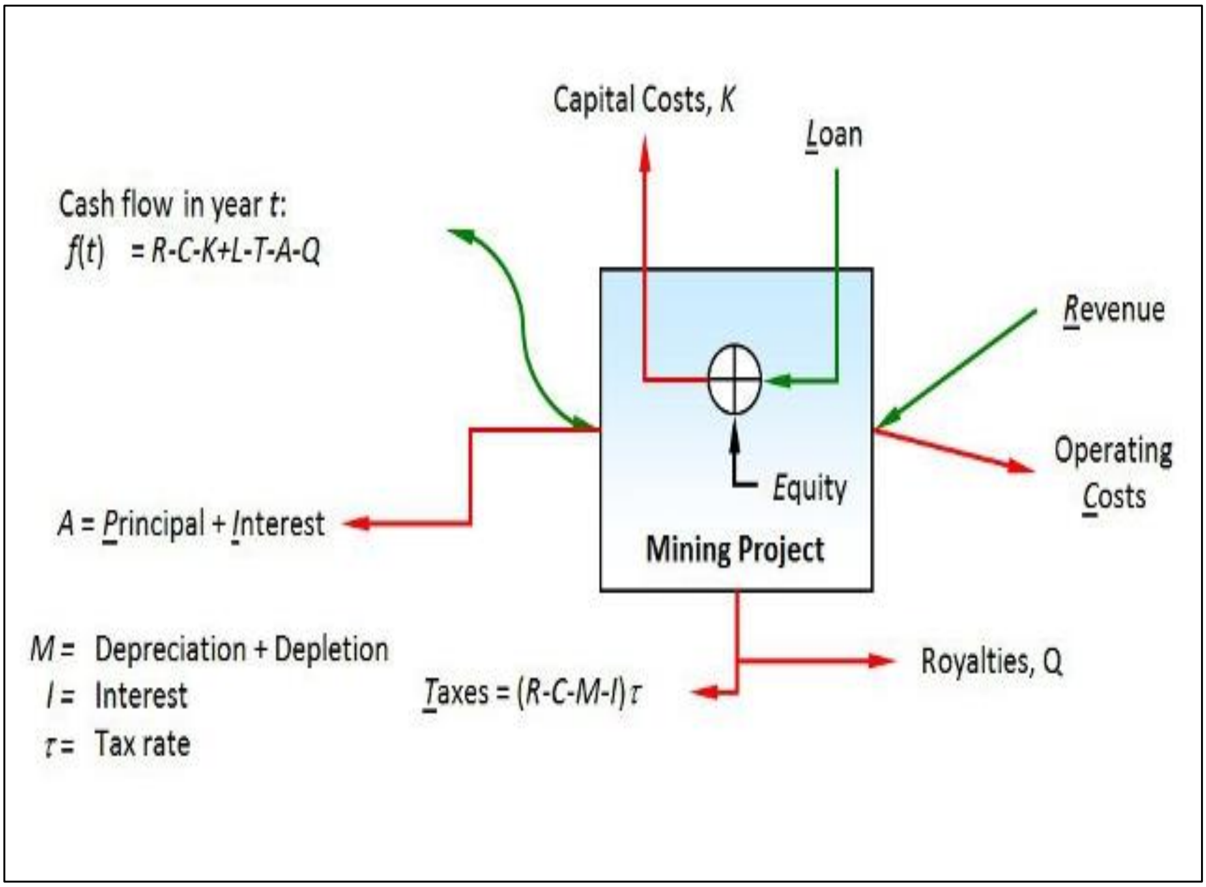

Figure 2.6: Input-output model of mining project cash flow during any

(Source: Edumine, 2015)

2.4.2 Valuation of a Cash Flow

The cash flow valuation is based on the time history of revenue generated and the cost associated with the project. Figure 2.7 represents 20 years, three years of construction and 17 years of operation. Values of cash flow at the end of each year are shown by the vertical arrows) and in Table 2.3(below).

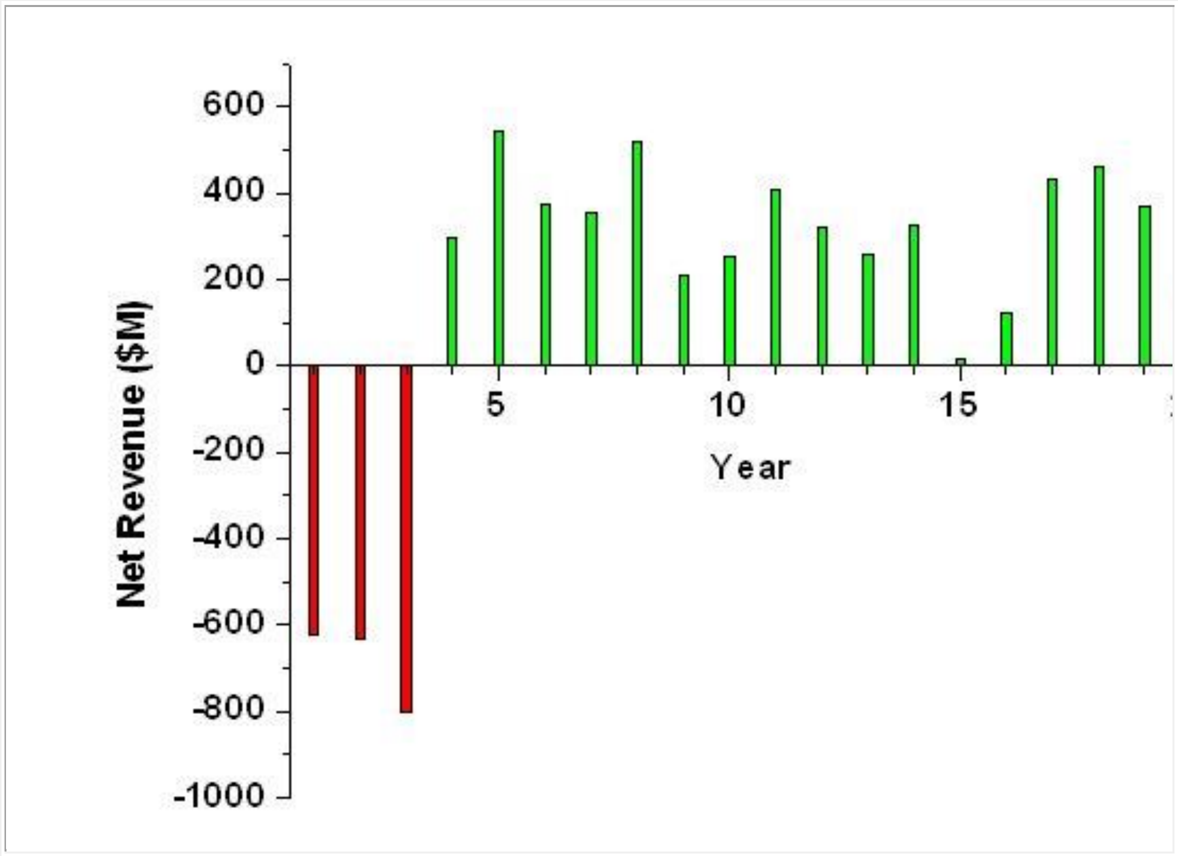

Figure 2.7: Annual net revenue cash flows of the proposed Cerro Casale project. The cash flows are assumed to occur at year end.

(Source: Bema Gold Corporation, 2006)

Year	Cash Flow ($M)	Cumulative CF	Phase
1	-622.86	-622.86	construction
2	-632.91	-1255.77	
3	-802.27	-2058.05	
4	298.59	-1759.46	operation
5	541.56	-1217.90	
6	374.06	-843.84	
7	355.29	-488.55	
8	518.41	29.86	
9	207.03	236.89	
10	251.14	488.03	
11	406.02	894.06	
12	321.90	1215.96	
13	256.60	1472.56	
14	324.80	1797.36	
15	17.32	1814.68	
16	124.08	1938.75	
17	433.54	2372.29	
18	459.91	2832.20	
19	368.76	3200.96	
20	160.25	3361.21	

Table 2.3: Cash Flows at Year End from Figure 2.5, and Cumulative Cash Flows

2.5.2.1 Construction

The duration of the construction period depends on the size of the operation (measured, for example, as an amount mined per day) but also on the logistics associated with construction; construction periods of two to four years are not uncommon. Cash flow is almost always negative during construction.

2.4.2.2 Start-up

The start-up period is the time during which the operation reaches full production capacity. This depends on the complexity of the operation. For example, an underground mine often takes more time to reach capacity than an open pit mine and a hydrometallurgical processing system takes more time to reach capacity than a flotation system.

2.4.2.3 Operation

The duration of the operation period (or mine life) depends mainly on the size of the operation and on the available ore reserves which may change during the operation, thus decreasing or increasing the mine life. Cash flow is typically positive during operation, but the actual value depends on the price of the product and on production costs which also change during the operation.

Value of these cash flows is measured using the Payback period, Net Present value and Internal rate of return. The three common measures of value are given in Table 2.4 for the proposed Cerro Casale project.

Measure	Value
Payback period	4.9 years from startup
Net present value @ r = 5%	$1348.33M
Internal rate of return	13.1%

Table 2.4: Measures of value for Cerro Casale project

2.4.2.4 Revenue Estimation

The basic equation for revenue is:

$$\text{Revenue} = \text{Production} \times \text{Unit Price}$$

Depending on what the mine produces, production can be mass of ore, concentrate, or metal. If the product is metal, then unit price is simply the price per mass of the metal which may be the current price as established by the metal markets or, more likely, a price set by some form of delivery or sales contract. If the product is a metal concentrate, then unit price would be the price per mass of concentrate which is established by the terms of a smelter or refinery contract. Extremely high grade ore that can be processed (after grinding) in a smelter or refinery is rare, but is essentially a high grade concentrate for which a sales contract with a unit price would have to be established. For example: for a time, the Eskay Creek mine in northern British Columbia sold raw ore to smelters in Japan and Quebec. (Edumine, 2015)

The unit price for a metal concentrate is a function of ore grade, metal recovery during processing, and the current metal price. The amount of valuable by-product metals in the concentrate adds to the unit price while the amount of impurities in the concentrate that are deleterious to the smelting or refining process will decrease the unit price.

Thus, there are several variables associated with revenue: production, grade, recovery, and price. Values of these variables at any time during mine operation can, in principle, be obtained given an orebody model and a plan for mining the orebody. Essentially the orebody model provides a grade and recovery distribution of both valuable metals and impurities within blocks of ore, while the mine plan provides the production level and sequence in which the blocks will be mined. (Edumine, 2015)

Most mining methods result in the mixing of waste rock with ore, also known as *dilution*. Dilution is expected and can be incorporated into the mine production plan. This does not affect revenue, but does affect operating costs since more material must be mined to maintain a particular planned level of metal production. It is unplanned dilution that affects revenue.

