Estimation of Gold Resources Using Single and Triple Channel Sampling - A Comparative Study

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Abstract

Single and triple sampling methods were carried out at Kwasi Mensah Shaft, blocks 5 and 6 of Anglogold Ashanti, Obuasi mine to compare the grade models obtained from the two channel sampling methods and to determine the better channel sampling method in terms of estimation of ore grades and its cost implications. The data collected was analysed using descriptive statistics and ordinary Kriging estimation methods. The results from the descriptive statistics showed that there was no significant difference in the grades of gold produced by the two sampling methods. This was also confirmed by the Kriging estimation method which produced similar grades of gold for the single channel (6.50 g/t) and triple channel (6.56 g/t). Considering the cost associated with each of the methods, the triple channel sampling yielded a much higher cost of $ 296 230 than the single channel sampling cost of $ 113 440 due its labour intensiveness and the bulkiness of the samples. The single channel sampling is therefore the better channel sampling method in terms of cost implications compared to the triple channel.

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Key-words: Single channel sampling, triple channel sampling, ordinary Kriging, descriptive statistics

1. Introduction

The use of underground techniques to exploit for orebodies initially require sampling of crosscuts and reef drives in order to determine the representative grade for a particular zone of the orebody. Computation of the grade of the orebody involves generation of the grade model from the information obtained from sampling using the appropriate software. Channel sampling which consists of cutting continuous grooves or channels across the strike of the vein and collecting the resulting chips from each channel to make up the sample is practiced at Anglogold Ashanti Obuasi mine. Two methods: single channel which consists of cutting single continuous grooves and triple channel involving cutting triple continuous grooves sampling are conducted.

This paper seeks to compare the grade models generated from these two channel sampling methods and to determine the better sampling method in terms of cost and the estimation of the ore grades. This will serve as a guide for underground mines who practice channel sampling in their estimation techniques to make the best decision on the type of channel sampling methods to adopt

2. Geological Setting

The bulk of the gold deposits in Ghana are located on a number of gold belts in the Palaeoproterozoic rocks of the West African Craton. These rocks are sub-divided into the Birimian volcanics and Birimian sedimentary Supergroup and the overlying clastic Tarkwaian Group. The Birimian volcanic and sedimentary units were intruded by syn and post tectonic granitoids (Fig. 1). The system was subjected to intense folding, shearing, faulting and low grade greenschists metamorphism during the Eburnean tectonic event (Hirdes et al., 1990) The folds have a general NNE to SSW trend and plunge to the north-east. The deformational event produced pervasive shears and thrusts, which acted as channels for gold laden hydro-thermal solution which deposited its load at the right physio-chemical conditions to form the gold deposits. Gold mineralisation probably occurred at the last stages of the orogenic cycle (Hirdes et al., 1990).

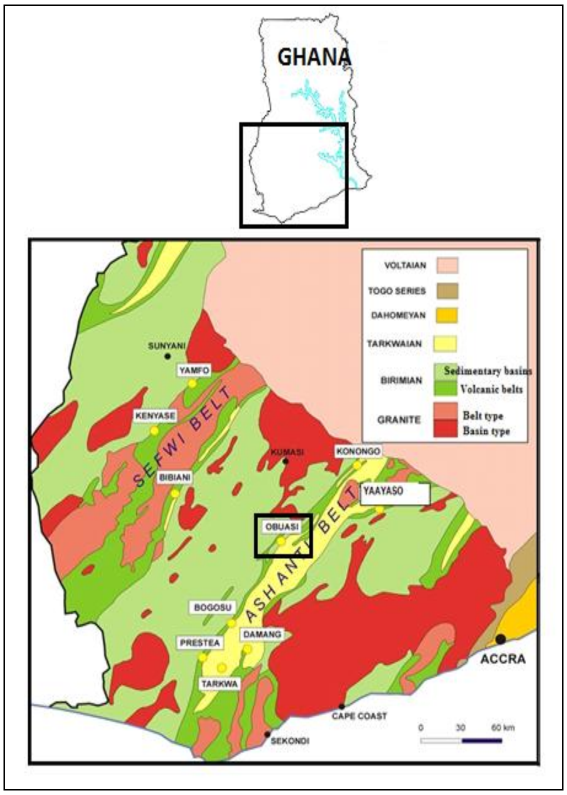

Fig. 1 Geology of south western Ghana showing the location of the study area on the Ashanti Gold belt (Anon, 2004).

