Open Pit Optimisation and Design of Tabakoto Pit at AngloGold Ashanti Sadiola Mine Using Surpac and Whittle Software*

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Abstract

This paper demonstrates the application of Surpac and Whittle in open pit optimisation and design. Exploration data on the Tabakoto deposit of AngloGold Ashanti Sadiola Mine (AASM) has established 13 652 661 t of gold resource with an average grade of 1.15 g/t that could be mined using open pit method. The aim of this paper is to optimise and design a pit to mine the deposit safely and profitably using Surpac and Whittle software. The work entailed: block modelling of the Tabakoto deposit using Surpac; importing the block model to Whittle for pit optimisation; and importation of the optimal pit back to Surpac for detailed pit design. In all, 55 nested pit outlines were generated but the one with the highest Net Present Value (NPV) of US$3 185 637 was selected as the optimal pit. The optimal pit contains 446 750 t of ore at an average grade of 1.709 g/t and 2 310 910 t of waste while the designed pit has 444 982 t of ore at an average grade of 1.683 g/t and 2 416 988 t of waste. It can be seen that using the optimal pit as base, the designed pit has less tonnes of ore, a lower grade and more waste. The difference in values is due to the expansion of the pit bottom and the creation of a ramp and berms in the designed pit which resulted in some ore loss and dilution. Again, the designed pit contains only 32.59% of the gold resource established by exploration, but the ore contained in the designed pit is what, under the current economic and geotechnical constrained, can be mined profitably and safely.

Keywords: Block Modelling, Optimal Pit, Pit Design, Surpac, Whittle

1 Introduction

The objective of open pit optimisation and design is to determine, prior to the start of mining operations, the final shape and size of the pit which contains ore that can be mined safely and profitably, having taken account of vital factors such as: geological setting of the deposit and topography, grade distribution, cut-off grade and hence mineral resource and reserve; geotechnical characteristics that constrain bench height and slope stability; environmental constraints; mining and processing costs, recovery and mineral price (Frempong-Boakye, 2004; Amankwa, 2011; Baochie, 2013; Dongboi, 2013; Elias, 2013; and Akisa and Mireku-Gyimah, 2015).

The Stepwise approach to open pit optimisation and design mine 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 ramps and berms.

These processes are so complex, laborious and time consuming that the use of computer software is unavoidable. Fortunately, today, various open pit optimisation and design software have become available to the mining industry. These software include Vulcan, MineSight 3D, Datamine, NPVS, Mineshed, Whittle, Surpac, Surfer, IGant, Xeras. The selection of one or a combination of these software by a mining company is a matter of preference, familiarity or peculiar usefulness. In this paper, Surpac and Whittle are used for optimisation and design of an optimal pit for the Tabakoto deposit of AngloGold Ashanti Sadiola Mine in Mali, West Africa. The choice of Surpac and Whittle is a matter of their availability, the ease of importing files from one to the other and also because they are common and widely used in the global mining practice.

2 Resources and Methods Used

2.1 Resources

The exploration data of Tabakoto deposit obtained from AngloGold Ashanti Sadiola Mining (AASM) in Mali West Africa, was the data input for the open pit optimisation and design work carried out in this papers, using Surpac and Whittle Software. For reason of confidentiality, some changes were made in the data such as hole identification names and numbers. From the exploration data, AASM had estimated 13 653 661 tonnes of gold resource

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with an average grade of 1.15 g/t that could be mined using open pit method (Anon., 2016). Mining and processing cost are those assembled by AASM over the years from its open pit operations in Mali. The selling price of gold was prudently taken to be $35.36/g ($1100/oz).

2.2 Methods

The method comprises three essential steps:

(i) Generating of an economic block model of the deposit using Surpac;

(ii) Exportation of the block model to Whittle software for pit optimisation; and

(iii) Exportation of the optimal pit from Whittle back to Surpac software for detailed pit design.

2.2.1 Generating of an Economic Block Model of the Deposit Using Surpac

Drill Hole Data Management

The drill hole data was arranged into four text files in Microsoft excel format which could be used in Surpac software for block modelling. The reason for drilled hole data processing was to present the data in a suitable form that facilitates block modelling using Surpac software. The text files were collar, survey, assay and geology. Tables 1, 2, 3 and 4 show the part list of each text file respectively.

Table 1 Part of the Collar Text File (Collar. Txt)

Hole ID	Northing (Y)	Easting (X)	Elevation (Z)	Max_ depth (m)	Hole Type
AB01	1532550.016	215791.4039	156.4383907	40	RC
AB02	1532549.931	215822.5858	156.6551794	40	RC
AB03	1532549.992	215879.0323	157.7654524	40	RC
AB04	1532549.95	215926.4391	159.2967053	30	RC

Table 2 Part of the Survey Text File (Survey. Txt)

Hole ID	Depth (m)	Dip	Azimuth
AB01	0	-52	91
AB02	60	-52	91
AB03	401.3	-55	92.5
AB04	0	-55	277

Table 3 Part of the Assay Text File (Assay. Txt)

Hole ID	Depth (m)	Dip	Azimuth
AB01	0	-52	91
AB02	60	-52	91
AB03	401.3	-55	92.5
AB04	0	-55	277

Table 4 Part of the Geology Text File (Geology. Txt)

Hole ID	Depth From (m)	Depth To (m)	Rock Type
AB005	0	2	LAT
AB005	2	4	LAT
AB005	4	6	LAT
AB005	6	8	LAT

Loading and Creation of Database

The Surpac database is an organised collection of data as a table of fields and records. After loading the text files into the Surpac database, drill hole layout and sections of the deposit were extracted from the database for plotting and display. The drill hole layout serves two significant functions:

(i) It helps engineers to study the plan and drillhole pattern and decide as to which planes to take the sections through.

(ii) It assists mining engineers and geologists to check drill hole collar coordinates against manually prepared maps as a way of validating the data.

The sections were taken within the area covered by the drill holes, that is between 1 533 050 N to 1 531 900 N, and 215 350 E to 216 450 E. Altogether, 15 sections were drawn at 10 m intervals. Figs. 1a, 1b and 1c show some of the sections. In each of the sections, the ore zones, constrained at 0.4 g/t cut-off grade, were delineated and digitised.

Creation of Solid 3-D Model

The demarcated ore zones were stitched together to form a wireframe model. This wireframe model was then validated to form a solid 3-D model (Fig. 2). When using Surpac, an area digitised in the clockwise direction encloses a solid block while an area digitised in the anticlockwise direction encloses as a void.

