Estimation of Gold Resources from Exploration Drilling using Conditional Simulation - A Case Study*

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Abstract

Estimation of gold resources from exploration drilling has passed through various phases and methods at the AngloGold Ashanti, Iduapriem Mine Limited, Tarkwa in Ghana. From the use of Inverse Distance Weighting (IDW) to the use of Ordinary Kriging (OK) and currently the use of Uniform Conditioning (UC). This is all with a view of improving the estimations before the grade control drilling is undertaken for mine planning and subsequent mining. This paper compares the estimates obtained from exploration drilling using conditional simulation with the results from ordinary kriging and actual production figures on a block by block basis for areas that have already been mined in the deposit. The results show that estimates using conditional simulation and ordinary kriging are similar; and, both appear to underestimate the resources.

1 Introduction

AngloGold Ashanti (AGA), Iduapriem Mine Limited, Tarkwa is located about 10 km South of Tarkwa town and about 320 km West of Accra, Ghana's capital city (Anon, 2007). Tarkwa is located within the rainforest belt of Ghana and experiences a wet semi-equatorial climate characteristed by a lengthy rainy season from March to November and a relatively short dry season from December to February. Annual rainfall averages about 1500 mm (Al-Hassan, 2007).

The AGA Iduapriem Mine concession is made up of the former Teberebie and Ghana Austrialian Goldfield (GAG) concessions. The former mines both started as open pit mines in the early 1990's. In 1996 Ashanti Goldfields Company (AGC) Limited acquired the Iduapriem Mine and took over the Teberebie Mine in the year 2000. The year 2004 saw the merger of AGC with AngloGold of South Africa to form the AngloGold Ashanti (AGA) group. This brought about the renaming of the mines within the concessions as AGA Iduapriem Mine Limited.

2 Geology

The Iduapriem Mine is situated at the Southern end of the Tarkwa syncline of the Tarkwaian system of rocks (Griffis et al, 2002). The Tarkwaian system is made up of four distinct units which occur above the Birmiain system of the West African craton. The units are the Kawere conglomerates as the lowest unit followed by the Banket series, then the Tarkwa phyllite and lastly the Huni Formation. The Banket series is the most economically important unit as it hosts extensive gold deposits. The regional geology of southern Ghana and the location of Teberebie is as shown in Fig 1. Gold mineralisation at the AGA Iduapriem mine is confined to about a 50 m thick section of the Banket conglomerate series. There are four gold bearing units within the conglomerates made up of the sub-Basalt reef (A zone), the Basalt or Main reef (called the B zone), the West or Middle reef (the C zone) and the Breccia reef (D zone).

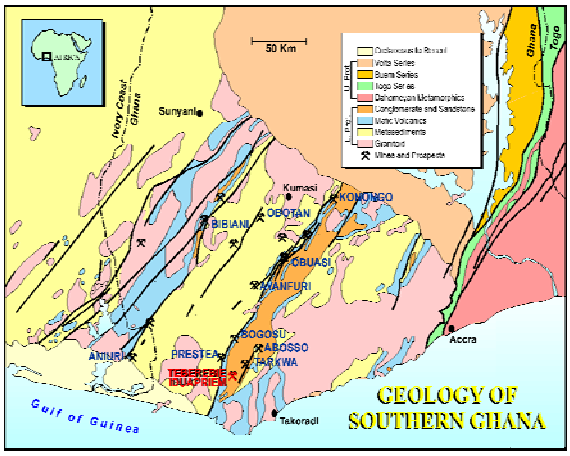

Fig. 1 Geology of Southern Ghana

Currently, mining takes place in the B and C zones only as the A and D zones are of relatively low gold grades (Griffis et. al., 2002). Fig. 2 shows a simplified section through the Teberebie pit.

3 Mining and Beneficiation

Mining at the Iduapriem mine currently is only taking place at the Teberebie pit with the conventional open pit mining method in use. After drilling and