2.1 Mine Geology

In the Obuasi area, the main ore channel from the town of Sansu to beyond Obuasi is a strong and very persistent zone of shearing and faulting. The reef comprised of very brittle and fractured lithologies that are associated with graphitic shears and joints (Goel and Wezenberg, 1999). Wherever these zones occur in the Birimian phyllites, they are usually indicated by veins and reefs of quartz in friable black "graphitic" schists and by shining black gouge and fault breccia. Birimian phyllites, schist, greywacke and metavolcanics of the Precambrian age are the major rock units in the immediate vicinity of the mine (Kesse, 1985).

According to Amanor and Gyapong (1989), the geology of Obuasi mine indicates that, the auriferous deposits are located in the extensive shear zone characteristically associated with carbonaceous schist. These fissures, which might have acted as ore solution channels are persistent both laterally and vertically, having been followed laterally for about 7 570 m and to the lower explored levels at 1 606 m below the surface. Two major shears, the steeply dipping Obuasi fissure and the flat dipping Cote D'or fissure join at the south section of the mine to form the main reef fissure. At the north section of the mine another prominent shear, the Ashanti spur, branches off to the west of the Obuasi fissure.

2.2 Stratigraphy

The rocks of the Obuasi area can be classified as superficial deposits, Tarkwaian Group, Birimian Supergroup and intrusive rocks (Amanor and Gyapong, 1989). Superficial deposits consist mainly of alluvium solids and terrace gravels which have been deposited as a result of weathering and erosion. The Tarkwaian Group consists mainly of quartzite and grits. It occurs as a thick series of white and grey quartzite, intercalated with bands of phyllites and pink mudstone and usually at the base of the group are locally well developed conglomerates and grits. The Birimian Supergroup consists primarily of grey and black slate, phyllites, sericite schist, carbonaceous schist and greywacke.

The intrusive rocks consist of dolerite, gabbro, epidorite and granitic rocks. The intrusive rocks cut both the Birimian and the Tarkwaian but no granitic rocks are known to cut the Tarkwaian. The Basin and the Belt type are the main granitic rocks found within the Obuasi area. The Basin type intrude into the Birimian sedimentary rocks whilst the belt type intrude into the Birimian volcanic belts. The weakly foliated textures of the belt type granitoids have led to the conclusion that the Belt type is generally younger than the Basin type granites, which are typically foliated and gneissic in some cases (Kesse, 1985)

3. Materials and Methods

Exposed ore in place either underground or open pit is usually sampled by channeling (Parks, 1957). Anglogold Ashanti, Obuasi mine employs channel sampling methods to sample crosscuts and reef drives in their underground operations. Channel sampling consists of cutting continuous grooves or channels across the strike of the vein and collecting the resulting chips from each channel to make up the sample. Single channel sampling consists of cutting single continuous grooves whilst the triple channels consist of cutting triple continuous grooves across the strike or the vein of the orebody.

ISSN: 2278-0181
Vol. 1 Issue 4, June - 2012

3.1 Channel Sampling

Channel Sampling was undertaken at block 5 and 6 of level 32 to 38 at Kwasi Mensah Shaft (KMS) of Anglogold Ashanti, Obuasi mine. Adequate personal protective equipments such as goggles, ear plugs, gloves and boot were worn for safety purposes. The crosscut to be sampled was examined to ensure that it was safe (i.e. supported, without misfires). The crosscut was then cleaned to the required floor, thoroughly washed and devoid of loose rocks. Three horizontal lines at 0.5 m intervals were clearly marked on the north and south walls respectively of the crosscut with red spray paint in the mineralised zone, the bottom line being 0.5 m above the floor of the crosscut.

