Economic Evaluation of the Kottraverchy Pit Deposit of Gold Fields Ghana Limited, Tarkwa Mine

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Abstract

Kottraverchy pit is one of the pits of Gold Fields Ghana Limited, Tarkwa Mine (TGL). The auriferous orebody at the pit consists of a succession of stacked tabular palaeoplacer units consisting of quartz pebble conglomerates. Operations at the pit has been halted since 2016, due to technical reasons. The mine intends to revisit the pit. For mining to resume at the Kottraverchy pit, the economic viability of the deposit must be determined per current economic and technical factors. The objective of this research work is to determine the economic viability of the Kottraverchy pit deposit. A final pit design has been developed for the exploitation of the deposit, under the given geotechnical and economic factors. The total tonnage of ore from the final pit design was 4 669 685 t. A Life of Mine (LoM) schedule predicted a mine life of 4 years. With a gold price of US$ 1 200/oz. and minimum rate of return (MRR) of 9.8 %, the project's net present value (NPV) would be US$ 8.31 M and the internal rate of return (IRR) is 28 %. Consequently, it is concluded that the Kottraverchy gold project would be economically viable. From the sensitivity analysis, it is inferred that the project will continue to be profitable until the gold price decreases beyond 8 % or the operating cost increases by more than 12 %.

Keywords: Internal Rate of Return Value, Discounted cash flow analysis, Sensitivity analysis

1 Introduction

The Gold Fields Ghana Limited, Tarkwa Mine (TGL) operates under seven mining leases covering a total area of approximately 20 825 hectares. TGL is located in South-Western Ghana near the Southern end of the Tarkwa Basin, within the auriferous Ashanti Belt and is 300 kilometres by road west of Accra, the capital of Ghana (Anon, 2012). The ore body at the Tarkwa Mine consists of a succession of stacked tabular palaeoplacer units consisting of quartz pebble conglomerates (gravel beds called reefs). The mine is currently mining multiple narrow reef horizons from three open pits. The Kottraverchy pit is one of the pits of the Tarkwa Mine. Operations at the pit has been halted since 2016 due to technical reasons. The mine intends to revisit the pit. For mining to resume at Kottraverchy, the economic viability of the mineral deposit must be evaluated, per current economic and technical factors. Involved with any evaluation of a major mineral project are a review of the original resource data, recalculation of the ore resource estimate and optimisation of the pit on the geologic model by considering the gold price, mining cost, processing cost, selling cost, the geologic model, the geotechnical slopes and the consequent determination of a suitable pit design for the deposit (Nsiah-Afriyie, 2015).

The systematic approach to open pit optimisation and design include: orebody modelling; assignment of attributes, such as grade, tonnage factors, resultant value derived from mining cost, processing cost and revenue, to the unit blocks of the block model (Rossi and Deutsch, 2014; and Osterholt and Dimitrakopoulos, 2007); using an optimisation algorithm to determine feasible pit outlines from which the outline with the highest Net Present Value (NPV) can be selected as optimal pit (Whittle and Vassiliev, 1997); and designing the detailed pit with safe ramps and berms (Mariko and Mireku-Gyimah, 2018). A mine project that is taken through this process will be executed successfully and profitably, without fear of risk or uncertainties (Nsiah-Afriyie, 2015).

The focus of this study is to evaluate the reserve of the Kottraverchy gold deposit and verify its feasibility through the recalculation of the ore resource, pit optimisation and pit design.

1.1 Location of the Mine

The Tarkwa Mine of Gold Fields Ghana Limited is an open pit mine located in Tarkwa, Western Region of Ghana. It is approximately 300 km west of Accra, Ghana’s capital city. The coordinates are approximately at latitude 5° 15’ N and longitude 2° 00’ W. Access to the Mine is by a tarred road and rail, which connect the mine to the port of Takoradi. From the Takoradi port to TGL by either means of transport is approximately 60 km southeast. Fig. 1 shows the location of the Kottraverchy pit on the TGL concession.