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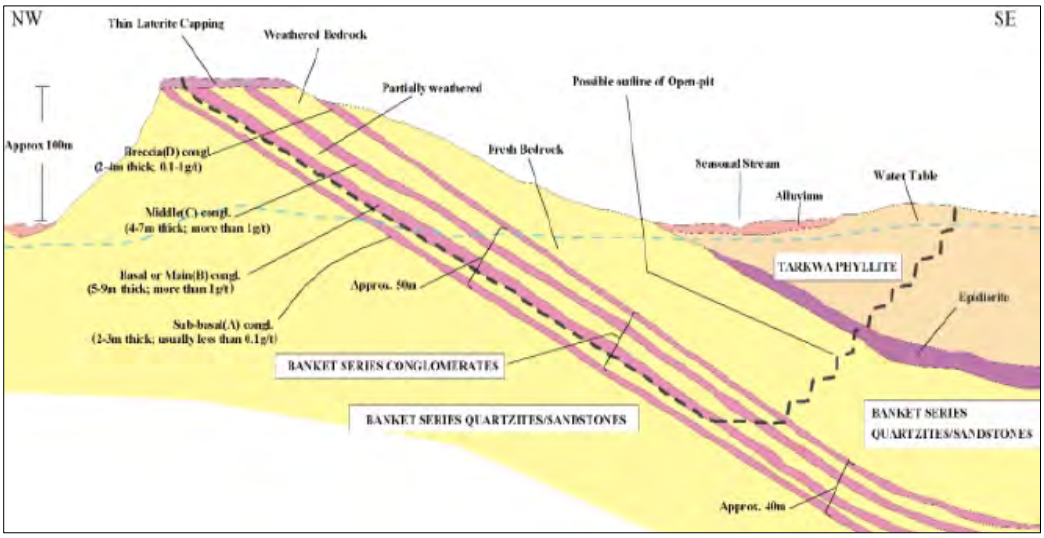

Fig. 2 A Simplified Section through the Teberibie Pit (After Griffis et al, 2002)

blasting Liebherr excavators are used to load a fleet of Catepillar 785 (150 tonne capacity) trucks which haul broken ore to a primary crusher just outside the pit and the product of the crusher is transported via a conveyor belt of over 5 km to the Iduapriem ore beneficiation plant. At the plant the run-of-mine ore is further crushed and ground. The finely ground material is slurried and pumped into leach tanks from where it gravitates to the carbon in pulp system of the plant for complete recovery of the gold (Anon, 2007).

4 Data Description

The data used in this paper was details from 64 exploratory drill holes. The drill holes, though not on a regular grid were aligned mainly in the East-West direction with average spacing of about 50 m (Fig. 3). The extent of the area used in the study was about 500 m by 450 m and over a single bench height of 6 m. The production figures used to compare the results of the estimates were for levels 1436 and 1439 in the three mineralised zones that were mined, from where the exploratory drill holes came.

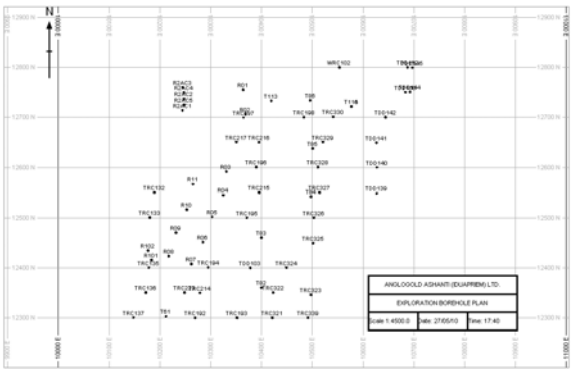

Fig 3. Plan of Exploration Drill Holes

The ordinary kriging estimates (obtained from the company) were also from the same area. The data was used to model the mineralised zones and to simulate the grade distribution using the Sequential Guassian Simulation (SGS) method for the comparisons.

5 Geological Modelling

Geological modelling was carried out using the Datamine Software with string modelling used to delimit mineralised zones within the area covered and a wireframe model was created by linking the closed strings. The wireframes then defined the mineralised volumes which were the basis of creating block models within the mineralised zone after the simulations were carried out. Fig 4 shows the three dimensional view of the wireframe model of the orebody. The samples within the wireframe were retrieved and used for further analysis.

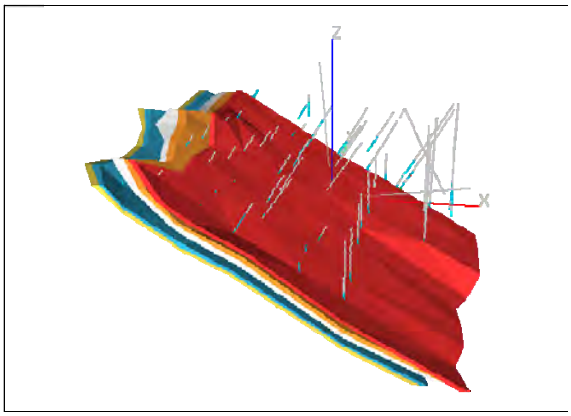

Fig. 4 Three Dimensional View of Wireframe Model

6 Statistical Analyses

The samples within the wireframe were retrieved and used for statistical analysis. The Datamine software statistical analyses tools were used to carry out a statistical summary of all exploration drill holes. Table 1 shows a part of the summary of the statistics as generated by the software