For the single channel sampling, a single channel on the same elevation as the horizontal line (1.0 m above the floor of the crosscut) was cut on the north and south walls of the crosscut respectively, throughout the entire length of the crosscut. A single cut as described above was made on both the east and west of the mineralisation into the barren rock over a distance of at least 6.0 m. Within a lithological unit, the maximum sample cut was 1.5 m so long as the intensity of geological features i.e. mineralisation remained uniform. The minimum sample cut was 0.15 m

For the triple channels, sampling started from the bottom line which lies at 0.5 m above the crosscut floor, then to the middle line and finally to the top line in order to prevent contamination. The channel sample groove was even and at least 2.5 cm wide and 1.3 cm deep. The channels were cut by a moil and a hammer whilst the material sampled was caught by sample trays, ensuring that the weight of a sample was about 1.5 kg.

The samples were transferred into a transparent plastic bag, sealed and tagged and taken to the laboratory for assay. Samples of known grades (coarse blank granites) were added to the transparent plastic bag for quality control purposes. Representative sections of the various lithological units and sample locations of both the north and south walls of the crosscut sampled were respectively captured in a field notebook. These aided in manual plotting of the faces of the crosscut on which the sampling activity took place.

3.2 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 Datamine software has the facility to input drill hole survey, assay and geological information from which 3D sample co-ordinates can be calculated. In modelling of the orebody, the drill hole collar co-ordinates were combined with digitised surface contour plans to produce drill-hole progress plans from which wireframe models were obtained. A wireframe is a closed loop of strings showing the orebody insitu. Out of the wireframe model, the grade model was generated. Compositing of the sample assays were done over specified intervals which relate the orebody to equal depth intervals down the holes and to the rock-type zones. Raw assay data were analysed by basic statistical techniques (descriptive statistics) and the results tabulated or presented as histograms. Geostatistical modelling of directional semi-variogram was undertaken using ordinary Kriging to determine the unbiased grade estimates of the two channel sampling methods. Drill hole sections were generated using the datamine software showing the drill and the orebody models each with its grade units or codes. Fig. 2A and fig. 2B show the block model of the orebody and drill holes in sectional view for the triple and single channel cut respectively.