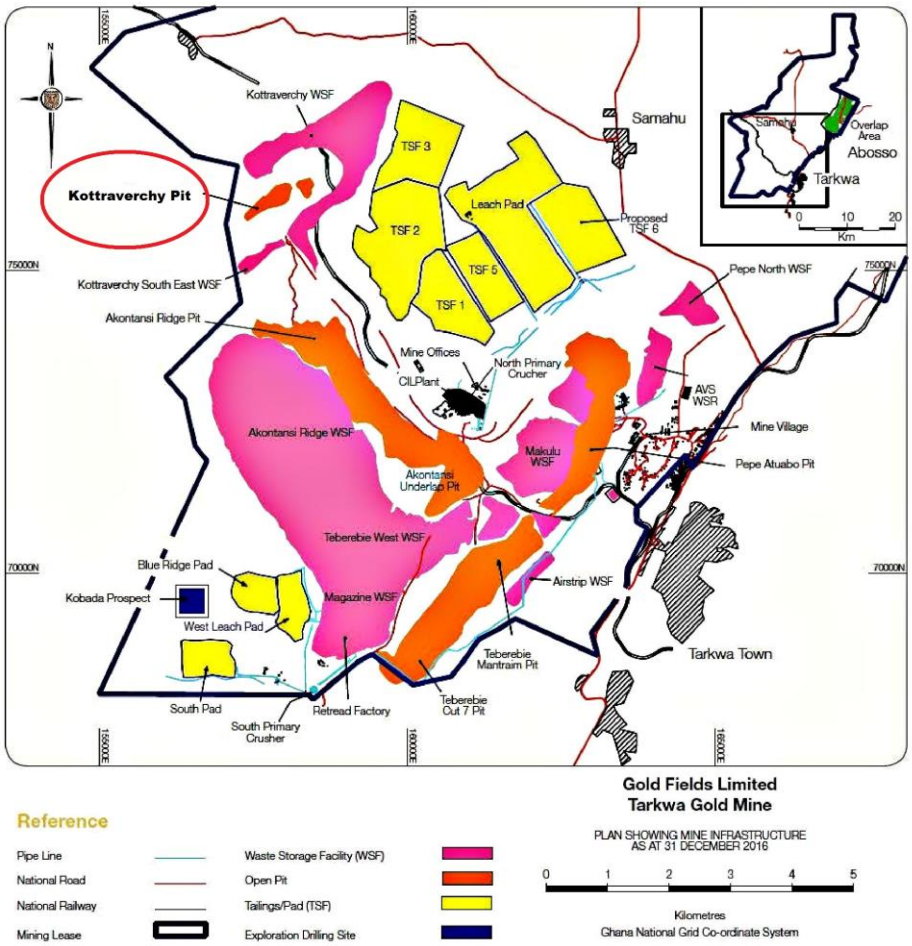

Fig. 1 Location of the Kottraverchy Pit on TGL Concession (Anon., 2012)

1.3 Physiography of the Study Area

The Tarkwa Mine is located in the tropical rain forest of Ghana which experiences high precipitation during the wet season that runs from April to November and a relatively lower precipitation during the dry season that runs from December to March (Davy-Constant, 2014). The seasons are primarily influenced by the moist southwestern monsoon winds during the rainy seasons, and dry northeastern trade winds (Harmattan) during the dry seasons.

The temperatures in the area are typically between 24° C and 36° C, with humidity as high as 90 % during the wet season and as low as 60 % during the peak of the dry seasons.

Annual rainfall in the Tarkwa area averages about 1700 mm, but annual and seasonal fluctuations are becoming increasingly pronounced. Storm events that deposit more than 70 mm in an hour are frequent.

The vegetation in the area is typically rainforest, characterised by tall and thick trees and tall grasses. However, a substantial portion of the vegetation has been removed due to timbering and mining.

The topography of the mine site is dominated by pronounced ridges, which reflect the underlying structural geology. The area is drained by secondary streams towards the west. There are no major rivers located on the mine property (Avane, 2009).

2 Materials and Methods Used

The drill hole data for resource estimation and parameters for pit optimisation and design were all provided by TGL. The annual tonnages and mine grades for the project were generated from project schedule based on the final pit design generated using Geovia Whittle and Surpac. A Life of Mine (LoM) schedule carried out in Alastri Tactical Scheduler predicted a mine life of 4 years.

Discounted cash flow analysis was used to evaluate the economic viability of the project while sensitivity analysis was conducted to assess the level of independent changes in the economic parameters that the project could absorb and still be economically viable and to determine the economic parameter that is most sensitive to viability of the projects.