2.4.2.5 Cost Estimation

Capital and operating costs

Next to the engineering effort required to design a mining project, estimating capital and operating costs of the operation is probably the most time-consuming task. Cost estimates can also have an effect on the design in a number of ways. If a particular scheme or configuration has technical advantages at little extra cost, then it might be adopted. Similarly, if a scheme is too costly, the design may have to be changed. Thus there is, or should be, considerable communication and feedback between the design and cost engineers. Ideally, design engineers do the costing. (Edumine, 2015)

Capital costs are the costs of physical assets used in production and processing and their construction and commissioning. These costs are recovered over the mine life as depreciation - deductions from revenue before tax. This is discussed below.

Operating costs are the costs of materials and labour directly associated with production and processing. They are usually expressed as "money units/mass." These costs are recovered (hopefully) from mine revenue

Type or Class	Usage	Methodology	Accuracy
5	Screening: comparison or rejection	Capacity factoring, parametric models, judgment, analogy	- [20%, 50%] + [30%, 100%]
4	Feasibility, Planning	Factored or parametric models,	- [15%, 30%]

		databases	+ [20%, 50%]
3	Budget authorization	Supplier prices, detailed unit costs	- [10%, 20%] + [10%, 30%]
2	Final design, Bid/Tender	Supplier prices, detailed unit costs, take-off estimates	- [5%, 15%] + [5%, 20%]
1	Check Bid/Tender documents	Supplier prices, detailed unit costs, take-off estimates	- [3%, 10%] + [3%, 15%]

Table 2.5: Types of cost estimates, their usage, methods used, and expected accuracy

(source: AACE International, 1997)

There are several levels of accuracy of cost estimates. One typical classification, developed by the American Association of Cost Engineers, is shown in Table 2.5 As the type or class number increases, the methods used become more detailed and specific, the accuracy improves, and the need to allow for unforeseen occurrences (contingency) decreases. Of course, the level of effort increases as the type or class number increases. There is a cost associated with everything, including cost estimates, and estimates cannot be made until the engineering is done. For this reason, the cost of a Type 4 or 5 mine feasibility study can be a few million dollars. (Edumine, 2015)

One important part of operating costs is *indirect costs* which are costs that benefit two or more parts of an operation e.g., maintenance, ordering parts, engineering, administration. Allocation of these costs can be important when making decisions about changes to an operation.

Taxes

Taxes are another cost of operation. However, once operating costs and production schedules are estimated, the calculation of taxes is done according to tax law of the jurisdiction in which the mine is located.

Taxes are paid on any revenue less a number of deductions such as:

- operating costs,
- depreciation of capital equipment,
- depletion allowances,
- interest payments on any loans, and
- royalty payments.

Operating costs are recognized at the time of expenditure. Depreciation occurs when a capital expense for an asset (e.g. a large haul truck) is not immediately recognized but is taken as a *non-cash* deduction over the life of the asset. The form of depletion allowances varies depending on the tax regime, but their intent is to account for the fact that the mineral reserve has a finite life and/or to provide incentives for exploration and development. If a loan has been used to help finance the project, the interest payments on that loan are tax-deductible. Finally, royalty payments may be tax-deductible depending on the tax regime. In Canada, royalty payments, usually a percentage of income from production, are made to a province and are 100% deductible from income when calculating federal tax. (Edumine, 2015)

Deductions for depreciation, depletion allowances, and loan interest result in "tax shields" or positive contributions to a cash flow stream. This can be seen by using the equations shown below; substitute the equation for tax into the equation for cash flow during operation to give:

$$\begin{aligned} f(t) &= R - C - T - A - Q \\ &= (R - C)(1 - \tau) + M\tau + I\tau - P - I - Q \end{aligned}$$

The tax shields $M\tau$ and $I\tau$ are significant contributions to the cash flow.

In some years, especially during the startup period, the sum of operating costs and other deductions may be greater than revenue in which case there is a loss and no tax for the year. The loss may be deducted from taxable income in later years, so-called "loss carry-overs".

Taxes are often not taken into account when valuing a mining cash flow. All-equity financing is assumed and depreciation and royalties are assumed to be zero. The operation should "stand on its own" without loan financing or tax benefits. Given all the uncertainties associated with prediction of cash flows from a mining operation, it seems suspect to use tax shields and loss carry-overs to make a mining operation appear more valuable. (Edumine, 2015)

Mining taxation is a specialized business; some accounting firms have a large number of staff dedicated to helping mining operations file their tax returns.

Discount Rate

An important parameter is the discount rate used in a net present value calculation. There is a reasonably well-defined procedure for determining which discount rate to use. It depends mainly on the type of metal being produced and on the nature of the risks the market perceives are associated with the mining industry.

Financing a mining operation involves determining where and how the capital costs for the operation will be obtained. The nature of financing (e.g. the amount of debt) can change the value of an operation and variants of discounted cash flow analysis can account for the effects of financing. However, since there are several ways in which a project can be financed, to avoid confusion financing considerations are usually separated from the estimation of the value of a project. The nature of the financing and its effect on valuation is the concern of financial professionals.

The value of any mining project is extremely sensitive to the price of the product. The expected behaviour of price during the mine life is very difficult to predict. However, it is useful to know how prices of metals and other mineral products are determined and to have some idea of the economic forces that affect these prices. Models of base and precious metal price behaviour are available and can be used to test the sensitivity of value to price. In the case of base metal mines which produce a concentrate, a smelter contract determines the price of the mineral product. It is therefore important to understand the basic structure of a smelter contract. (Edumine, 2015)

To the extent that there are uncertainties in the orebody model, the mine plan, capital and operating costs, and in metal price, there will be uncertainty in revenue. Such uncertainties, particularly in price, can have a significant effect on value. If the uncertainty can be modeled, then its effect on value can be estimated.

Discounted cash flow does a good job of accounting for the value in a project, but it assumes that once the project is designed and built, it cannot change. In this sense discounted cash flow assumes a static project and cannot capture the ability of a project or the project managers to adapt and change the project in response to prices or other conditions which might affect the success of the project. Such flexibility, if present, goes by the name of real options and provides additional project value.

2.5 Risk and Return

Return is determined by the cost of an investment - what was originally paid for the investment. In the stock market, that cost is share price. The return is mostly influenced by the market for whatever the mining company produces, but also by the nature of the mining operations (e.g., its costs) and the management (e.g., strategic plans) of the company. These influences lead to the uncertainty associated with investment, but investors will "price" the uncertainty through buying or selling the company shares thus changing the share price and therefore the expected return. Thus if the demand for a particular metal increases, the profits of a company producing that metal can be expected to increase and so demand for shares in the company will increase, leading to an increase in share price and therefore an increase in return. Likewise, investors will respond negatively by selling shares in a mining company whose management strategy leads to a situation where the company cannot maintain a reasonable supply of high quality reserves.

The uncertainty associated with investing means that any investment carries a risk. If smart investors take a risk, they are not doing it for some sort of adrenaline rush; it is real money they are using and some reward must occur for taking the risk. If it were any other way, there would be no point in investing in projects of any kind. All investment would be in guaranteed government securities (e.g., Treasury bills) and the entire economy would grind to a halt.

Given that risk and return are related, to estimate the expected return of shares in a company some method of characterizing risk must be available.

CHAPTER THREE

RESEARCH METHODOLOGY AND INFORMATION OF THE MINE

3.0 Introduction

In this chapter the information of the mine and methodology used for the research are described. A description of the study area, the research approach and design is also presented in this chapter. Furthermore, an overview of the methods used in processing the data is described.

3.1 Research Approach and Design

According to Holme & Solvang (1991) the type of research question being posed reflects the choice of a research strategy. For this study, the quantitative approach to research was used. Burn and Grove (2005) describes quantitative research as a formal, objective, systematic process where the use of numerical data is applied to examine the cause and effect relationship between variables. The descriptive research design was adopted by using the case study method for this research. A case study research design is described as the empirical enquiry that investigates a contemporary phenomenon within a real life context (Zucker, 2001).This method allowed the researcher to use the Whittle optimisation model to determine the behavior of the Net Present Value of the Awonsu mineral deposit by varying some economic and operational variables such as gold price, mining cost and processing cost.

3.2 Study Area

The study area for the research can be seen as the cultural, social, and physical site in which the researcher conducts the study (Lisa, 2008). Study area selection is a significant component of the research process. Berg (2004) indicates that the selection of an inappropriate location could weaken or ruin findings. The study was carried out at the Ahafo Mine of Newmont Ghana Gold limited. The Awonsu project of the Ahafo Mine was chosen for this study. The choice for the study area for this research was based on a number of reasons besides being within the convenient reach of the researcher. The Awonsu mining project is one of several projects being assessed by Newmont Mining Corporation.

The phase one of the deposit has been mined out with some portion being backfilled with waste. It is essential that studies are conducted to ascertain the economic viability of the project.

3.3 Site Overview

The Ahafo gold property is located in western Ghana near Kenyasi and Ntotoroso in the Brong–Ahafo Region, about 290 km northwest of Accra. It is 107 km northwest of Kumasi, and 40 km south of, Sunyani, the capital of the Brong-Ahafo Region.

The Project is being developed in two phases, Ahafo South Area (Phase One) and Ahafo North Area (Phase Two), which are separated by a narrow belt that has been designated as a Forest Reserve as shown in Figure 3.2. Newmont commenced mining operations from two open pits, namely the Apensu and Subika pit, in the Ahafo South Area in January 2006, with plant wet commissioning in June 2006. The plant and pit layout in Ahafo South is shown in Figure 3.1.