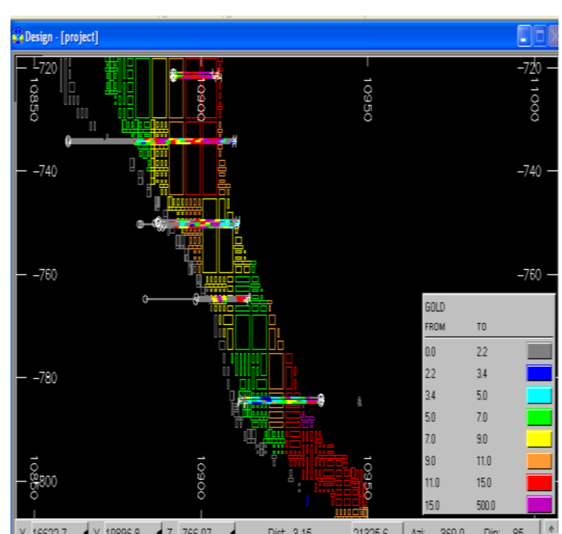

Fig. 2A Sectional view Block model for triple channel cut

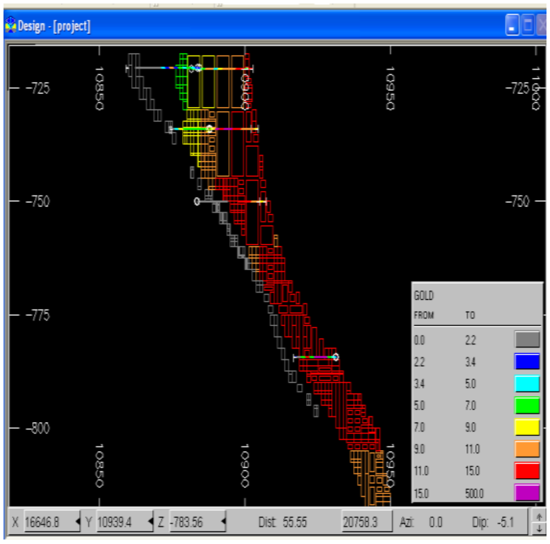

Fig. 2B Sectional view block model for single channel cut

4. Results

The data collected was analysed using both descriptive statistics and ordinary Kriging methods.

4.1 Statistical Analysis

In the sampling work carried out at blocks 5 and 6, 11 128 and 29 083 samples were obtained from the single and triple channel sampling methods respectively in the various crosscuts and reef drives. The classical method of resource estimation specifically, the statistical estimator was first used to analyse the data. Basic statistical analyses in both numerical and graphical representations of all the 11 128 samples were carried out using the datamine software after the block models were generated and the results summarised in fig. 3A. The maximum grade was reduced to a sill value of 132 g/t to minimise erratic variation due to a high nugget effect caused by erratic high grade values. This reduced the total number of samples to 11 125 (fig. 3B). Histogram and cumulative frequency curves were plotted to display the grade distribution of the samples as shown in fig. 4

FILE: c:\database\zone12\school pro\5cut1samp.dm VARIABLE:GOLD

TOTAL NUMBER OF RECORDS	11128
NUMBER OF SAMPLES	11128
NUMBER OF MISSING VALUES	0
NUMBER OF VALUES > TRACE	11128
MAXIMUM	485.3430
MINIMUM	0.0100
RANGE	485.3330
TOTAL	70902.7933
MEAN	6.3716
VARIANCE	134.3
STANDARD DEVIATION	11.59
STANDARD ERROR	0.1099
SKEWNESS	13.59
KURTOSIS	383.8
GEOMETRIC MEAN	1.6483
SUM OF LOGS	5561.4323
MEAN OF LOGS	0.4998
LOGARITHMIC VARIANCE	5.2436
LOG ESTIMATE OF MEAN	22.6821

Fig. 3A Descriptive statistics for single channel

FILE: C:\Database\zone12\SCHOOL PRO\bhkrig1c.dm VARIABLE:CAP
WEIGHTING FIELD: LENGTH

TOTAL NUMBER OF RECORDS	11125
NUMBER OF SAMPLES	7416
NUMBER OF MISSING VALUES	3709
NUMBER OF VALUES > TRACE	7416
MAXIMUM	132.0000
MINIMUM	0.0100
RANGE	131.9900
TOTAL	97687.1167
MEAN	8.9505
VARIANCE	115.5
STANDARD DEVIATION	10.75
STANDARD ERROR	0.1029
SKEWNESS	5.469
KURTOSIS	46.10
GEOMETRIC MEAN	5.2044
SUM OF LOGS	18002.9696
MEAN OF LOGS	1.6495
LOGARITHMIC VARIANCE	1.5984
LOG ESTIMATE OF MEAN	11.5735