2.1 Resource Block Modelling and Estimation

2.1.1 Variogram Modeling

Data for the resource estimation, comprising of 1 231 Reverse Circulation (RC) drill holes and 222 Diamond Drill (DD) holes were obtained from the Mineral Resource Department of TGL. Semi-variograms were generated for each of the four estimation domains namely, A1, A3, AFC1 and AFC3, to quantify the magnitude of the anisotropy within each domain. The anisotropy parameters (Table 1) were used to determine weights during the resource estimation.

Table 1 Variogram Parameters for the Reefs

Domain	Max. Search Radius	Plunge	Dip	Bearing	Major/Minor	Major /Semi-Major	Nugget	Sill	Range	Model
A3	52.001	53.22	89.86	253.67	1.66	1.37	0.46	0.82	52.001	Sph
A1	61.21	53.21	89.87	252.60	4.04	1.48	0.397	0.97	61.21	Sph
AFC3	100.12	52.27	89.77	258.47	4.65	1.00	0.335	0.68	100.12	Sph
AFC1	45.23	53.99	89.88	262.16	1.04	6.06	0.202	1.00	48.23	Sph

2.1.2 Block Modeling

A block model was generated from the orebody wireframe model using the Block model tool in Surpac. A block size of 25 x 25x 3 m was chosen in the X, Y, and Z directions respectively, based on careful analysis of possible equipment, mining method and mining selectivity, together with the geology of the orebody at Gold Field, Tarkwa Mine (Assibey-Bonsu and Krige, 1999). A total of 209 266 blocks were created in the orebody wireframe model. Each block model was filled with attributes, which contain properties used in assessing the orebody. All the attributes were created within SURPAC using Attributes tool, which is part of the Block modelling tools. The block model parameters are shown in Table 2.

Table 2 Summary of Block Model Parameters

Parameter	X	Y	Z
Minimum Coordinate (m)	3000	7000	-280
Maximum Coordinate (m)	5000	13000	200
User Block Size (m)	25	25	3
Minimum Block Size (m)	25	25	3
Rotation (°)	0	0	0

2.1.3 Resource Estimation

The Ordinary Kriging algorithm was used to estimate the resources of the Kottraverchy deposit, as it is known to perform better in the Tarkwaian palaeoplacer deposit (Al-Hassan and Adjei, 2015;

Abotsi, 2014; Al-Hassan and Fiadonu, 2014; Davi-Constant, 2014; Annels, 1991). The measured resource was classified according to the SAMREC Code at a cut-off grade of 0.42 g/t.

2.2 Pit Optimisation

The Gemcom Whittle software was used for the pit optimisation. The resource block model was imported into Whittle. After the various parameters for the optimisation was set, the optimisation was run to produce a set of nested pits. The flow chart for the pit optimisation is shown in Fig. 2 Table 3. shows the economic and technical parameters used for the pit optimisation.

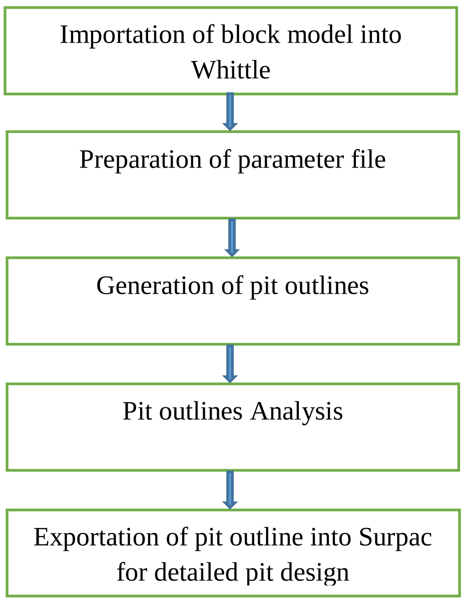

Fig. 2 Flow Chart for Pit Optimisation Using Gemcom Whittle (Appianing and Mireku-Gyimah, 2015)