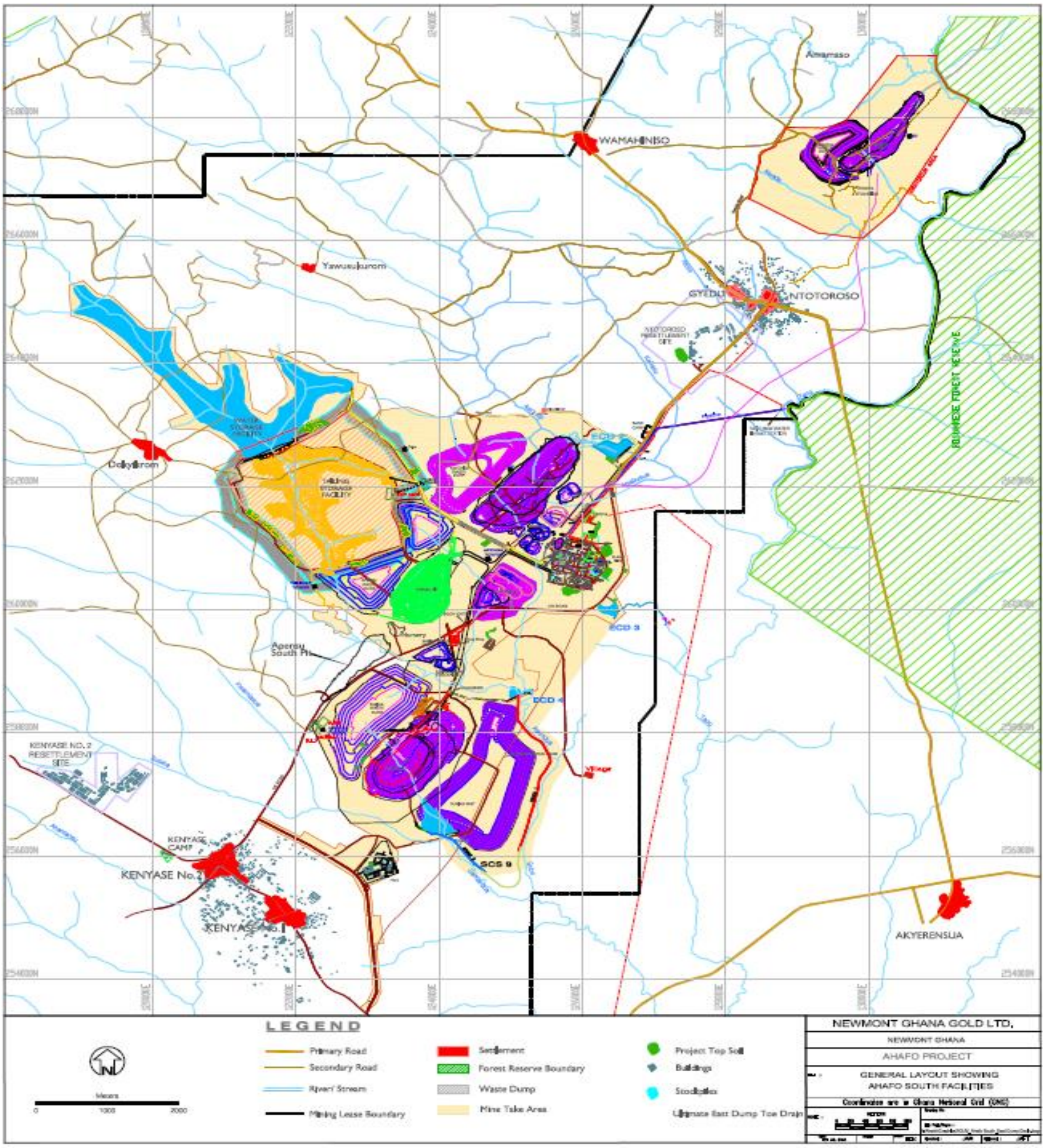

Figure 3.1 Map Showing the General Layout of the Ahafo South Facilities

3.4 Awonsu Geology

The pit area is dominated by the Kenyase Thrust fault that strikes north-south through the pit and separates the hanging wall granitoid to the east with the meta-sediment of the footwall to the west. A series of graphite alteration zones were intersected in the metasediments, three of these units were subsequently modeled, and thickness ranges from 3 – 20m.

In the oxidized zone, gold grains, ranging in size from 5 µm to 10 µm, are associated with pyrite or occur as inclusions in or marginal to, goethite of pyrite origin.

In primary material, gold is predominantly associated with pyrite. Gold occurs mostly as inclusions within the pyrite or as sub-micrometer size veinlets. Gold particles usually range from 2 µm to 30 µm. Pyrite grains occur both as euhedral and subhedral crystals as large as 1.5 mm in size.

A total of 5 geotechnical domains have been delineated in the Awonsu area, a schematic of the domains is presented in Figure 3.2. Domains have been selected on varying criteria including lithology, geological structure and planned pit geometry. Each geotechnical domain has been given pit design parameters that reflect the expected rockmass conditions.

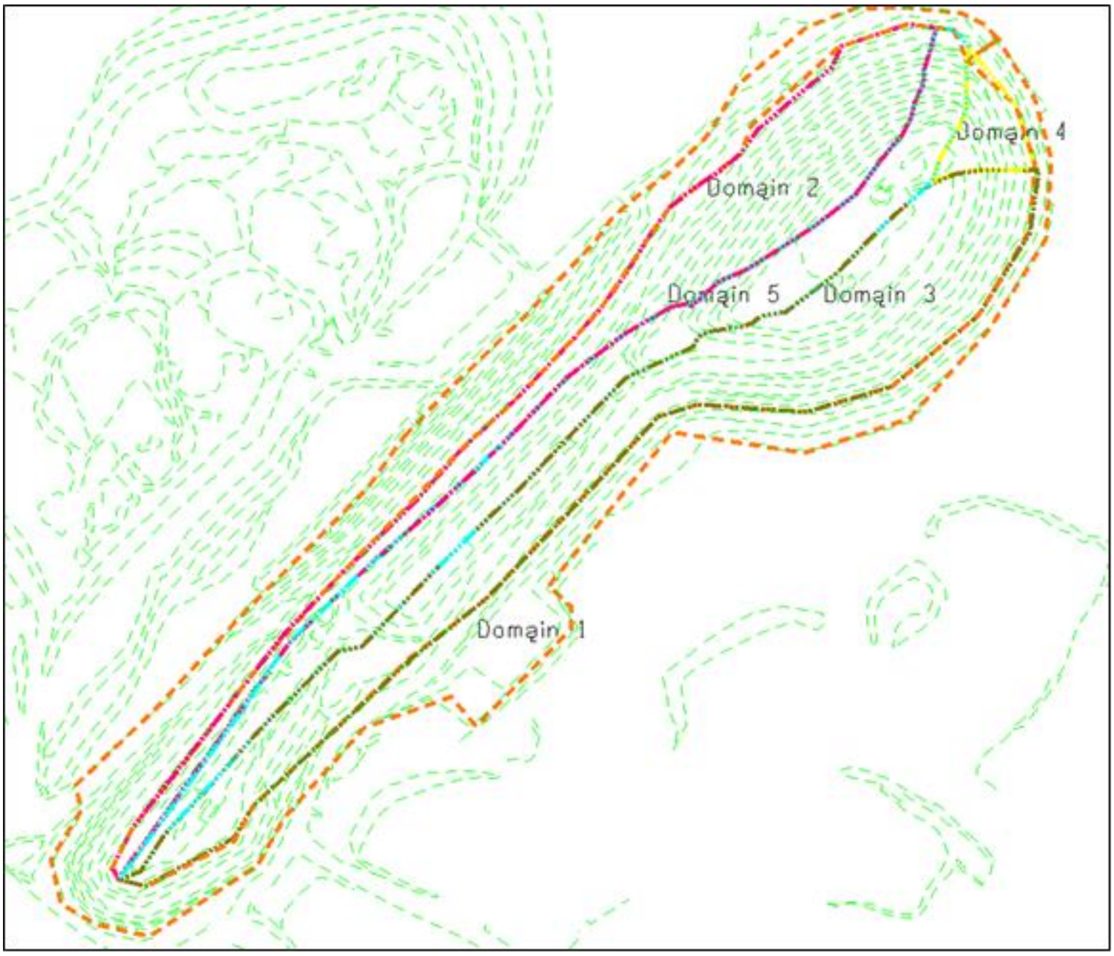

Figure 3.2 Schematic diagram of Awonsu geotechnical domains

3.5 Methods of Data Collection

Secondary data was used for the research work. The secondary data was collected through desk review of available documentation from three main sources including the Geotechnical department, the Mine planning department and the Exploration department of Newmont Ghana Ahafo Mine. Secondary data such as inter ramp angle, berm width, geotechnical domains and bench face angle were obtained from the Geotechnical department. The geologic block model was obtained from the Geological department whiles the Mine planning section provided the researcher with data on commodity price, mining cost, processing cost, selling cost and royalty. Auxiliary information was utilized for the examination work.

3.6 Data Processing Instruments and Procedures

Two main computer based programs, The Gemcom Whittle 4X and the Mintec Minesight, were used in processing the secondary data. The Gemcom Whittle 4X was used for the optimisation process and the Mintec Minesight was used for the pit design.

Microsoft excel was used to determine the Net Present Value of the pit

3.6.1 The Gemcom Whittle 4x

The Whittle software is one of the numerous pit optimization software used in strategic mine planning. The Whittle software was developed by Jeff Whittle and was sold to Gemcom Software International in 2001. The Whittle programming was utilized to produce various pit shells despite the fact that the Minesight programming was utilized as a part of setting up the block model for the optimization. Thios work started with analysing and preparing the block model in Minesight by creating the items needed for the optimisation work. The model was then imported into Whittle and pit slopes were set. A setup of the economic parameters such as the mining cost, processing cost, royalties, recovery metal price etc. were also done and finally the optimisation run.

The following steps and equations are systematically followed to calculate the economic value for each block in the model.

Step 1: Estimating the Mining Cost Model ($/block)

$$MiningCost = \left((Bench - 1) * Incremental\ Mining\ Cost + Mining\ Cost\right) * \frac{tonnes}{block}\ \ldots\text{.}$$

Eqn. 3.1

Step 2: Estimating the Metal Recovered Model (Oz/block)

$$MetalRecovery = Metalgrade * \frac{tonnes}{block} * Recovery$$ .... **Eqn. 3.2**

Step 3: Estimating the Block Revenue Model ($/block)

$$Block\ Revenue = (Price - Selling\ Cost) * Metal\ Recovery$$ ....**Eqn. 3.3**

Step 4: Estimating the Block Value If Milled Model ($/block)

$$Block\ Value_{\text{if milled}} = BlockRevenue - \left(\text{millcost} * \frac{tonnes}{block}\right) + Mining\ Cost$$ ......**Eqn. 3.4**

Step 5: Generating the Block Economic Model ($/block)

$$BlockEconomic = \max\{BlockVal_{ifmilled}, MiningCost\}$$ ....**Eqn. 3.5**

3.6.2 The Minesight Design Tool

The ultimate pit generated is a theoretical pit as it lacks access ramps, berms and strictly follows the jagged outline of the orebody. The triangulated surface and contour outline of the base pit was imported into the Pit Expansion menu in MineSight. Once an initial ultimate pit has been produced by optimisation work, a properly designed pit is required, which incorporates haul roads, berms and different bench/berm configurations. A rough estimate of the additional tonnage required for addition of haul road into a pit, and its associated mining cost, will quickly demonstrate the care required with its placement.

The data required for pit designing in MineSight are the optimised block model with its associated wireframes and design slope angles. The optimised model is loaded into the graphics and the slope angles are set using the ROSSETTE. The ROSSETTE is a 3-D plot in space on which all angles and berms are specified. The command enables the slope angles at different azimuths to be set and these angles can be saved into a file and recalled any time such design operation is repeated.

The reference outline or base is the starting outline and the choice depends on the skills and experience of the designer. Most design processes are started from the bottom to the top. Prior to that, the location of, stockpiles, waste dumps and ROM pad must be borne in mind.