Creation of Empty Block Model

From the solid 3-D model an empty block model was created with the following information: block model identification name, origin, extent, and unit block size. Table 5 is the report of the block model while Fig. 3 shows the empty block model.

Table 5 Block Model Extent

Type	Northings (Y)	Eastings (X)	Elevation (Z)
Minimum Coordinates	1532500	215470	-3
Maximum Coordinates	1532820	215950	183
User Block Size	10	10	3
Total Blocks	9279		

Filling the Empty Block Model with Attribute Values

Attributes were added into the empty unit blocks in order to contain the information of each unit block in the block model. Some model attributes value and characters were filled into the model directly whilst others had to be assigned by interpolation. Fig. 4 presents the unit blocks in the block model and their attributes where the attributes of a unit block is shown. The attribute refers to the characteristics or the properties of a mineral such as grade, density, and orezone.

Addition of Constraints

The addition of constraints was primarily to control the selection of blocks from which interpolations were made or from which information was obtained (Appianing, 2015). Some constraints were: Digital Terrain Model (DTM) of the topography, which was used as a limit between the air and the rock, grade which was used to demarcate the waste and the ore, all the blocks that had a grade value below 0.4 g/t were considered as waste and those with values of 0.4 g/t and above were considered as ore. The grade of each block was estimated by using Ordinary Kriging (OK) method. The variography was carried out in order to get estimation parameters for the ordinary kriging using the "Geostatistics-Variogram Modelling" menu in the Surpac.