Table 3 Kottraverchy Optimisation Parameters

Parameter	Value
Metal price	US$ 1,200/oz
Processing cost	US$ 9.42/tonne
Royalty	5 %
Discount rate	9.8 %
Ore premium	US$ 0.30/tonne
Waste haul (per bcm)	y = 0.123x + 4.4698 ; where x = elevation
Drill and Blast	US$ 0.72/tonne
Grade control	US$ 0.01/tonne
Management fee	US$ 0.30/tonne
Technical Services	US$ 0.17/tonne
Oxide slope angle	27°
Transition slope angle	40°
Fresh slope angle	40°

2.2.1 Pit Outline Analysis

Anon. (1998) defines pit shell as the outline generated as a result of a pit optimisation which contains the blocks worth mining. The pit outlines were analysed based on the best and worst case scenarios. The best-case scenario involves mining out the first pit and then mining out each subsequent pit shell from the top down, before starting the next pit shell. On the other hand, the worst-case scenario involves mining each bench completely before starting on the next bench. The advantage of the best case scenario lies in setting an upper limit to the achievable Net Present Value although its schedule is seldom feasible because the push-backs are usually too narrow(Appianing and Mireku-Gyimah, 2015; Anon, 1998).

2.3 Kottraverchy Pit Design

The ultimate pit generated from the pit optimisation is a theoretical pit as it lacks access ramps, berms and strictly follows the jagged outline of the orebody (Nsiah-Afriyie, 2015). The triangulated surface and contour outline of the base pit was imported into Surpac. The final pit design would incorporate haul roads, berms and benches. The design began from the bottom of the pit (base string) and expanded upwards to intersect the surface topography. The design was done using the expansion tools in Surpac. The switchback type of ramp was used. The ramp width was set at 30 m for dual lane, at gradient of 10 %. The width was selected considering the dump trucks size and allowance for space between the dump trucks and the edge of the ramp. After designing the pit to the surface, a digital terrain model (dtm) was generated from the pit strings and intersected with the surface topography dtm. The parameters that were used to design the pit are shown in Table 4.

Table 4 Kottraverchy Pit Design Parameters

Parameter	Value
Bench height	18 m
Flitch	3 m
Minimum bench width	30 m
Pit bottom elevation	-54 mRL
Ramp width	30 m dual lane
Ramp gradient	10%
Oxide face angle	27°
Transition face angle	75°
Fresh face angle	75°

2.4 Financial Analysis

The objective of the financial analysis is to provide realistic cost estimates that would serve as the basis to evaluate the economic viability of the mineral project. No cost of capital was included for infrastructure, site works, processing plant and mining equipment, since the pit of interest is part of the pits of an already operating mine. Thus, for this project, only the operating cost was estimated. The basis for the cost estimate are given below:

i. The cost estimate for the mining operations is based on contract mining. Equipment operation and maintenance are carried out by the contractors;

ii. All costs are based on working regime of 2 shifts/day, 10 hr/shift for 360 days/year;

iii. Capital expense was included to account for the cost of stripping;

iv. Escalation of operating cost is not considered;

v. All costs are made in US dollars.

The operating cost is estimated per tonne of ore mined and treated. It is categorised into two forms; Mining cost and Processing cost.

The mining cost comprises the contractors' and mine supervisors' cost.

The processing cost encompasses the cost of all owner workers, excluding the mine supervisors. It also includes the owner vehicles' maintenance and operating cost, mine office cost, treatment plant's maintenance and operating cost, grade control cost, and assaying cost. Table 5 gives a summary of the annual operating cost estimates per tonne of ore mined and treated. The cost estimates were provided by TGL.

Table 5 Summary of Operating Cost Estimates

Item \ Year	0	1	2	3	4
Mining Cost (@ US$ 2.87/t)	0	6 333 157	13 528 181	20 571 920	31 322 540
Processing Cost (@ US$ 14.78/t)	0	6 193 536	11 946 226	19 708 572	27 592 109
Total Operating Cost (US$)	**0**	**12 526 693**	**25 474 407**	**40 280 492**	**58 914 649**

2.4.1 Revenue Estimation

The Annual Gross Revenue (AGR) is calculated as:

AGR = Recovered metal (g) x Gold price ($/g) (1)

The gross revenue for each operating year was estimated using the following data

i. Estimated tonnage productions of 419 048 t, 808 270 t, 1 333 462 t, and 1 866 834 t for years 1, 2,3 and 4 respectively;

ii. Average mill head grade of 1.03 g/t, 1.16 g/t, 1.34 g/t and 1.58 g/t for years 1, 2, 3, and 4 respectively;

iii. Base case gold price of US$ 1 200/oz.;

iv. Mill recovery of 97.2 %; and

v. Mine Call Factor (MCF) of 97 %.