The geotechnical data that was used is shown in Table 3.1.

Domain	Zone	Inter ramp Angle(°)	Batter Angle(°)	Bench Height(m)	Catch Bench Width (m)
Domain 2	Footwall (graphite)	34	55	8	6.3
Domain 3	Hanging wall (granitoids)	50	70	16	7.6
Domain 4	Hanging wall (granites & GVM)	52	65	16	5.0
Domain 5	Footwall (GVM)	45	55	16	4.8
Domain 1	Saprolite	30	65	8	10.1

Table 3.1 Geotechnical data used for the Awonsu Design Expansions

(Source: Author’s Construct, 2015)

3.6.2.1 Detailed Pit Design

A detailed design of the pit was done by expansion from bottom to top so as to ensure adequate operational space at the pit bottom. The final exit of the ramp was targeted to face the processing plant. The block model was merged with the contour outline of the optimised pit. Designing of the pit was achieved by using the expansion tools in the Application Menu of the Design Window.

Creation of a pit base string

The lowest elevation of the pit contours was checked so as to locate the base of the pit in the plan view and was set at that elevation to generate the pit bottom. The pit base string was created using the optimised pit contour as a guide. The contour was expanded to enclose the ore blocks while ensuring that the minimum pit bottom dimension of 35 m was adhered to. Clipping limits were set so that successive contours can be viewed when planes were moved forward for designing.

Creation of ramps

Following the creation of the pit base string a ramp was constructed to get to the next bench. The width of the ramp was set at 30 m to allow for the width of dump trucks and allowance for space between the dump trucks and the edge of the ramp. The ramp gradient was maintained as 10%.

Creation of crest and toes strings

The crest string generated from the previous section was used to create the berm at that elevation. This crest string served as the toe string for the next bench. A ramp connecting this bench to the next bench was then created. Ramps to successive benches were located so as to connect to one another and as much as possible face the direction of the processing plant. The design process of toe, ramp and crest was thus continued to the surface.

Intersection of the pit and topography

A DTM of the pit designed was created and then intersected with the DTM of the topography. The segments of strings which protruded above the topography were trimmed off.

CHAPTER FOUR

RESULTS AND DATA ANALYSIS

4.0 Introduction

Outcomes of the pit optimization are analyzed in this section. Each pit shell created a Net Present value which was used to develop a bar graph for the analysis. The optimal pit for Awonsu is selected based on this graph and it is the pit with the highest Net Present Value (NPV). A detailed pit design was done based on the selected optimal shell incorporating ramps (roads) and safety berms. Total ore tonnes, waste tonnes and average grade of the optimal pit and designed pit were evaluated to the degree of change. This chapter again presents the results of sensitivity analysis to show the impact of changes in gold price, mining cost and processing cost on Net Present Value of the of the project.

4.1 Input Data

The mining cost, processing cost, rehabilitation cost, royalty and metal price used in the optimization process. For the purpose of this research work, the Technical Services Department of Newmont Ghana Gold Limited provided all these input variables. These economic parameters are shown in Table 4.1.

Parameter	Saprolite	Primary
Mining Cost (US$/tonnes)	4.61	4.92
Processing Cost (US$/tonnes)	14.14	20.97
Price of Gold (US$/Oz)	1200	1200
Processing Recovery (%)	95.9	87.1
Royalty (%)	4	4

Table 4.1: Input economic parameters

(Source: Author's Construct, 2015)

4.2 Output of Awonsu Pit Optimisation

What is the selected optimal pit shell for Awonsu pit at an evaluation metal price of $1200/Oz?

From the input data, whittle generated 27 nested pits using a revenue factors ranging between 0.67 and 1.21 ($800 - $1450/oz) at an increment of 0.02 ($25/oz). The output data were in the form of total ore and waste tonnes for each pit shell as well as their respective Net Present Values. This information was extracted into Microsoft Excel and a graph plotted out of it for analysis.

From the graph shown in figure 4.1 pit shell 10 created from a revenue factor 0.854 was chosen as the ideal pit. This ideal pit selected corresponds to a gold price of $1025. Pit shell 10 was selected because it generated the highest Net Present Value of $ 122 Million for the best case scenario and $ 93 Million for both the worse and specified case. Regardless of the way that the metal tonnages increments somewhat from pit shell 10 to pit shell 27, the measure of waste tonnes delivered keeping in mind the end goal to mine the ore tonnes in these pits are too high thusly making them less cost-effective to mine contrasted with pit shell 10. The optimal shell for the Awonsu deposit at a selling gold price of $1200 is pit shell 10 ($1025 pit shell).

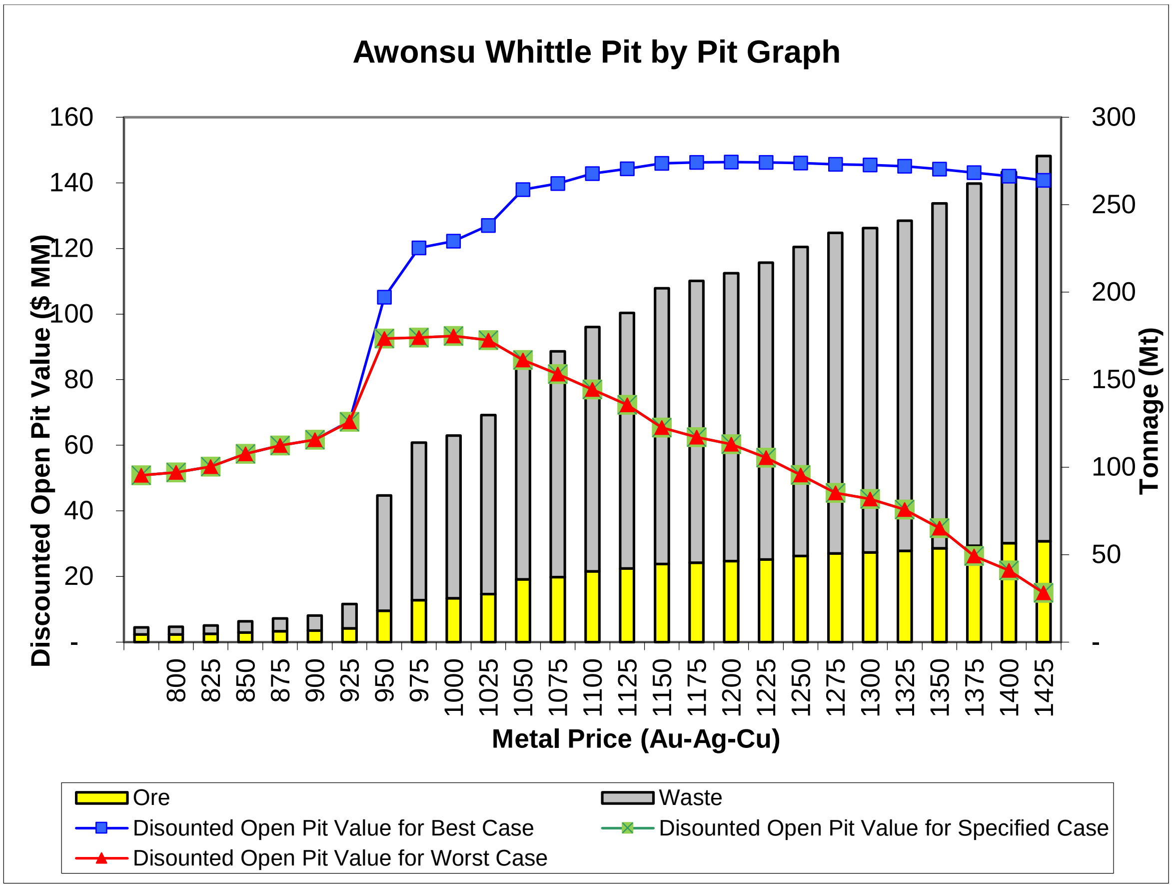

Figure 4.1 Pit Shell vs. Net Present Value (NPV)

(Source: Author's Construct, 2015)

4.3 Awonsu Phase two Pit design

Based on the pit selected for the Awonsu project, a detailed pit was designed. Despite the fact that because of operational requirements the design digressed somewhat from the ultimate pit outline in some areas, it was carefully done to follow the outline of the optimal shell. The pit will be mined within six years at an annual production rate of 20 million tonnes.

The pit design was done based on the outline of the optimal pit shell so that the Net Present Value of the design would be almost the same as the selected shell. Areas where there were deviations were as results of leaving a minimum mining width of 40 meters from the already mined out phase. Figure 4.2 below shows a 2D Comparison between Pit Design Outline and Ultimate Pit Limit Outline on plan view and figure 4.3 shows a 2D Comparison between Pit Design Outline and Ultimate Pit Limit Outline on cross-sectional view.