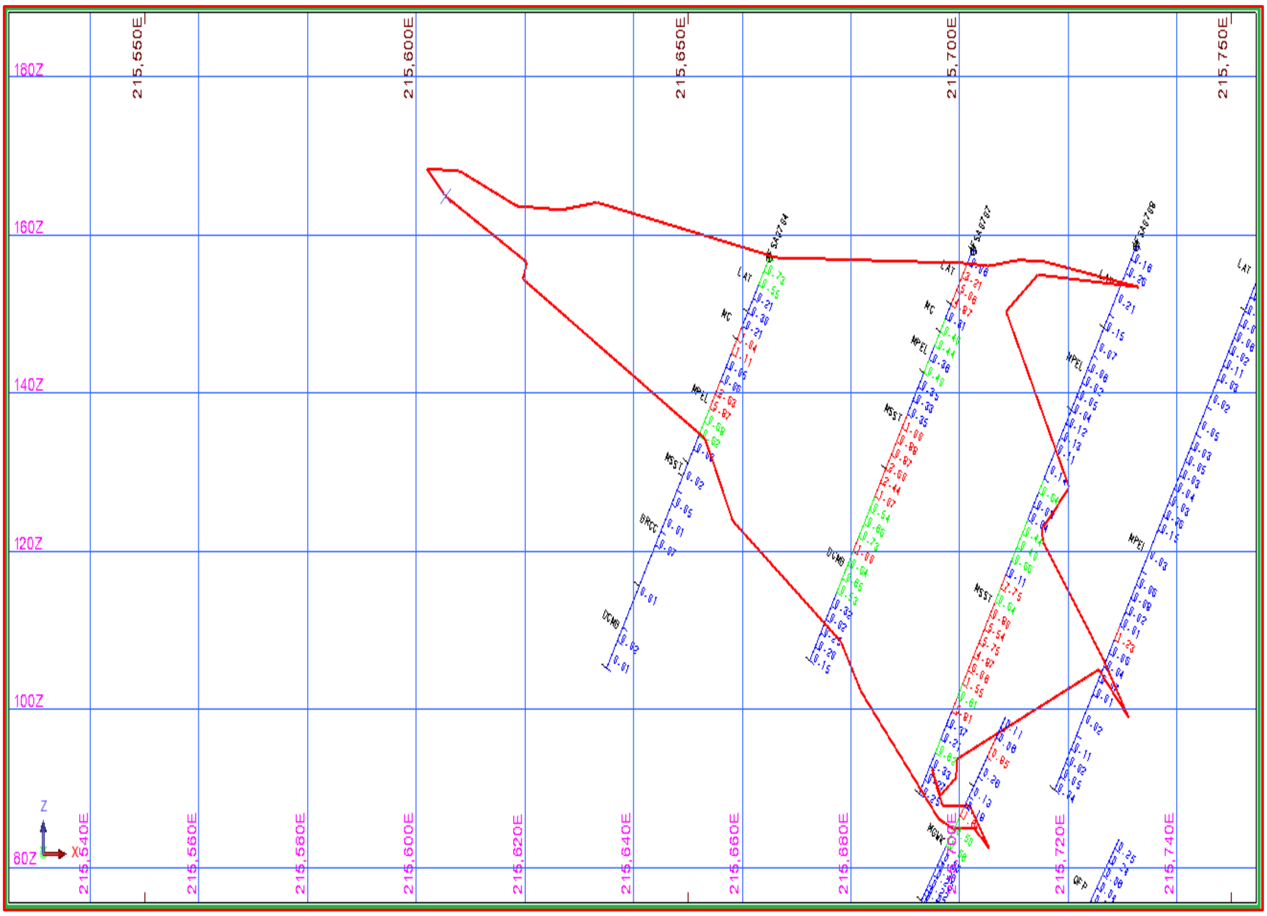

Fig. 1a Section at 1532710 N showing Digitised Ore Zone

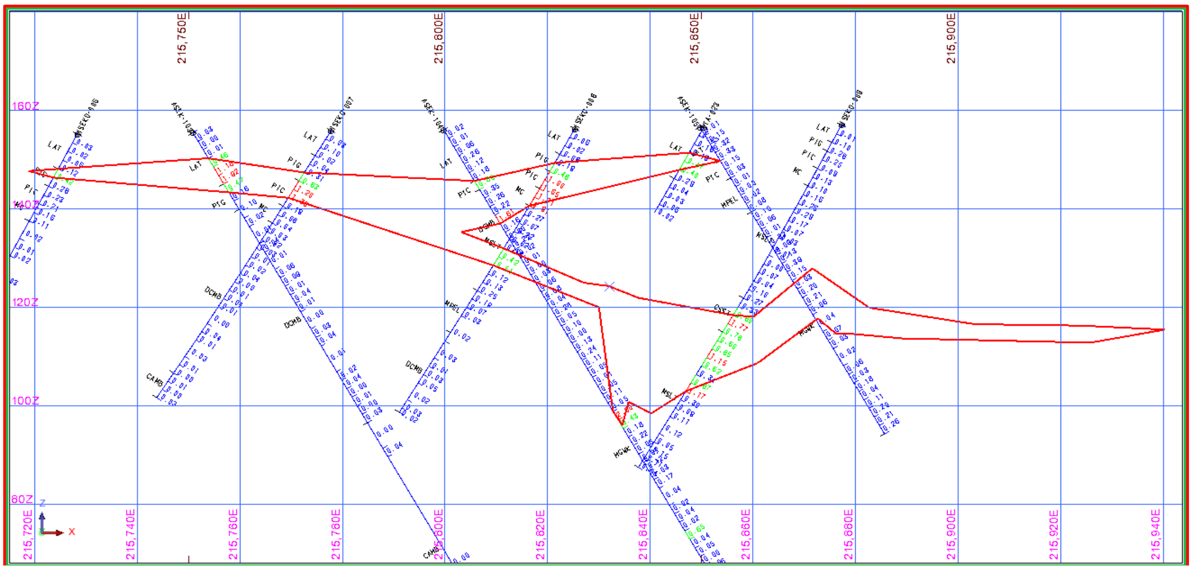

Fig. 1b Section at 1532520 N showing Digitised Ore Zone

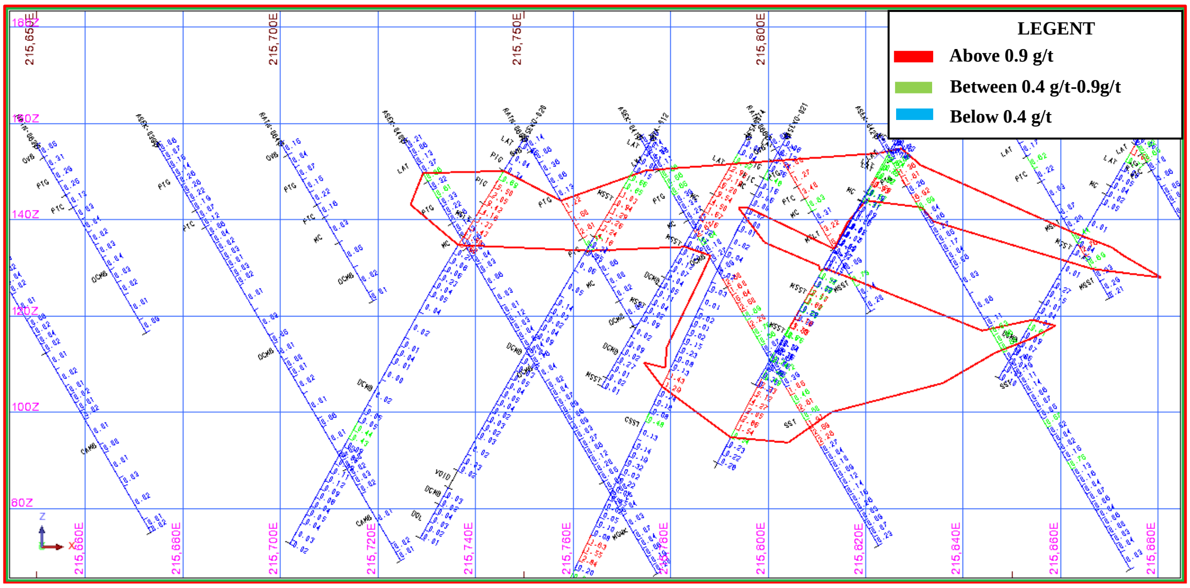

Fig. 1c Section at 1532600 N showing Digitised Ore Zone

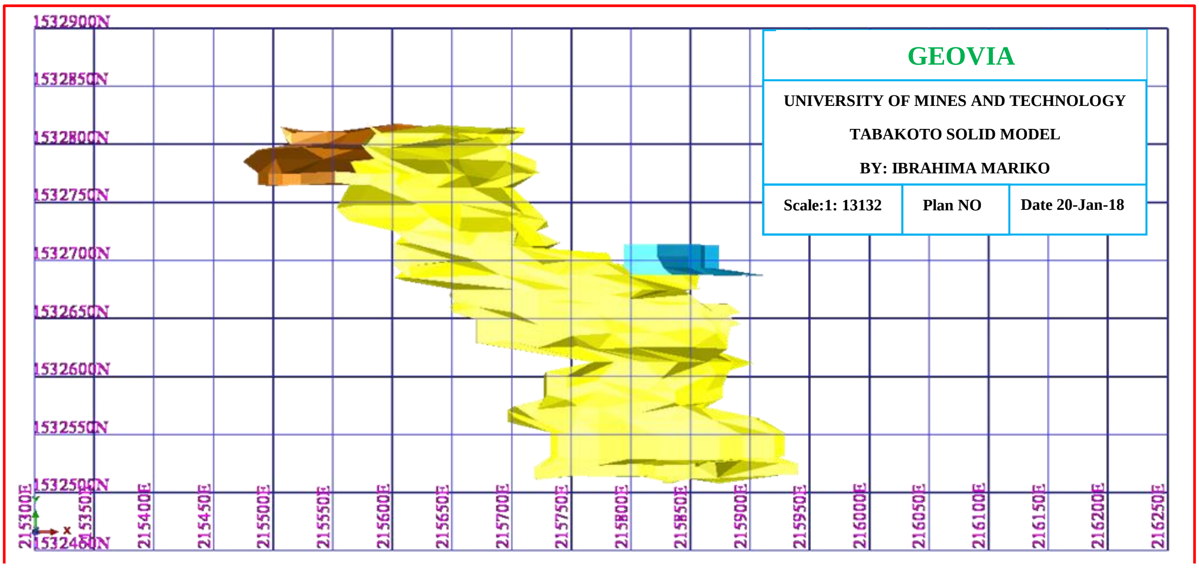

Fig. 2 Solid Model of the Tabakoto Deposit

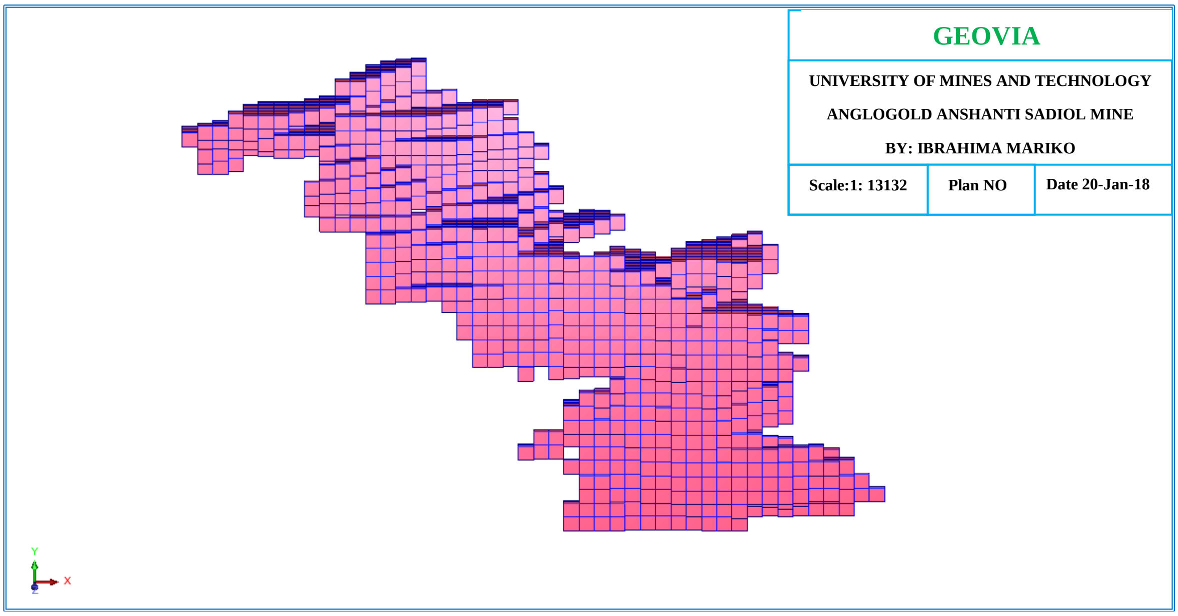

Fig. 3 Empty Block Model

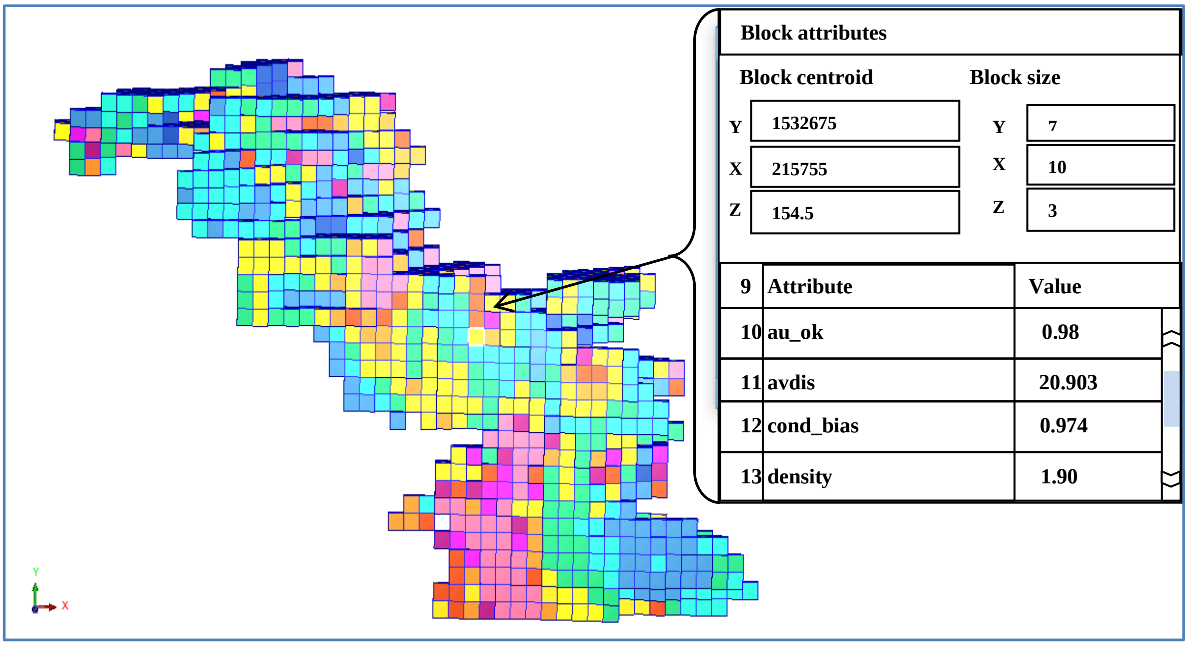

Fig. 4 Unit Blocks in the Block Model and their Attributes

2.2.2 Exploration of the Block Model to Whittle Software for pit optimisation

Optimisation Using Whittle Software

The resource block model of the Tabakoto deposit (Fig. 4) was exported into the Whittle software to facilitate optimisation of the pit. The economic and technical parameters used for the optimisation are shown in Table 6. Fig. 5 shows a summary flow chart of optimisation in Whittle.

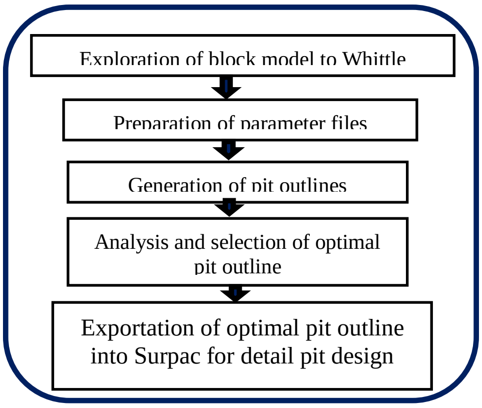

Fig. 5 Flow Chart of Optimisation in Whittle

Table 6 Parameters Used for the Optimisation

Cost per tonne of mining	**4.79**
Cost per tonne of processing	27.70
Gold price	$35.36/g ($1100/oz)
Selling cost	$2.62/g ($81.49/oz)
Capital cost	$5 788 234.47
Discount rate	10 %
Mining recovery	95 %
Mining dilution	5 %
Revenue factor range	from 0.84 to 2 at 0.02 steps
Overall slope angle	70°

Generation of Pit Outlines