2.4.2 Investment Decision Criteria

There are numerous criteria for measuring the economic viability of projects. For this work, criteria used are the Net Present Value (NPV) and Internal Rate of Return (IRR) as they have been found to have widespread use in the mining industry.

Net Present Value (NPV)

The net present value (NPV) is the difference between the present value of the expected cash inflows and the present value of the expected cash outflows (Kite, 1995). It can be expressed mathematically as (Mireku-Gyimah, 2017):

NPV = ΣPV of Cash Inflows @ i - ΣPV of Cash Outflows @ I (2)

Where i is the minimum rate of return

A positive NPV (NPV > 0) indicates that the project is considered economically viable. When the NPV is zero (NPV = 0), the project breaks even. The project is considered economically unacceptable when the NPV is negative (NPV < 0)

Internal Rate of Return (IRR)

The IRR is defined as the discount rate that makes the present value of the cash inflows equal to the present value of the cash outflows in a capital budgeting analysis, where all future cash flows are discounted to determine their present values (Hayes and Abernathy, 2007). It may also be defined as the interest rate at which the NPV of a project is equal to zero It may be expressed mathematically as (Mireku-Gyimah, 2017):

IRR = r for which ΣPV of Cash Inflows @ i = ΣPV of Cash Outflows @ i, or

$$\text{IRR} = r \text{ for NPV @ } r = 0 \qquad (3)$$

Where: r = the interest rate; and

i = the Minimum Rate of Return (MRR).

When IRR is greater than the minimum rate of return (MRR), the project is considered economically acceptable. The project breaks even when the IRR is equal to the minimum rate of return. When the IRR is less than the minimum rate of return, the project is considered economically not acceptable.

2.4.3 Cash Flow Analysis

The discounted cash flow was used to examine the economic viability of the Kottraverchy mineral project because of its simplicity and wider acceptability. The Net Present Value (NPV) and Internal Rate of Return (IRR) investment decision criteria were used for assessing the profitability of the project. The following parameters were used considering the Mining and Mineral laws of Ghana (Anon., 2006):

i. A royalty of 5 % is payable on the gross revenue;

ii. An income tax of 35 % is payable on the taxable income;

The cash flow is also based on the following parameters:

iii. The gold price of US$ 1 200/oz. is provided by Gold Field Ghana Limited;

iv. NPV discount rate of 9.8 % is provided by Gold Fields Ghana Limited; and

v. A rate of US$ 1/oz. on the gross revenue, is payable to Gold Fields Foundation.

2.4.4 Sensitivity Analysis

Sensitivity Analysis of a mineral project refers to the investigation of the effect of changes in the project's economic parameters such as capital cost, revenue and operating cost on the economic viability of the project. Sensitivity analysis is required because the project's economic parameters are all only estimates, and can change over time.

The approach is to vary one of the economic parameters while keeping the others constant and calculating the NPV and IRR consequent to the changes. A graph of the NPV and IRR against the changes in the economic parameter will give the effect of the change in the parameter on the viability of the project (Arroja and Baafi, 2018).

3 Results and Discussion

3.1 Resource Block Model

Since some part of the resource blocks have been mine out, the resource model was depleted to the current topography of the pit. From the study, the measured resource constitutes about 6.3 Million tonnes with an average grade of 1.31 g/t Fig 3 shows the measured resource blocks estimated below the current topography of the Kottraverchy pit.

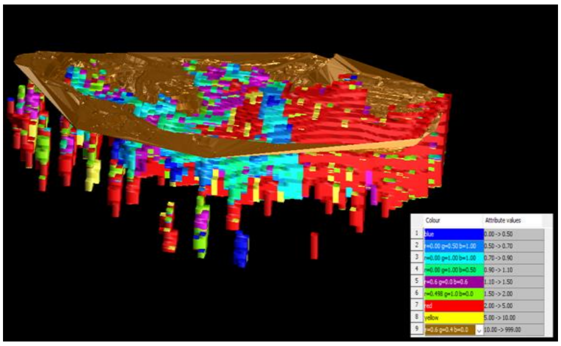

Fig. 3 3D View of the Measured Resource Blocks below the Current Topography of the Kottraverchy Pit.