Fig. 3B Descriptive statistics for single channel after a top cut of 132g/t

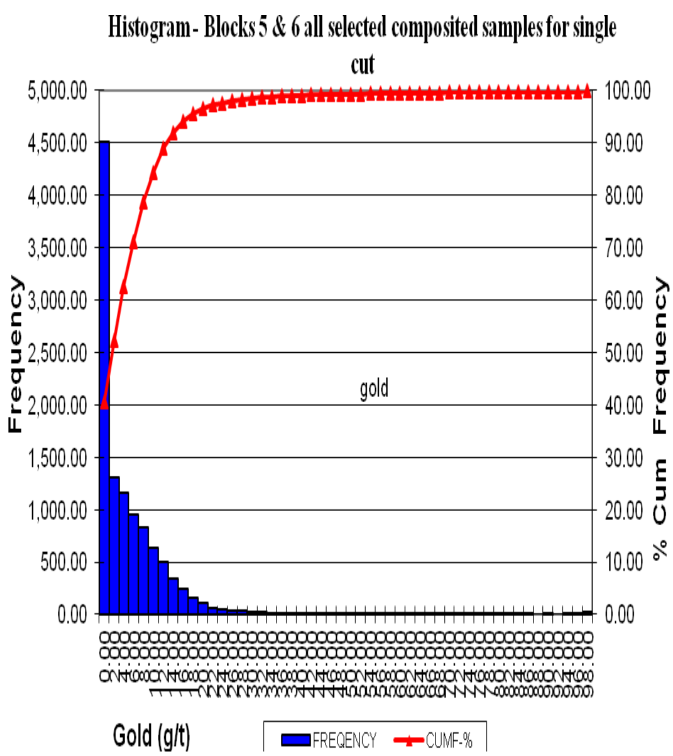

Fig. 4 Graphical representation for Single Channel cut

Similarly, for the triple channels, statistical analysis of all the 29 083 samples was carried and the results displayed in fig. 5A. The maximum grade was reduced to a sill value of 132 g/t to minimise the phenomenon of nugget effect in the statistical estimation reducing the samples to 29 073 (fig. 5B). Histogram and cumulative frequency curve were plotted to display the grade distribution of all selected composited samples for the entire block as shown in fig. 6.

FILE: C:\Database\zone12\SCHOOL PRO\5cut3samp.dm VARIABLE:GOLD
WEIGHTING FIELD: LENGTH

TOTAL NUMBER OF RECORDS	29083
NUMBER OF SAMPLES	29083
NUMBER OF MISSING VALUES	0
NUMBER OF VALUES > TRACE	29083
MAXIMUM	897.1740
MINIMUM	0.0100
RANGE	897.1640
TOTAL	301930.0729
MEAN	7.0787
VARIANCE	172.2
STANDARD DEVIATION	13.12
STANDARD ERROR	0.6354E-01
SKEWNESS	19.65
KURTOSIS	922.1
GEOMETRIC MEAN	1.9506
SUM OF LOGS	28497.5404
MEAN OF LOGS	0.6681
LOGARITHMIC VARIANCE	5.3256
LOG ESTIMATE OF MEAN	27.9634

Fig. 5A Data statistics for Triple Channel cut

FILE: C:\Database\zone12\SCHOOL PRO\bhkrig3c.dm VARIABLE:CAP
WEIGHTING FIELD: LENGTH

TOTAL NUMBER OF RECORDS	29073
NUMBER OF SAMPLES	20838
NUMBER OF MISSING VALUES	8235
NUMBER OF VALUES > TRACE	20838
MAXIMUM	132.0000
MINIMUM	0.0100
RANGE	131.9900
TOTAL	284793.5360
MEAN	9.2921
VARIANCE	125.8
STANDARD DEVIATION	11.22
STANDARD ERROR	0.6407E-01
SKEWNESS	5.636
KURTOSIS	47.08
GEOMETRIC MEAN	5.6166
SUM OF LOGS	52891.9853
MEAN OF LOGS	1.7257
LOGARITHMIC VARIANCE	1.4065
LOG ESTIMATE OF MEAN	11.3475