In all, 55 nested pits outlines covering the range of revenue factor values from 0.84 to 2 defined in the parameters file and the model file. This was achieved through the 3-D Lerchs-Grossman algorithm employed by the Whittle Optimiser. The results were kept in a results file containing all blocks that must be mined to obtain the maximum value for a particular pit. The results file then became the input for analysis.

Analysis of Pit Out line

For each pit, the “best case”, “worse case” and “specified case” schedule analyses were performed. The graphics and spreadsheet of output data were generated to improve easy interpretation. Fig. 6 shows the total ore and the waste tonnages mineable in each pit and their cash flow values. The selection of the optimal pit could be based on various criteria such as: NPV, stripping ratio and cut-off grade. In this work, NPV was used to choose the optimal pit. The highest NPV was recorded at Pit 10 in the best-case scenario. The best-case scenario consists of mining out the smallest pit, and then mining out each subsequent pit shell from the top down, before starting the next pit shell; the worst-case scenario consists of mining each bench completely before starting on the next bench. A pit shell is the outline formed as a result of a pit optimisation which contains the blocks worth mining (Anon., 1998) and the specified case utilises cut-backs and scheduling information contained in the lower half tab of the schedule tab. These are user defined and generally aim at developing a practical schedule that results in a high NPV (Ayuba, 2014).