3.2 The Pit Optimisation Results

Whittle generated 32 nested pits from the optimisation sequence. 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. The pits and their corresponding NPVs were imported into Microsoft Excel to plot graphs for analysis. Pit shell 17 was selected because it generated the highest Net Present Value of US$ 10 Million for the best-case scenario (Fig. 4). The pits and their corresponding NPVs are shown in Table 6. It can be seen from the table that the NPV increases gradually to Pit 17 and then starts reducing afterwards.

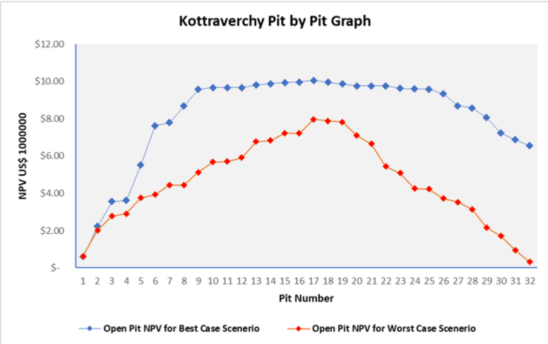

Fig. 4 Pit by Pit Graph of the NPV against the Pit Shells

Table 6 Pit Numbers and their Corresponding NPVs

Pit	NPV (US$)
12	9 678 789
13	9 810 597
14	9 885 787
15	9 940 321
16	9 966 625
17	10 064 380
18	9 964 383
19	9 874 501
20	9 764 379
21	9 763 287
22	9 760 379

3.3 The Final Pit Design

The detailed pit design was carried out in Surpac using the optimal pit outline of pit 17, which was generated by the Whittle optimiser. Final pit design was required because the ultimate pit (Fig. 5) lacks access ramps and berms. The pit design was done based on the optimal pit shell so that the Net Present Value of the design would be almost the same as the selected shell. The final pit design is shown in Fig. 6.

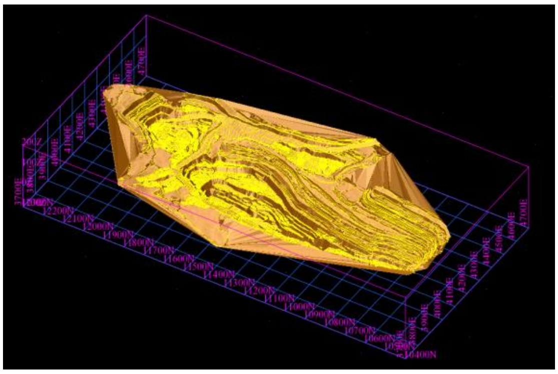

Fig. 5 Kottraverchy Ultimate Pit

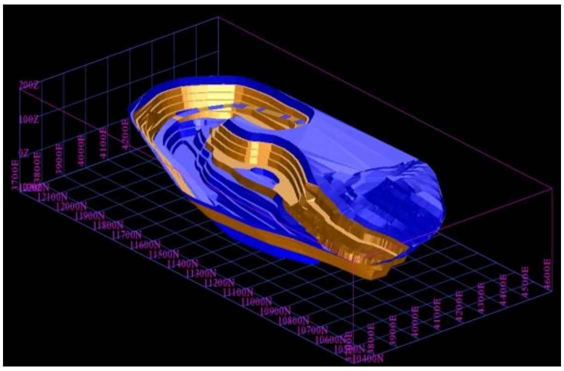

Fig. 6 Kottraverchy Pit Design

The optimal pit output was compared to the final pit design output to verify whether there was significant difference between the outputs of the two designs. The optimal pit produced 4.5 Million tonnes of ore at an average grade of 1.38 g/t whereas the pit design produced 4.7 Million tonnes of ore at an average grade of 1.37 g/t. Fig. 7 is a graph showing a comparison between the optimal pit and the pit design tonnages. It can be inferred from the graph that the ore and waste tonnages of the optimal pit compares well with that of the final pit design.