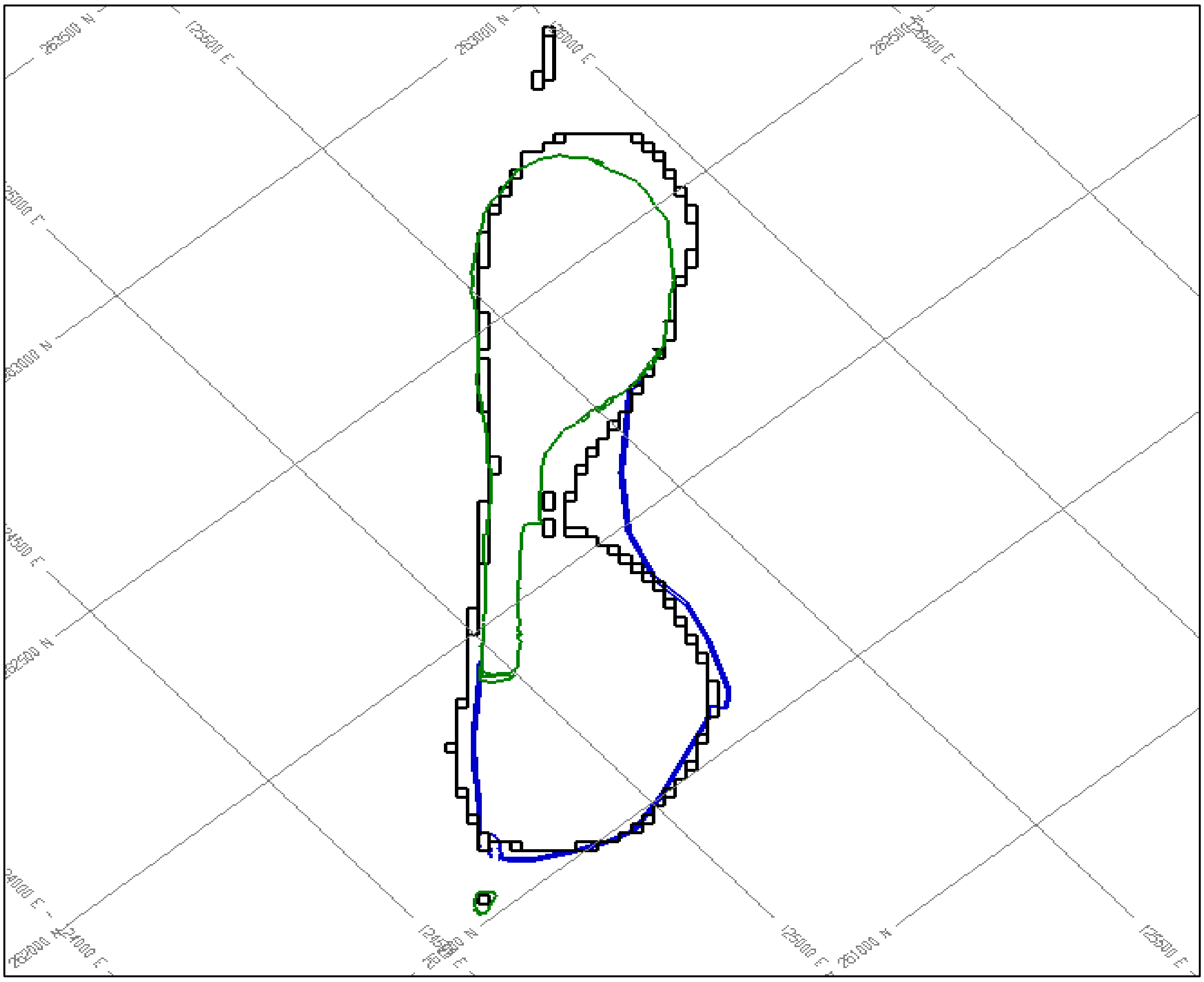

Figure 4.2: 2D Comparison between Pit Design Outline and Ultimate Pit Limit Outline (Plan View)

(Source: Author’s Construct, 2015)

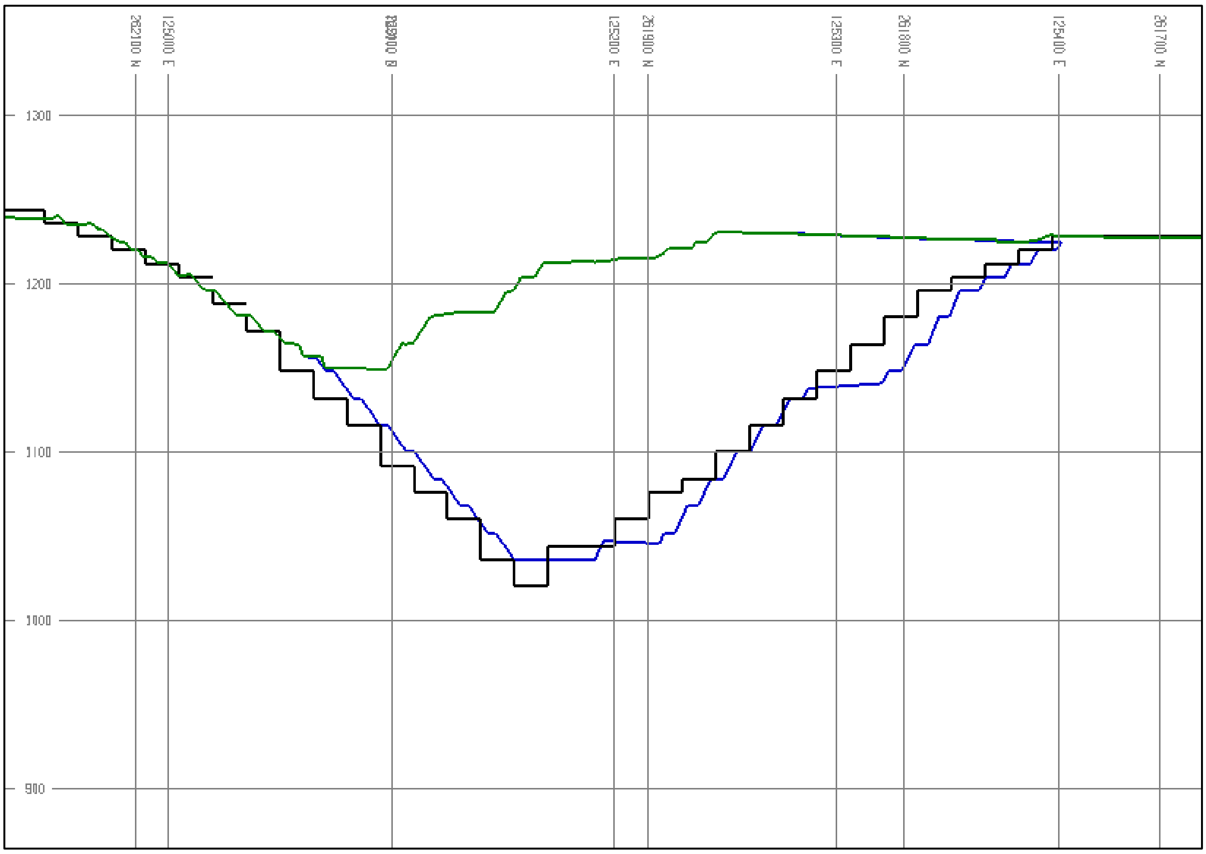

Figure 4.3: 2D Comparison between Pit Design Outline and Ultimate Pit Limit Outline (Cross-sectional View)

(Source: Author's Construct, 2015)

The final pit design is 268 meters deep and 0.6 kilometers wide with an average length of 2 kilometers. Figure 4.4 shows the final pit design for the Awonsu deposit

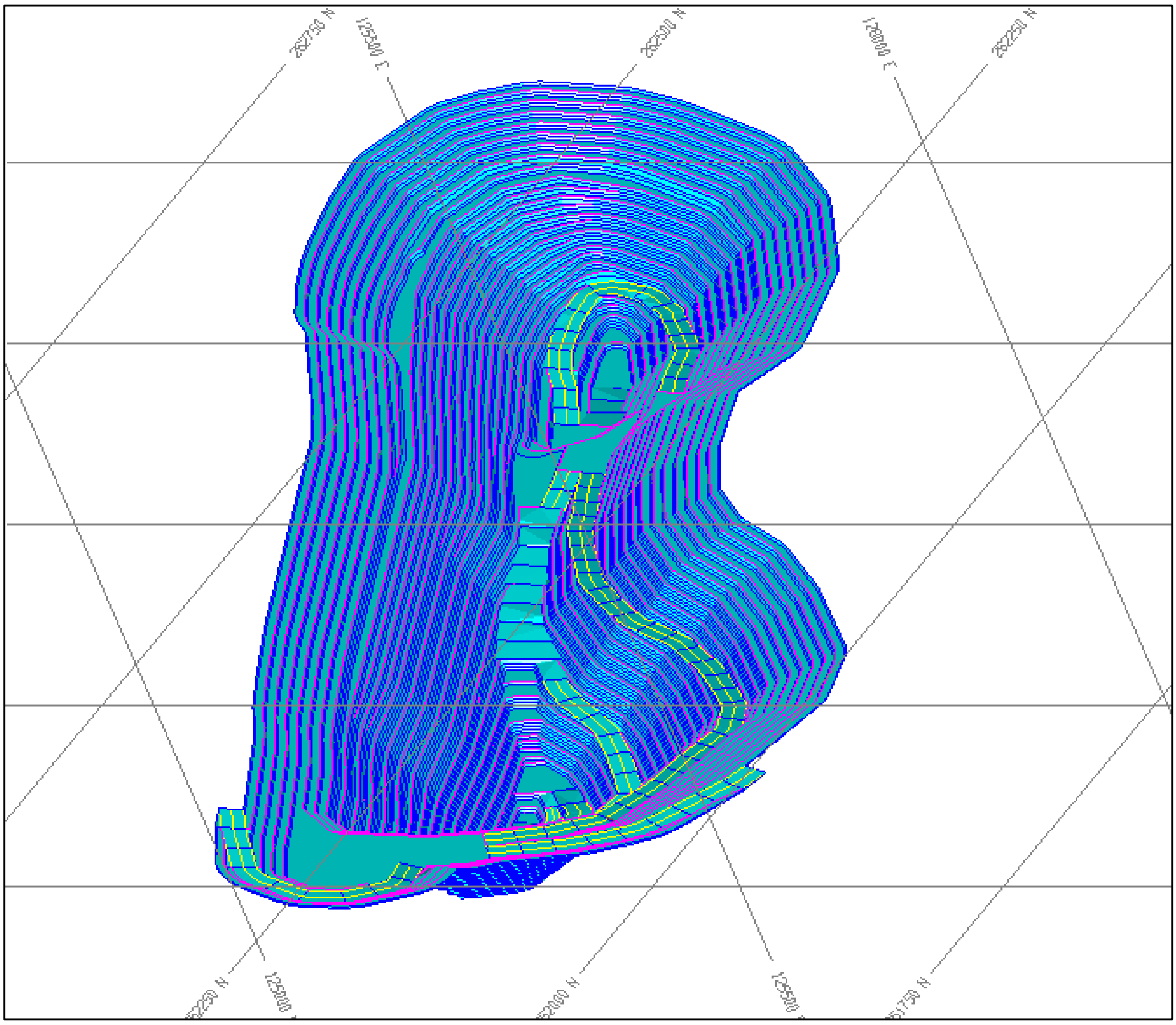

Figure 4.4: Suitable Pit Design for the Awonsu Deposit

(Source: Author's Construct, 2015)

After the design work, a comparison of the design output and that of the optimal pit shell was done. From the results shown in figure 4.5, the total tonnage of ore in the design was 26 million tonnes whiles that of the optimal pit shell was 22 million tonnes. This represented an increase of 17%. The total tonnage of material for the designed pit was 120 million tonnes against the optimal pit shell of 107 million tonnes representing an increase of 12%. Fig 4.5 shows a tonnage comparison between the pit design and the ultimate pit limit.