Table 1 Summary of Statistical Analyses

Parameter	All Drill Holes	Zone C	Zone B1	Zone B2
Samples	2981	228	416	303
Min Val (g/t)	0.01	0.04	0.07	0,08
Max Val (g/t)	15.06	8.95	11.9	7.6
Mean Val (g/t)	1.09	1.89	2.11	1.80
Variance $(g/t)^2$	1.95	2.25	2.14	1.77
Std Dev (g/t)	1.39	1.5	1.46	1.33
Skewness	2.74	1.70	2.26	1.52
Kurtosis	13.37	3.87	8.18	2.86
CV (%)	127	79	69	74

7 Conditional Simulation

The conditional simulation algorithm called SGS available in the Datamine (Studio 3) software was applied to the exploration data set. This algorithm requires that the distribution of the data to be normalised. The software does the normalisation automatically once the option is chosen in the dialogue box of the software (Anon, 2010). The data in the three zones were treated separately and used for their respective variography.

Variography of Transformed Data: Experimental semi-variograms were calculated in 4 directions 0^o, 45^o, 90^o, and 135^o in each of the three zones on a rotated axes used by the mine which is 008^o Azimuth and 32^o Dip. The semi-variograms appear to be isotropic in all the zones. The experimental points appeared to exhibit the characteristics of the spherical scheme; and were therefore fitted with simple spherical models. Table 2 shows the parameters of the models. A sample model is shown in Fig 5 for zone C normal score values.

Table 2 Summary of Normal Score Semi-variogram Models

Zone	C_0 $(g/t)^2$	a (m)	C $(g/t)^2$	Sill $(g/t)^2$
C	0.207	71.7	0.792	0.999
B1	0.241	21.1	0.758	0.999
B2	0.268	45.4	0.731	0.999

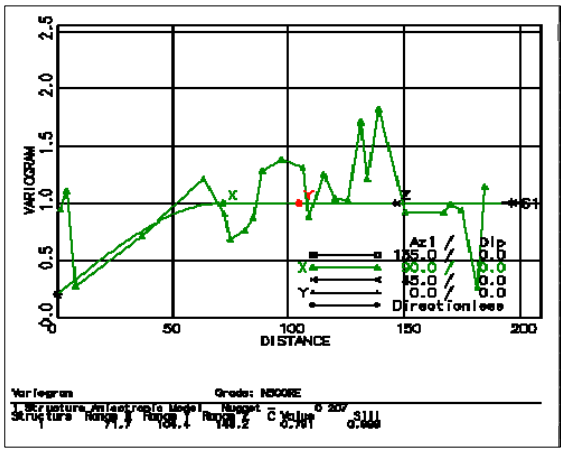

Fig. 5 Semi-Variogram Model for C Zone in 90° Direction

7. 1 Results of Conditional Simulation Estimates:

The SGS using the Datamine (studio 3) simulation module was carried out. In doing this, 30 realisations were generated in each zone using 5 m by 5 m by 6 m cuboids and with the minimum and maximum values for each zone as constraints. The exploration drill hole values used in each zone were those used in the simulation. The prototype used in the generation of realisations was the same but the wireframe model was used to constrain each zone of interest. The Datamine command ADDMOD was used to combine the zones into a single model which was used to evaluate the mining blocks.

In evaluating the mining blocks the average value of the 30 (realised) values in each simulated block was used and the results are shown in Table 3. This was premised on the fact that average values of all realisations at a point will be equivalent to the kriging estimate of that point (Vann et. al., 2002).

8 Comparison of Resource Estimation Results with Production Figures

To assess how the estimates from conditional simulation compare with estimates from ordinary kriging and the production figures, grades and tonnages of the individual blocks were compared. The detailed results of grades and tonnages from the mine for ordinary kriging and production figures are also shown in Table 3. Figs 6 and 7 show the comparisons of the grades and tonnages respectively on a block by block basis.