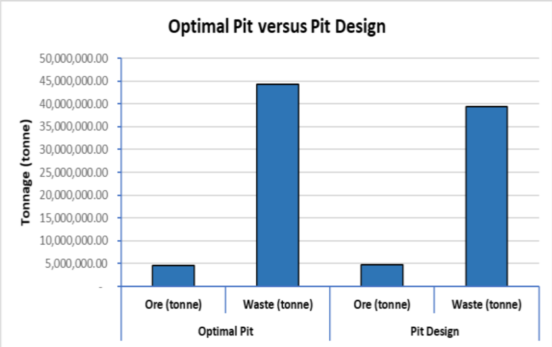

Fig. 7 Tonnage Comparison between Ultimate Pit and Pit Design

3.4 Project Financial Analysis

The annual tonnages and respective mine grades used in generating the discounted cash flow are from the project schedule which is based on the final pit design for the Kottraverchy deposit. The results of the discounted cash flow analysis are summarised in Table 7. At a Minimum Rate of Return (MRR) of 9.8 %, the Net Present Value (NPV) is $8 307 673.13, and Internal Rate of Return (IRR) is 28 %. This shows that the project is profitable, owing to the fact that the NPV is positive and the IRR is greater than the MRR.

Table 7 Discounted Cash Flow Model for Kottraverchy project

Gold Price= US$ 1,200/oz					
Project Life = 4 yrs					
Mine Call Factor (MCF) = 0.97					
Recovery = 0.972					
Discount Rate = 9.8 %					
Item / Year	0	1	2	3	4
Total Ore Tonnes (t)	0.00	419,048.45	808,269.69	1,333,462.24	1,866,854.46
Mined grade (g/t)	0.00	1.06	1.20	1.38	1.63
Head Grade (g/t)	0.00	1.03	1.16	1.34	1.58
Recovered Ounces (oz)	0.00	13,438.07	29,332.80	55,649.50	92,153.86
Gross Revenue (US$)	0.00	16,125,679.08	35,199,361.65	66,779,397.52	110,584,631.16
Less:					
Royalty (@ 5 %)	0.00	806,283.95	1,759,968.08	3,338,969.88	5,529,231.56
Gold Fields Foundation	0.00	13,438.07	29,332.80	55,649.50	92,153.86
Capital Expense (CAPEX)	0.00	24,225,407.03	17,030,385.39	9,986,641.27	2,520,732.17
Operating Cost	0.00	12,526,693.34	25,474,406.98	40,280,492.35	58,914,649.34
Taxable Income	0.00	(21,446,143.31)	(9,094,731.60)	13,117,644.52	43,527,864.22
Less:					
Income Tax @ 35 %	0.00	(7,506,150.16)	(3,183,156.06)	4,591,175.58	15,234,752.48
Cash Flow	0.00	(13,939,993.15)	(5,911,575.54)	8,526,468.94	28,293,111.74
NPV (9.8 %)	$ 8,307,673.13				
IRR	28%				

3.2 Sensitivity Analysis

Figures 8 and 9 show the results of the sensitivity analysis. It can be inferred that the project will continue to be economically viable until the gold price decreases beyond 8 %. Again, the project will cease to be viable should the operating cost increases by more than 12 %. The project is sensitive to changes in gold price than in operating cost.