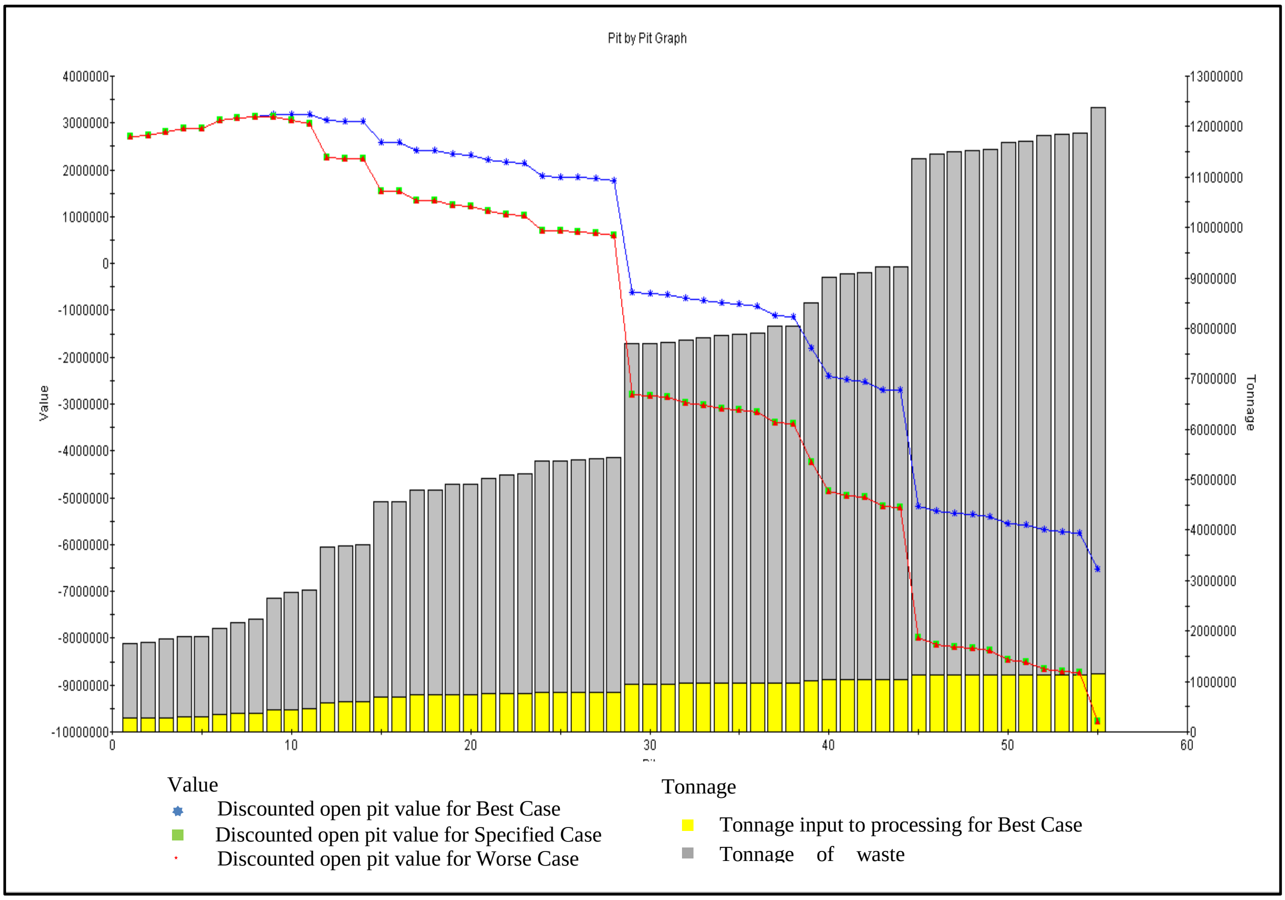

Fig. 6 Total Ore and Waste Tonnage versus NPV Value of Nested Pit

Selection of Optimal Pit

Pit 10 was selected as the optimal pit based on the highest best case NPV value of US$3 185 637. Table 7 presents the incremental pit value analysis that shows that the NPV increases gradually to Pit 10 and then starts reducing from Pit 11 onwards.

Table 7 Incremental Pit Value

Pit No.	NPV ($)
6	3 046 277
7	3 111 510
8	3 125 213
9	3 184 549
10	3 185 637
11	3 179 319
12	3 044 642

Sensitivity Analysis

Sensitivity analysis was conducted to see the variation in NPV when mining cost or gold price is varied between -10% and +10%. while the other remains constant Fig. 7 shows the changes in NPV as the gold price or mining cost varies. From Fig. 7 it can be observed that changing in gold price while keeping all other parameters constant is directly proportional to the NPV, the higher the gold price the higher the NPV and the lower the gold price the lower the NPV. On the contrary, the NPV is indirectly proportional to the mining cost, when the gold price is constant that is the NPV as the mining cost increases. Fig. 7 also shows that the NPV is very sensitive to the changes in gold price whist slightly sensitive to the mining cost.