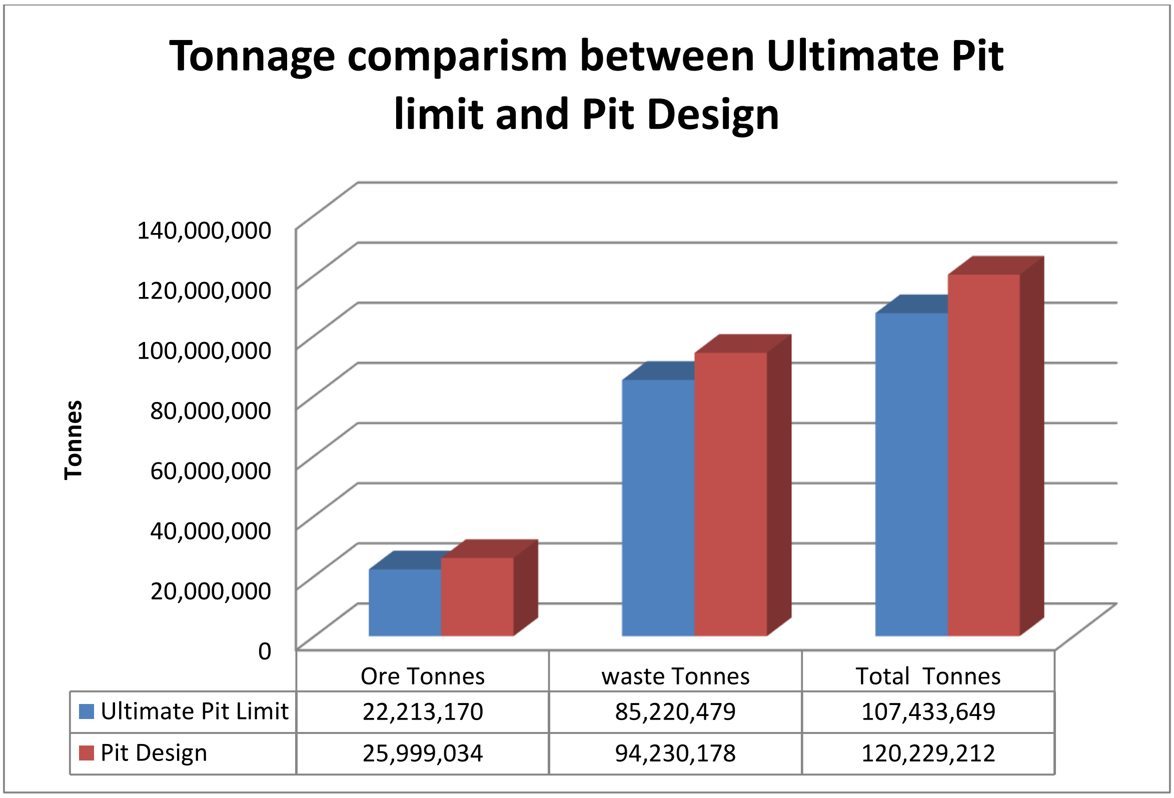

Figure 4.5: Tonnage Comparison between Ultimate Pit Limit and Pit Design

(Source: Author's Construct, 2015)

4.4 Cashflow and Sensitivity Analysis

The Pit designed out of the ultimate pit limit produces total revenue of $1.39 billion and the cost associated with this revenue is $1.22 billion. The free cashflow of the design is $171 million and a discounted cashflow of $60 million. Table 4.2 shows a summary of the pit economics

AW Pit Design	Economic Analysis				
		Grade			Rcvd
	Tons	(g/t)	Ozs	Recovery	Ozs
Total Oxide Waste	10,850,288				
Total Primary Waste	83,379,890				
TOTAL WASTE	94,230,178				
Total Oxide Low Grade	15,624	0.58	291	95.9%	279
Total Oxide Medium Grade	0	0.00	0	0.0%	0
Total Oxide High Grade	15,490	1.92	956	95.9%	917
TOTAL OXIDE ORE	31,114	1.25	1,247	95.9%	1,196
Total Primary Low Grade	10,561,650	0.83	280,638	81.5%	228,618
Total Primary Medium Grade	1,844,590	1.19	70,789	84.5%	59,817
Total Primary High Grade	13,561,680	2.26	984,169	88.8%	873,780
TOTAL PRIMARY ORE	25,967,920	1.60	1,335,597	87.0%	1,162,215
TOTAL ORE TONS	25,999,034	1.60	1,336,844	87.0%	1,163,410
TOTAL TONS	120,229,212	0.35	1,336,844	87.0%	1,163,410
Mining Costs	$437,568,157				
Process Costs	$405,187,316				
Reclamation Cost	$21,660,773				
TOTAL DIRECT	$864,416,246				
G/A Percentage	17.63%				
G/A Costs	$152,375,280				
Recovered Ozs	1,163,410				
Refining - CH Costs per Oz	$6.09				
Refining - CH Costs	$7,085,169				
Royalty Percentage	4.0%				
Price of Gold	$1,200				
Royalty Expense	$55,843,699	Total Strip Ratio - 3.6 : 1			
TOTAL OPER COSTS	$1,079,720,394				
Sustaining Capital	$145,366,651				
Project Capital	$0				
TOTAL COSTS	$1,225,087,045				
Recovered Ozs	1,163,410				
Price of Gold	$1,200				
Revenue	$1,396,092,474				
Costs	$1,225,087,045				
Cash Flow	$171,005,429				
Discount Rate	8.0%				
Discounted Cash Flow	$60,161,813				
Tax Rate	28.0%				
Total Tax	$47,881,520				
After Tax Cash Flow	$123,123,909				
Discounted After Tax Cash Flow	$43,316,505				
IRR	14.6%				
Cash Cost per Rcvd Oz	$928				
Total Costs per Rcvd Oz	$1,053				
Total Costs per Rcvdd Oz (After Tax)	$1,094				

Table 4.1: Summary of Economic evaluation of the Pit design

(Source: Author's Construct, 2015)

Changes in gold price, mining cost and processing and G&A cost were tested on the Net Present Value of the design pit. This test was very necessary to assess the impact of these economic variables on the viability of the Awonsu deposit.

The economic inputs were changed between a range of ±20% and the corresponding NPV for each percentage change was recorded.

4.4.1. Sensitivity of NPV of Pit design to Changes in Gold Price

Gold price is very a critical economic parameter in every gold mining industry since it drives the revenue. Any slight change in gold price can have a serious impact on the business. In order to determined how robust the Awonsu project is, the evaluation gold price was changed between ±20% at an interval of 10% and its corresponding NPV recorded. This data was used to generate a graph to know the trend of gold price change on the NPV of the Awonsu project. A 10% rise in gold price increases the NPV by 169% whiles a 10% fall in gold value decreases the NPV by 169%. It shows that gold price change has a greater impact on the project's viability. The Awonsu project breaks even at a gold price of $1129/Oz representing a reduction of 6% in gold price. Figure 4.6 shows a graph of the gold price change on the NPV of the Awonsu project.

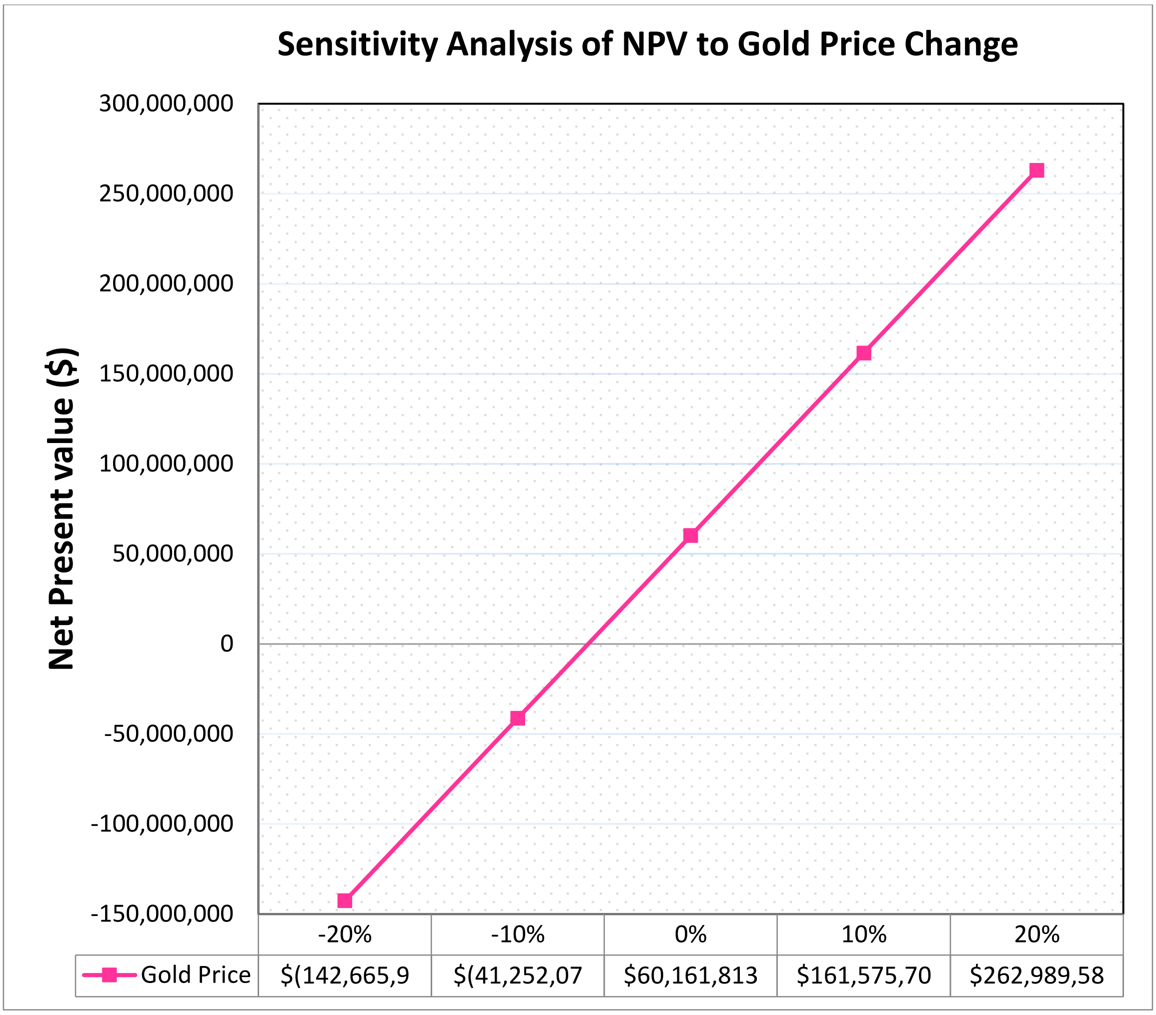

Figure 4.6: Sensitivity Analysis of NPV to Gold Price Changes

(Source: Author's Construct, 2015)

4.4.2 Effect of Mining Cost change on the NPV of the Awonsu Project.

The Pit design was again tested for changes in mining cost. The mining cost was changed between ±20% at an interval of 10% and its corresponding NPV recorded. Relative to the base case, a 10% increase in mining cost results in a decrease of 78 % On the other hand, a 10%reduction in mining cost reduces the base case NPV by 78%and. The project is again very sensitive to changes in mining cost and breaks even when the mining cost increase by 12.8%.

Figure 4.7 shows a graph of the change in mining cost to NPV of the Awonsu project.