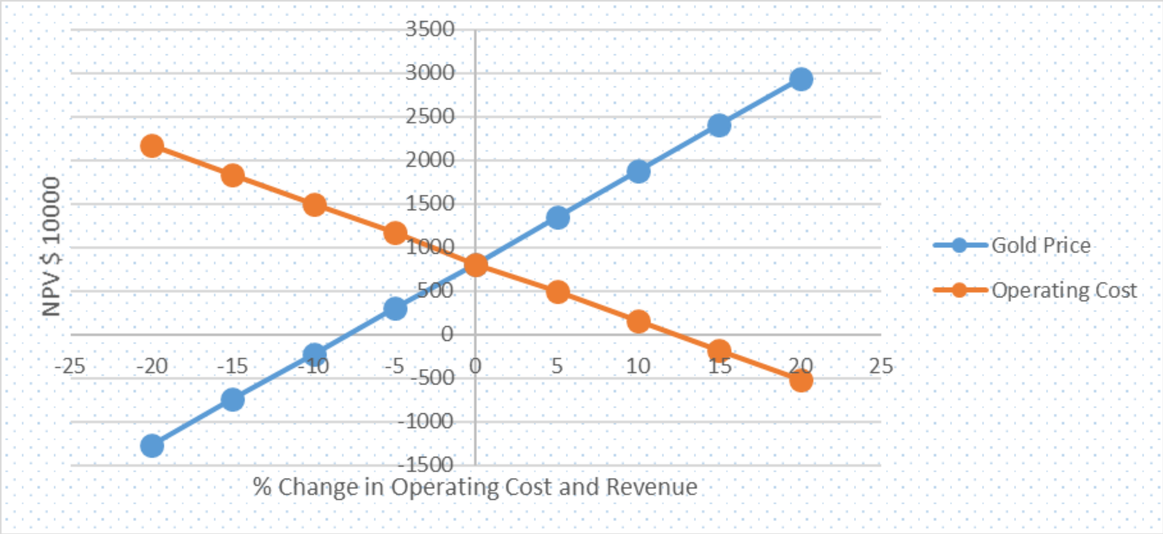

Fig. 8 Variation of Economic Parameters with NPV

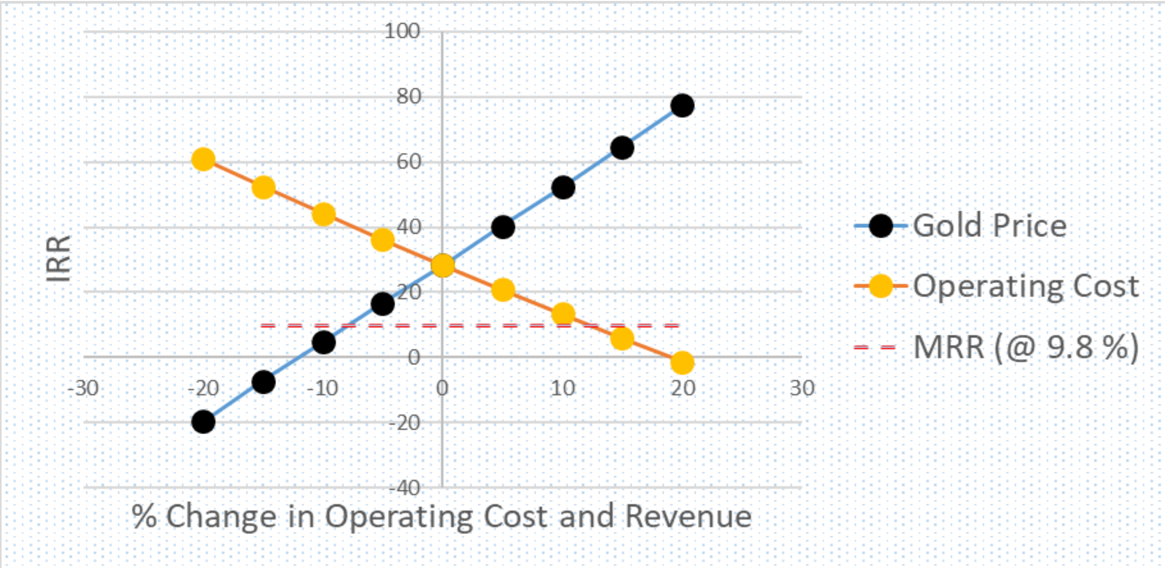

Fig. 9 Variation of Economic Parameters with IRR

4 Conclusion and Recommendation

4.2 Conclusion

The pit design produced 4.7 Million tonnes of ore at an average grade of 1.37 g/t, and 39 Million tonnes of waste. The project would have a stripping ratio of 8.4:1.

With a gold price of US$1 200/oz and MRR of 9.8 %, the project's NPV is US$ 8.3 Million and the IRR is 28 %.It is concluded that the Kottraverchy project is economically viable. The sensitivity analysis shows that the project will continue to be profitable until the gold price drops more than 8 % or the operating cost increases beyond 12 %.

3.2 Recommendation

It is recommended that Gold Fields Ghana Limited, Tarkwa mine resume mining at Kottraverchy pit, as the project is economically viable with an NPV of US$ 8.3 M and IRR of 28 %.

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