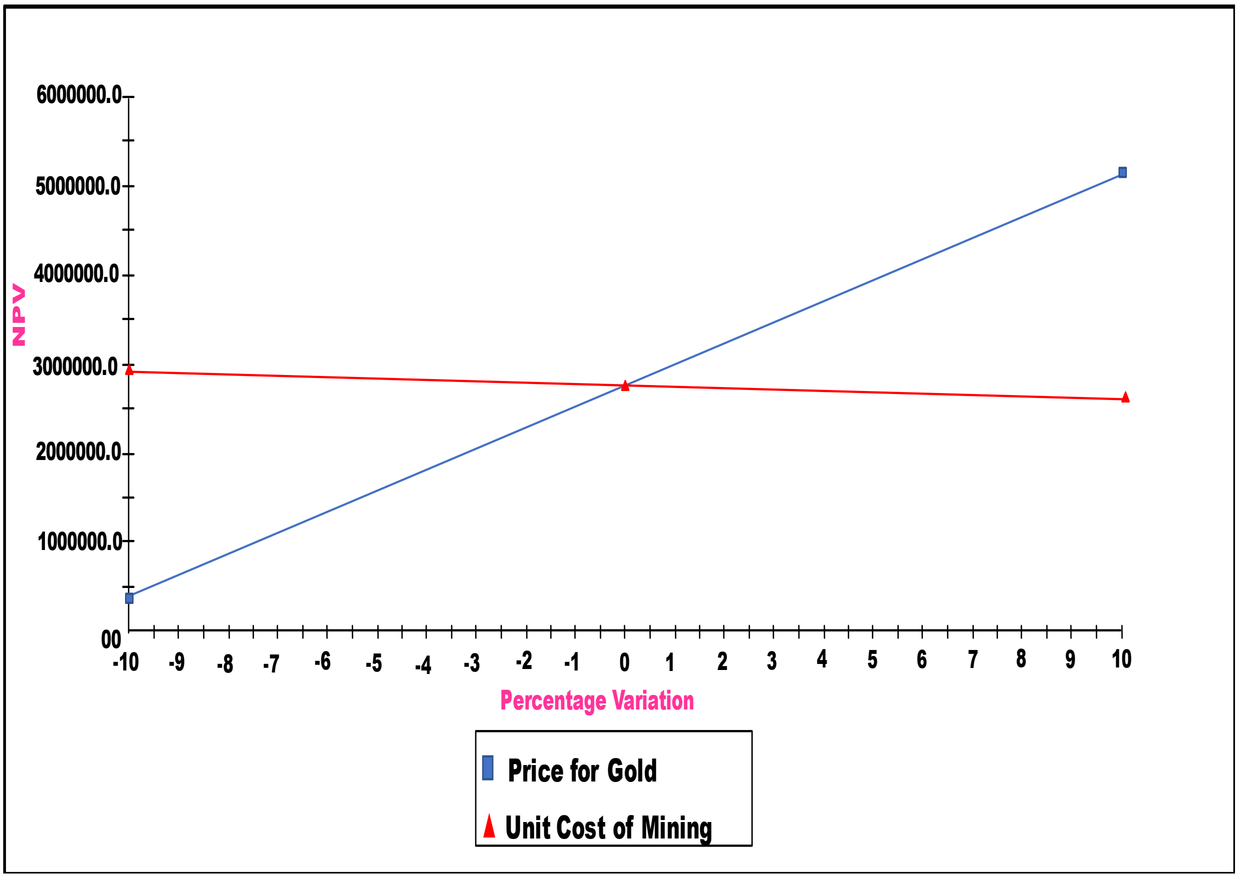

Fig. 7 Sensitivity of Discounted Cashflow (NPV) to Various Parameters

2.2.3 Final Pit Design Using Surpac Software

The optimal pit (Pit 10) from Whittle (Fig. 8) was exported into Surpac for detail pit design. The tools in the menu of Surpac Software were used for the design. The design procedure requires adding the missing parameters such as berms and other parameters. Table 8 shows applied design parameters. The selection of the parameters was done for the safety reason such as overall slope to keep the wall from collapsing, bench road wide and gradient to give suitable area for equipment flexibility.

Table 8 Design Parameters

Parameter	Units	Value
Ramp and Haul Road Width	m	25
Ramp Gradient	%	10
Type of Ramp		switchback
Overall Wall angle	degrees	70
Bench width	m	5
Bench height	m	10

The steps for final pit design process as follows:

(i) Pit base string creation;
(ii) Designing of ramp;
(iii) Intersection of the pit and topography.

Pit Base String Creation

The design began from the bottom of the pit to create more workable space and expanded upwards to the surface topography (Fig. 9). The optimised pit contour was used to create the base string. The contour was expended in such a way to contain the mineable ore blocks and at the same time follows the optimised pit contour. Fig. 10 shows detailed pit design while Fig. 11 shows the detailed design superimposed on the solid model.

Designing of Ramp

The pit was designed with switchback ramp and was created on the high wall elevations. A ramp of 25 m width was selected according to the size of dump truck at the gradient of 10%.

Pit-Topography Intersection

After designing the pit to the surface, a DTM of the designed pit was constructed and intersected with the DTM of the surface topography. The results were extracted to form a pit-topography string file and a DTM (Fig. 9).