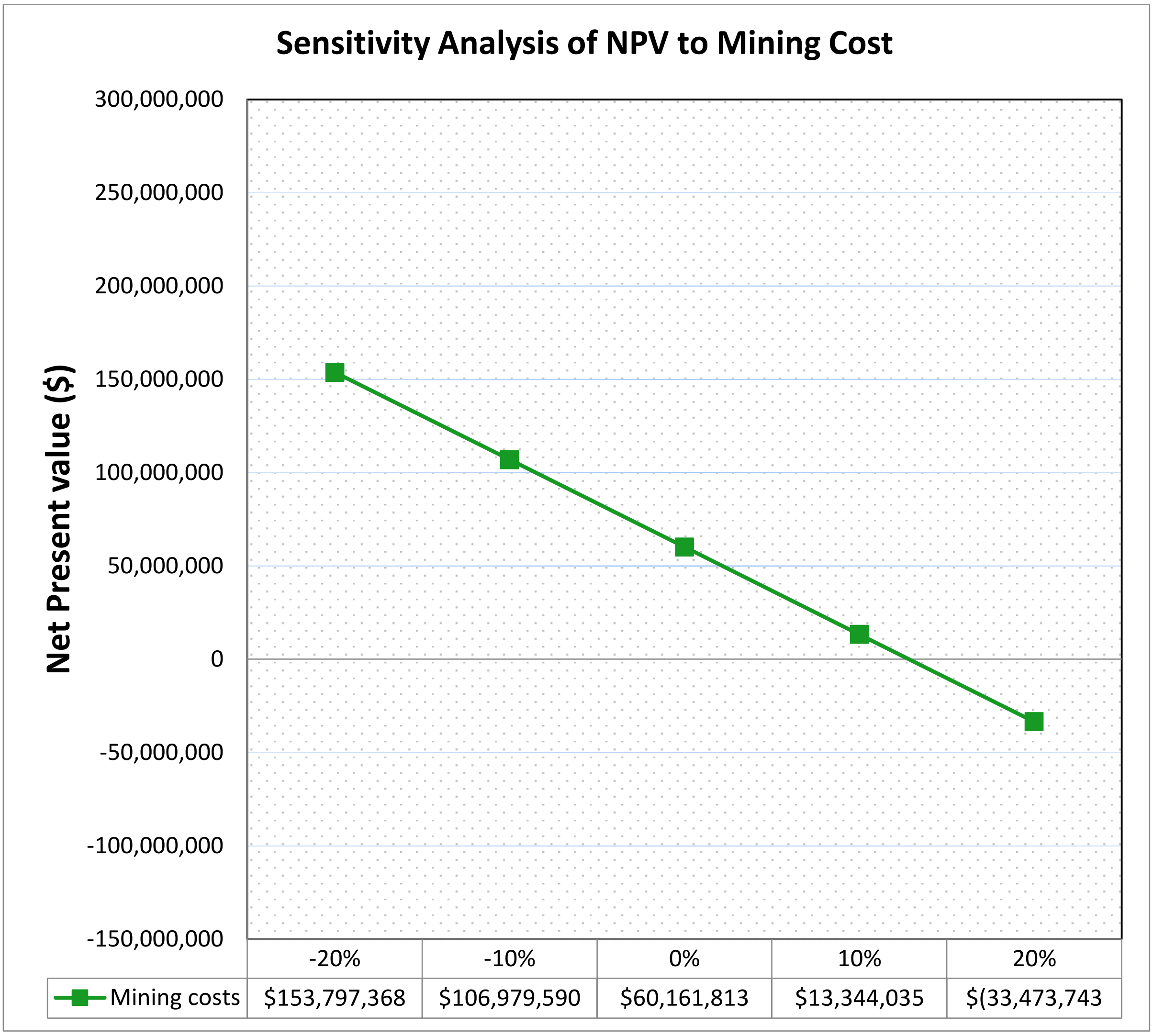

Figure 4.7: Sensitivity Analysis of NPV to Change in Mining Cost

(Source: Author's Construct, 2015)

4.4.3 Effect of change in the Processing and G&A cost on the NPV of the Awonsu Project

The effect of changes in processing and general and administrative cost on the NPV of the Awonsu deposit was also examined. The investigation revealed that a 10% increase in the processing and G&A cost on the base NPV results in a decrease of 57% of the NPV and a 10% reduction in processing and G&A cost reduces the NPV by 57% The project is moderately sensitive to changes in processing and G&A cost and breaks even when the cost increases by 17.5%. Figure 4.8 shows a graph of the change in processing and general and administrative cost to NPV of the Awonsu project.

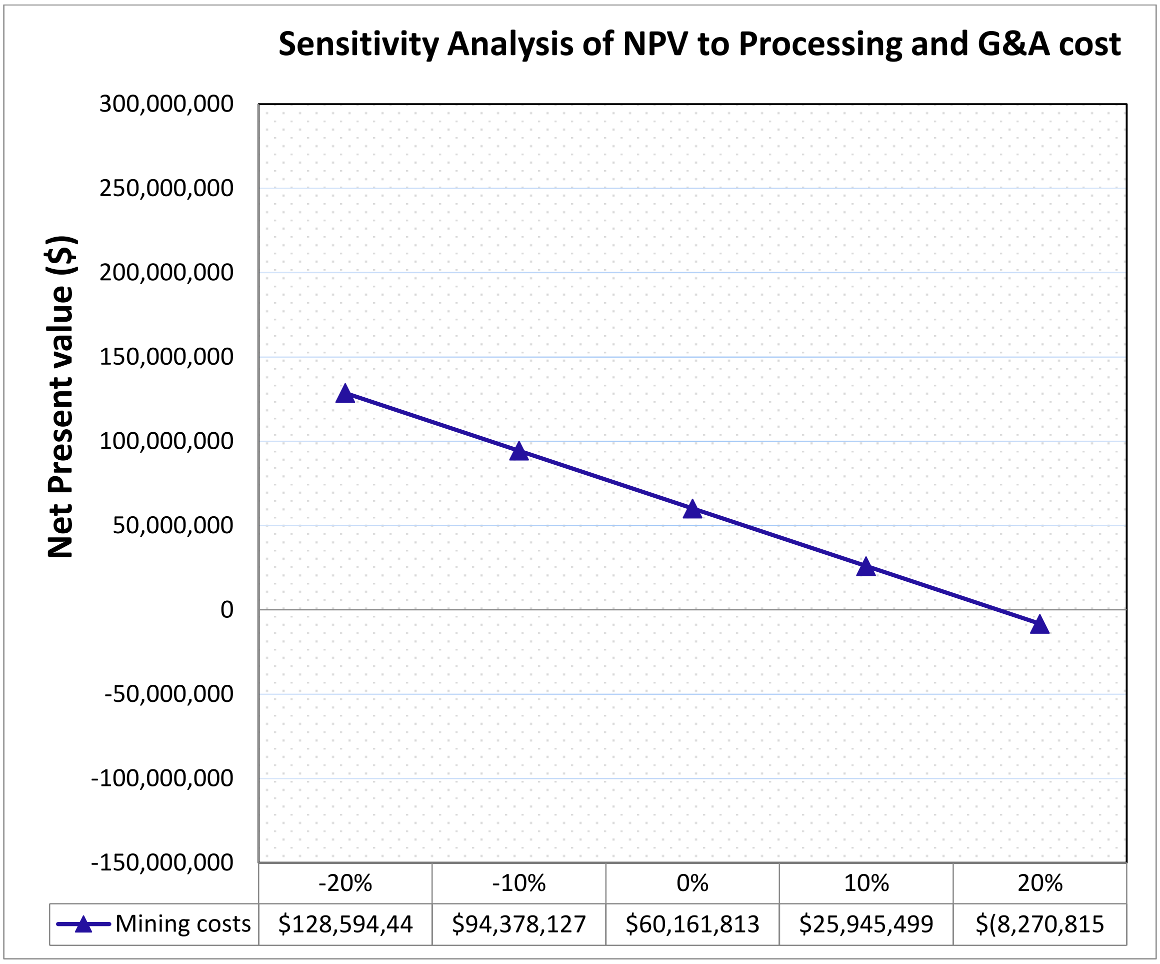

Figure 4.8: Sensitivity Analysis of NPV to Change in Process Recovery Factor

(Source: Author's Construct, 2015)

In summary, the economic viability of the Awonsu project depends largely on the gold price since it is the most sensitive economic parameter. Any change in the metal price can render the project profitable or unprofitable. Figure 4.9 is a spider graph which shows the sensitivity the three economic inputs to the NPV of the base case. It can be seen from the graph that, the Awonsu pit design is extremely sensitive to gold price changes, very sensitive to changes in mining cost and reasonably sensitive to changes in processing and general and administrative cost.