9 Discussion of Results

The statistical analyses showed that delimitation of mineralised areas into zones improved overall average values of gold grade. The Kurtosis and co-

Table 3 Results of SGS Estimates of Mined Blocks

		Conditional Simulation Estimation		Ordinary Kriging (Resource Estimation)		Ordinary Kriging (Grade Control)		Production Figures	
Block No.	Zone	Tonnage (t)	Grade Ave (g/t)	Tonnage (t)	Ave Grade (g/t Au)	Tonnage (t)	Ave Grade (g/t Au)	Tonnage (t)	Ave Grade (g/t Au)
2027	B1	16 406.6	1.934	15 637.9	2.123	18 594	2.03423	12 794.2	1.92
2028	B2	18 166.9	1.519	17 674.5	1.885	16 227	2.0215	18 110.1	1.81
2029	B1	15 379.7	1.932	15 327.2	2.189	19 761	1.91518	17 839.8	1.84
2030	B2	17 211.9	1.836	18 239.8	1.718	15 710	1.78572	18 560.6	1.66
2031	B1	15 316	2.057	16 366.7	2.026	18 436	2.24151	16 127.9	2.04
2032	B2	14 641.4	1.669	15 225.1	1.375	15 277	1.76155	21 173.5	1.61
2033	B1	22 160.6	2.273	15 716.7	1.772	23 378	1.71896	26 759.7	1.58
2034	B2	16 228.1	1.835	14 504.3	1.636	15 465	1.49607	22 344.8	1.38
2035	B1	22 447	1.821	21 332	1.927	22 391	2.12673	20 633.9	2
2036	B2	13 818.5	1.586	14 296.8	1.499	17 939	1.52209	21 804.2	1.39
3014	C	93 14.2	1.833	10 259.7	1.954	9 740	1.97313	11 172.4	1.92
3015	C	10 133.5	1.704	11 458	1.986	10 070	2.07206	12 974.4	2.09
3016	C	N/A	N/A	N/A	N/A	2 073	1.64839	4 144.6	0.96
3017	C	8 103.2	1.637	8 494.2	1.626	11 487	1.63012	12 163.5	1.31
3018	C	N/A	N/A	N/A	N/A	1 808	1.14325	4 234.7	1.05
3019	C	19 932.4	1.637	11 013.9	1.41	13 807	1.46558	16 668.5	1.29
3020	C	N/A	N/A	N/A	N/A	1 323	1.45752	3 694.1	1.34
3021	C	13 055.9	1.534	12 362.4	1.448	12 496	1.95639	16 938.8	1.83
TOTAL	**7**	**223 312.9**	**1.815**	**217 909**	**1.788**	**245 982**	**1.845**	**278 140**	**1.665**

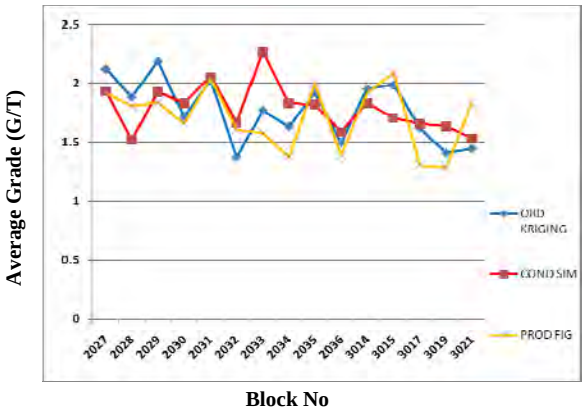

Fig 6. Comparison of Average Grades

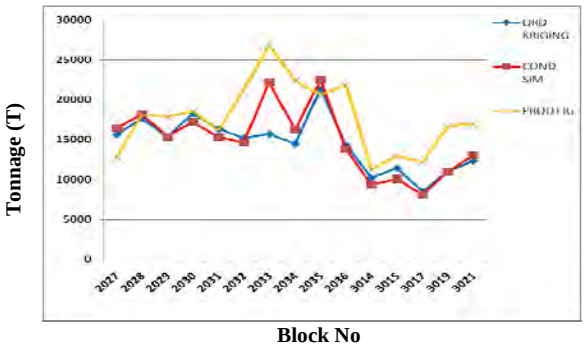

Fig. 7 Comparison of Estimated Tonnages with that Produced

efficient of variation (CV) values confirm that the distributions of gold grade values in all the zones are not normal.

Estimated values of the mining blocks from conditional simulation were not very different from those obtained from ordinary kriging except for block 2033 which happens to fall in B1 zone where from variography has a very short range and is therefore highly variable.

The comparison of estimates with production figures again shows some similarities in terms of gold grade values but the tonnages from production were consistently higher.

10 Conclusions

From the results obtained from conditional simulations and discussions it can be concluded that:

- Delimiting ore zones improves expected average grades of mineral resources.
- Estimates using Ordinary Kriging and conditional simulation gave similar and reasonable average grades of mining blocks though tonnages were underestimated in both cases when compared with production figures.

Recommendation

Based on the conclusions it is recommended that conditional simulation method can be used to estimate mineral resources from exploration data but the accuracy expected will be similar to that of the ordinary kriging method.

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