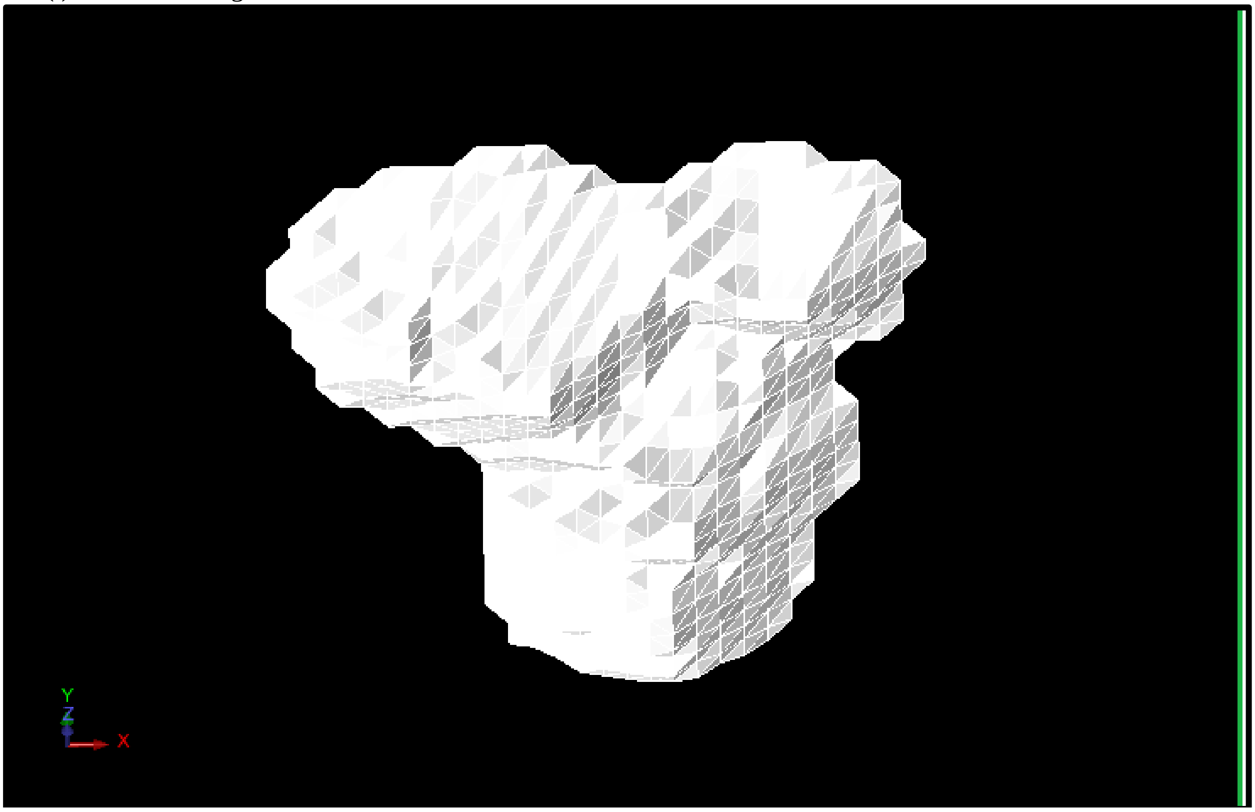

Fig. 8 Whittle Optimal Pit

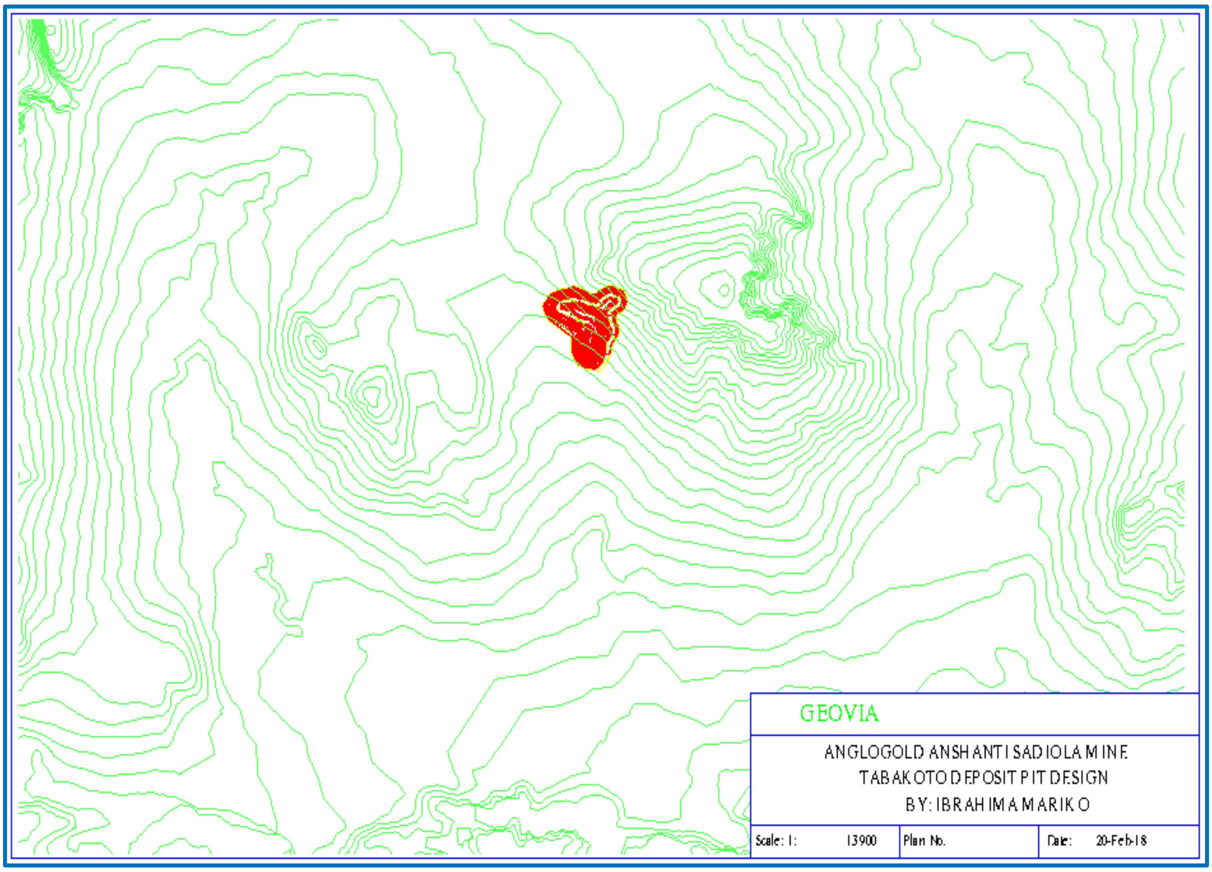

Fig. 9 Location of Tabakoto Pit in the Surface Topography of AASM

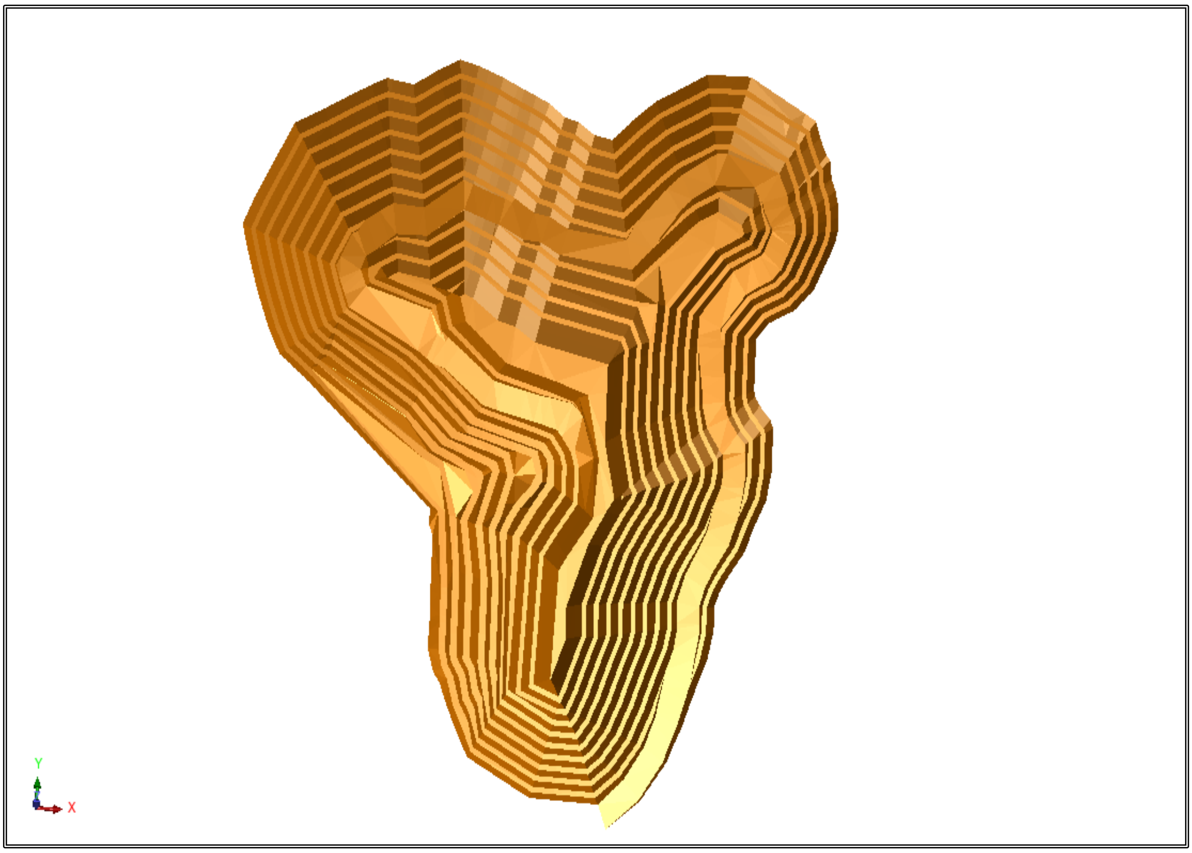

Fig. 10 Final Pit Design

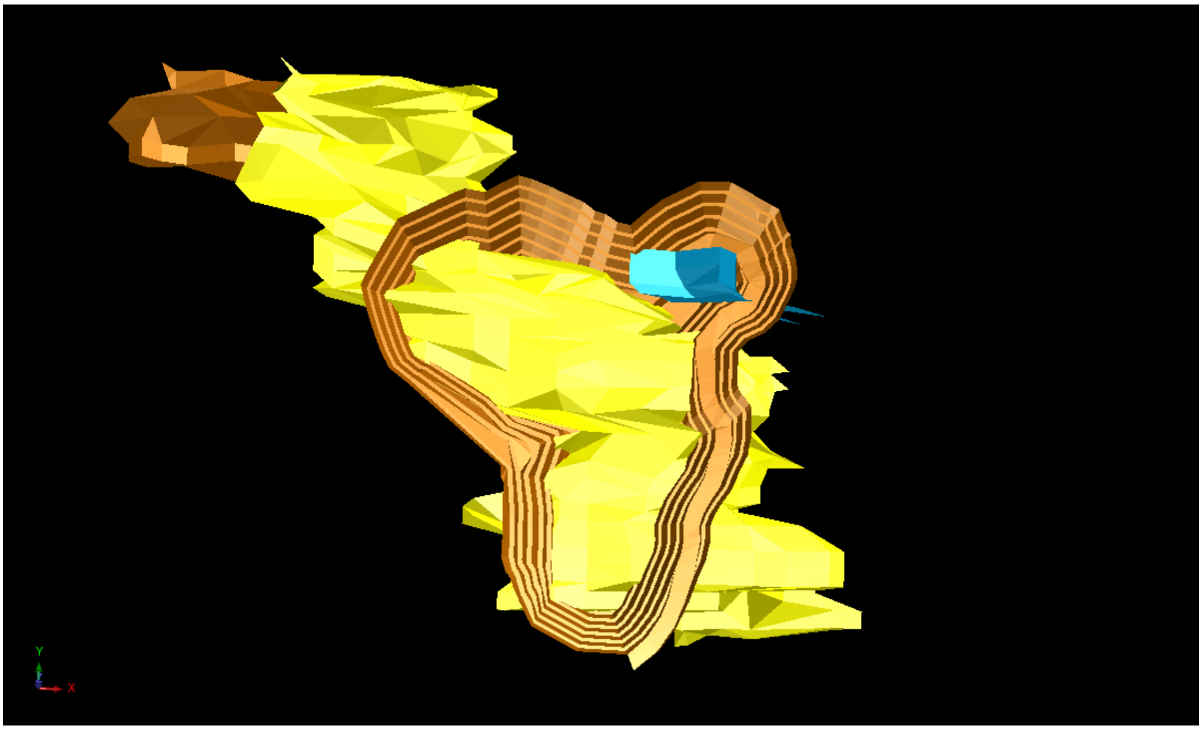

Fig. 11 Detail Pit Design Superimposed on the Solid Model

3 Results and Discussion

Exploration data on the Tabakoto deposit of AngloGold Ashanti Sadiola Mine (AASM) has established 13 652 661 t of gold resource with an average grade of 1.15 g/t that could be mined using open pit method. The aim of this paper is to optimise and design a pit to mine the deposit safely and profitably using Surpac and Whittle software. The results of the work are summarised in Table 9, from which it can be observed that using the optimised pit as base, the final pit design increased in total tonnes by 4% and decreased in grade by 2%. Also, the final pit design has a total ore of 444 982 t at an average grade of 1.683 g/t and expected recoverable gold of 704 130 g (22 638.29 oz) while the optimised pit has 446 750 t of ore at an average grade of 1.709 g/t and 717 879 g (23 080.33 oz) recoverable gold. Similarly, the NPV from the designed pit is 12% lower than the NPV from the optimised pit. The difference in values is due to the expansion of the pit bottom and the creation of a ramp and berms in the designed pit which resulted in some ore loss and dilution.

Table 9 Whittle Optimised Pit versus Final Pit Design