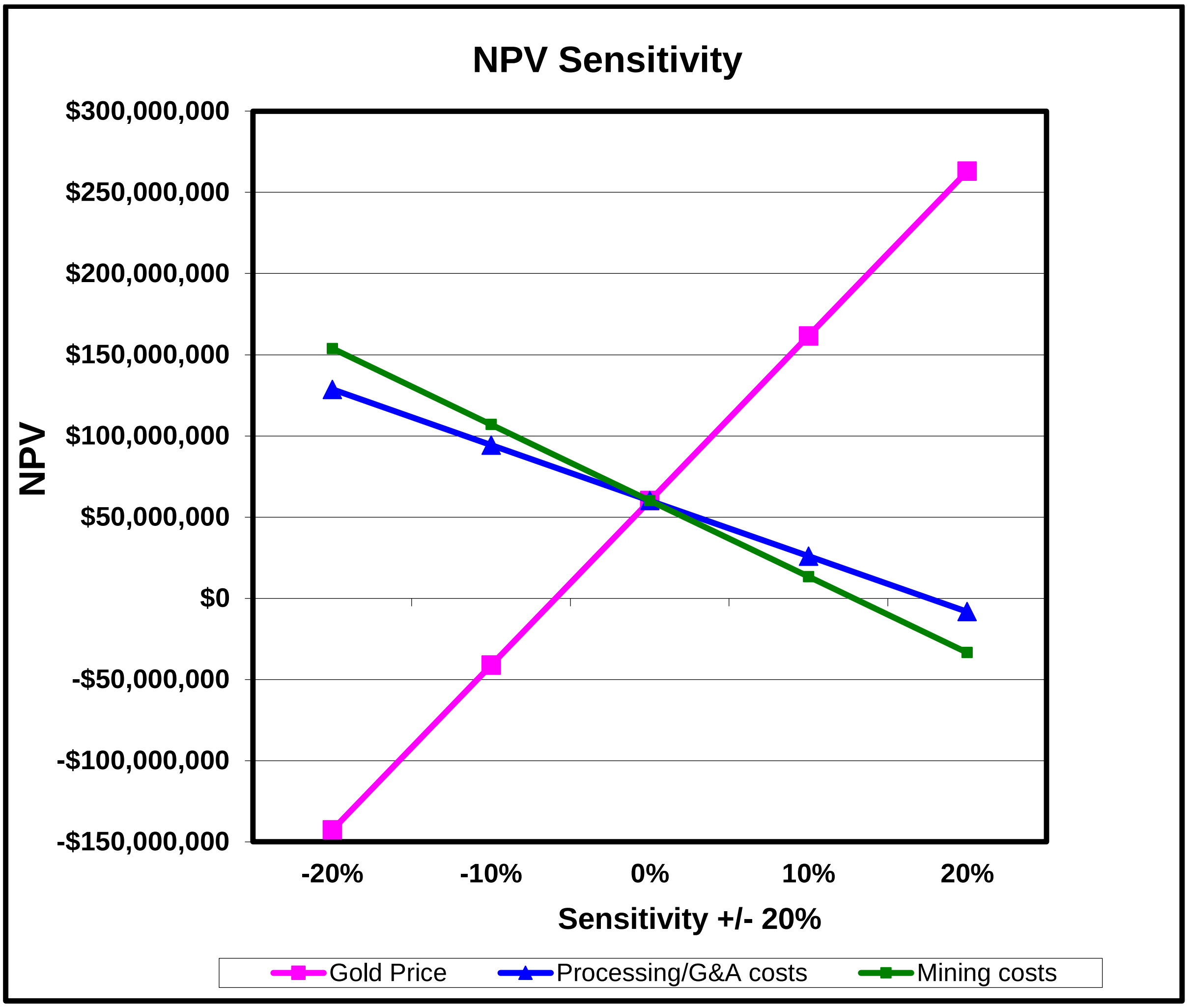

Figure 4.9: Spider Graph showing Percentage Change in Various Parameters vs. NPV

(Source: Author's Construct, 2015)

CHAPTER FIVE

FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

The principal objective of this study was to determine the economic feasibility of the Awonsu phase two deposit beyond the already mined out phase one at an evaluation gold price of $1200. In this section, result of the data anlysed in chapter four is presented. It ends by conclusion and recommendation.

5.1 Research Findings

Results from this study show that the Awonsu phase two optimal pit is pit shell 10 representing a gold price of $1025. The pit design out of the optimal pit shell produced a total of 120 million tonnes of material out of which 26 million tonnes is ore and the remaining 94 million tonnes waste. The stripping ratio of the project is 3.6:1 and it represents the quantity of waste needed to mine to get a unit quantity of ore. The 26 million tonnes of ore will be processed at an average grade of 1.6g/t to produce 1.2 million recovered ounces. The Awonsu pit designed has a total depth of 268 meters and width of 0.6 kilometers with a length of 2 kilometers. It will take six years to mine this pit at an annual production rate of 20 million tonnes and seven years to finish processing the ore. The study further reveals that the Awonsu pit design breaks even at a selling gold price of $1129 representing a fall of 6% below the evaluation price.

The Awonsu Phase two pit produces total revenue of $1.39 billion the total cost to mine and process the ore is estimated at $1.22 billion. The free cashflow of the design is $171 million and a discounted cashflow of $60 million Awonsu pit design is extremely sensitive to gold price changes, very sensitive to changes in mining cost and reasonably sensitive to changes in processing and general and administrative cost.

5.2 Conclusion

The Awonsu phase two design is financially profitable at the evaluation price of $1200. The pit designed out of the selected pit shell produces an ore tonnes of 24 million at an average grade of 1.6g/t and recovered ounces of 1.2 million. The free cashflow of the project is $171 million and when discounted at 8% for six years, results in a Net Present value (NPV) of $60 million. The Internal Rate of Return (IRR) of the project is 14.4% and total cost per recovered ounce is $1053. The Return on Capital Employed (ROCE) is 14% which means for every $1 invested in the project will yield a return of 14 cents. The project breaks even at a gold price of $1129/Oz.

5.3 Recommendations

It is recommended that:

1. the Awonsu phase two deposit should be mined using the pit designed out of the optimal pit shell in order to get the highest Net Present Value.
2. management of Newmont Mining Corporation make use of financial derivatives to eliminate the potential risk of changes in gold price.
3. narrowly spaced exploration drilling ought to be done to convert most of the inferred material into indicated.
4. all other projects of Newmont Ghana Gold Limited should be tested and see the effects of the three economic parameters on its net present value.

REFERENCES

Akbari, A. D., Osanloo, M., Shirazi, M. A. (2008) 'Ultimate pit limit determination through minimizing risk costs associated with price uncertainty'. *International Journal of Engineering*, vol. 19, no 5-1, pp 23-38.

Annels, A. E. (1991) *Minerals Deposit Evaluation, A Practical Approach*, Chapman and Hall, London, England, 436 pp.

Asabere, R. K. (2000) *Surface Mine Planning and Designing*" Unpublished MSC. Lecture Notes, University of Mines and Technology, Tarkwa, 113 pp.

Askari-Nasab, H. (2006). "Intelligent 3D Interactive Open Pit Mine Planning and Optimisation" Ph.D Thesis Report, University of Alberta, Edmonton, 167 pp.

Berg, B. L. (2004) *Qualitative Research Methods for the Social Sciences*. 5th ed. Boston: Pearson Education, Inc.

Burns N., and Grove S.K. (2005). *The Practice of Nursing Research: Conduct, Critique, and Utilization* (5th Ed.). St. Louis, Elsevier Saunders

Crawford, J. T. and Hustrulid, W. A. (1979), "Open Pit Mine Planning and Design", SME Mining Engineering Handbook, H. L. Hartman (ed.), 2nd edition, Vol. 1, American Institute of Mining, Metallurgical and Petroleum Engineers, New York, 99 pp.

Dagdelen K. (2001) "Open pit optimization—strategies for improving economics of mining projects through mine planning", 17th International Mining Congress and Exhibition of Turkey-IMCET, Ankara, pp. 117-121

Fourie, G. A. and Dohm Jr., G. C. (1992), "Open Pit Mine Planning and Design", SMEMining Engineering Handbook, H. L. Hartman (ed.), 2nd edition, Vol. 1, Society for Mining, Metallurgical and Exploration, Inc. Littleton, Colorado, pp. 1247 – 1297.

Holme, I. M., and Solvang, B. K. (1991), *Research Methodology: the Qualitative and Quantitative methods*. Student literature Publishers

Hustrulid, W. and Kuchta, M. (1995) *Open Pit Mine Planning and Design*, Balkema Publishing, Rotterdam

Jack, H. M. (2010) *Going for Gold: The History of Newmont Mining Corporation.* 1st edition. University Alabama Press

Koskiniemi, B.C. (1979)*Hand methods In Open Pit MinePlanning and Design,* ed. Crawford &Hustrulid.SME/AIME Transactions, pp. 187-195.

Kumekpor, K. B. (2002)*Research Methods and Techniques of Social Research*, Sonlife Printing Press and Services, Accra

Lerchs, H., Grossmann, L. (1965)*Optimum Design of Open-Pit Mines*. CIM Bulletin, pp. 47-54.

Lillico, T.M. (1974)*Economics and Open Pit Design – Beware of Break-Even Ratios*. International Journal of Rock Mechanics, Mining Science & Geomechanics Abs., Vol. 11(8), A17.

Lisa, M. G. (2008). *The Sage Encyclopedia of Qualitative Research Methods*. 1st edition. Sage Publications, Inc.

Loonergan, J. E. (2008), “Long-Term Mine Planning for Open Pit Mines”, Mintec Inc., Tuscon, AZ, USA, White Paper, 22 pp.

Mardon, C., Goode, A. J., and Rozman, L. I.(1995) Use of Whittle Four-D in the optimisation and analysis of Paddington stage 3, Presented to Optimizing with Whittle Conference, Perth

Mintec, Inc. (2012) Company: Developing smarter software solutions for more than 40 years. INTERNET http://www.minesight.com/en-us/company.aspx [Accessed 19August 2014].

Mireku-Gyimah, D. (2012) “Mineral Project Evaluation” Unpublished MSc. Lecture Notes in Mining Engineering, University of Mines and Technology, Tarkwa, Ghana, 64 pp.

Mohadini-Yahaya, A. (2006) “Open Pit Mines Design – A Case Study”, Unpublished MSc. Thesis Report, University of Mines and Technology, Tarkwa, Ghana, 116 pp.

Met-Chem (2014) Pit Design and Mining Development. Retrieved August 16, 2014, from Met-chem.com: http://www.met-chem.com/en/services/pit.aspx

Rolley, P. and Johnson, N. (1997) Aspects of geological uncertainty on the optimal open pit, Presented to Optimising with Whittle Conference, Perth, April.

Rossi, M. E. and Van Brunt, B. H.(1997) Optimizing conditionally simulated orebodies with Whittle 4D, Presented to Optimizing with Whittle Conference, Perth, April.

Rowdy B. and Phil J. (2008) “Whittle Mine Planning” Perth, Australia, 167 pp.

Lantuejoul, C. (2002) Geostatistical simulation; models and algorithms. Springer, Berlin.

Simon, P. (1997) Project Risk Analysis and Management GuideEdition.APM Group Ltd.

Steffen, O.K.H., W. and Holt, V.R.,(1970) Optimising open pit geometry & operational procedure; *Proc. Open Pit Mining Symposium*, Johannesburg; pp. 9-31

Tucker, S. A. (2000) "Optimal Open Pit Planning and Design", Unpublished MSc. Thesis Report, University of Mines and Technology, Tarkwa 173 pp.

Whittle, D. (1997). *The Relationship Between Economic Design Objectives and Reserve Estimates*, Proceedings of the Resources to Reserves Inputs Seminar, AusIMM, Melbourne

Whittle, G. (2004) *Global Asset Optimisation*, in Proceedings of Orebody Modelling and Strategic Mine Planning Conference, pp 361-366 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Whittle, G., Stange, W. and Hanson, N. (2007) Optimising Project Value and Robustness, in Proceedings International Mine Management Conference, pp 139-147 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Whittle, J. (1988) '*Beyond Optimisation in Open- Pit Design'*. in Kostas, F. (ed.). *Proceedings of the First Canadian Conference for Computer Applications in the Minerals Industry*, held 7-9th March 1988 at Balkema, Rotterdam, pp. 331 – 337.

Whittle, J. (1993) "The Use of Optimisation in Open Pit Design", Whittle Programming Proprietary Limited, Melbourne, Australia. 40pp.

Whittle, J. (1990) 'Open Pit Optimisation in Surface Mining'. In Kennedy, B. A.(ed) *Conference Proceedings of Society for Mining, Metallurgy and Exploration*, Inc, Colorado, Chapter 5 3 pp 470-475 www.edumine.com (An introduction to mining investment 2015.)

Zhao, Y., Kim, Y.C. (1992) *A New Ultimate Pit Limit Design Algorithm.*23rd APCOM, pp. 423-434.

Zucker, D.M. (2001) *Using case study methodology in nursing research: The Qualitative Report*