	Resource	Optimised Pit	Final Pit Design	Difference %
Pit Shell	-	10	10	
Ore Tonnes (t)	13 652 661	446 750	444 982	
Waste Tonnes (t)	-	2 310 910	2 416 988	
Total Tonnes (t)	**-**	**2 757 660**	**2 861 970**	**4**
Gold (g/t)	1.150	1.709	1.683	-2
Recoverable Gold (g)	-	717 879	704 130	-2
Stripping ratio	-	5.17	5.43	5
NPV ($)	-	3 185 637	2 815 283	-12

4 Conclusions

The purpose for this research was to examine the exploration data of Tabakoto deposit of AASM in Mali which was already planned to be mined using open pit mining method and use Surpac and Whittle to optimise and design a final pit that could be mined profitably and safely taking into consideration the geotechnical, geological and economic parameters. The following conclusions are drawn from this work:

(i) The optimised pit has 446 750 t of ore at an average grade of 1.709 g/t and 717 879 g (23 080.33 oz) of recoverable gold which would be mined with a stripping ratio of 5.17:1 and Net Present Value (NPV) of $3 185 637;

(ii) The final pit design will produce 444 982 t of ore at an average grade of 1.683 g/t, an expected recoverable gold of 704 130 g (22 638.29 oz) at a stripping ratio of 5.43:1 and expected revenue of US$24 899 433.88. The NPV is $2 815 283; and

(iii) The NPV of the optimised pit is very sensitive to changes in gold price while marginally sensitive to -10% and +10% variation in the mining cost

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