Fig. 5B Data statistics for triple channel after a top cut of 132g/t

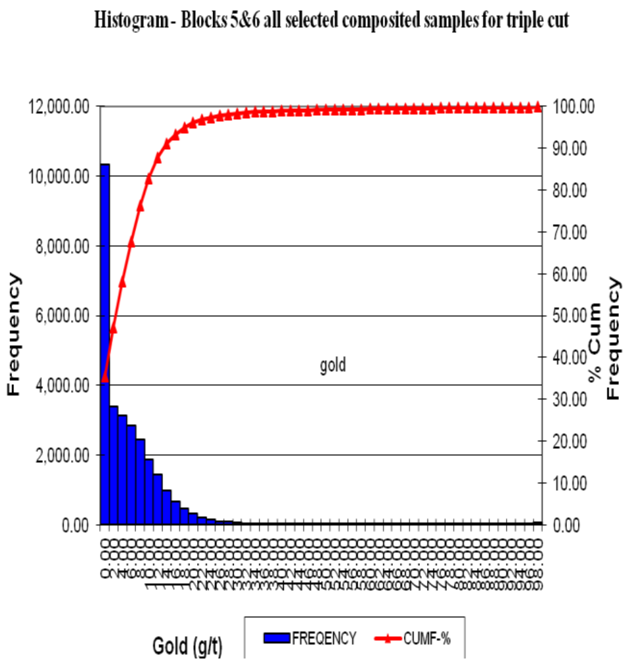

Fig. 6 Graphical representation of Triple Channel cut

The summary of the statistical estimation of the single and triple channel sampling are shown in Table 1. The average grade of gold for the block obtained from the single and triple channel sampling methods were 8.95 g/t and 9.29 g/t respectively. It can be seen that, the triple channel recorded higher average grade of gold than the single channel at a maximum value of 132 g/t. This shows that there was no significant variation in the grades.

Table 1. Summary of Statistical Estimation of Single and Triple Cut

Parameter	Single Channel	Triple Channels
Number of Samples (N)	11125	29073
Maximum Value (g/t)	132.00	132.00
Minimum Value (g/t)	0.010	0.010
Range	131.99	131.99
Average grade of gold (g/t)	8.95	9.29
Variance	115.50	125.80
Standard deviation	10.75	11.22

4.2 Kriging Estimation of the Block

Furthermore, using the ordinary Kriging estimator which assigns appropriate weights to the samples by considering their variability, continuity and anisotropy of the data points and size of the block being estimated, the grades of gold for the single and triple channel were very close with no significant differences. The ounces of gold to be produced from the block were also very close compared to the significant differences in the cost analysis of the project. The average grade and ounces of gold from the block estimated by the Kriging method (Table 2) were 6.50 g/t and 1 810 732.55 oz respectively for the single cut, whilst that obtained for the triple channels were 6.56 g/t and 1 827 447.01 oz. It can be seen that both channel sampling methods recorded close grades of gold for the block. However, the triple channel sampling method yielded a relatively higher grade and ounces of gold than the single channel.

Table 2. Summary of ordinary Kriging Estimation of Single and Triple Cut

Parameter	Single Channel	Triple Channel
Average grade of gold in the ore (g/t)	6.50	6.56
Volume of ore (m^3)	2998095	2998095
Density of ore material (t/m^3)	2.89	2.89
Tonnage (t)	8664494.55	8664494.55
Ounces of gold (oz)	1810732.55	1827447.01

1 Ounce of gold = 31.103g, Cut-off grade = 2.2 g/t

Since the sole aim of every mining company is to make profit and minimise cost, the cost implications associated with each of the sampling method were also taken into consideration. The cost analysis was done in terms of assaying and labour (Table 3). The cost involved in the single and the triple channel sampling methods were $113 440 and $296 230 respectively. There is therefore a significant difference in the cost involved in both sampling methods. The triple channel method yielded a higher cost than the single channel method.

Table 3. Cost Analysis

Cost Parameter	Single Channel Sampling	Triple Channel Sampling
Number of samples	11128	29083
Number of labourers per day	6	15
Assaying cost per sample ($)	10	10
Labour cost per day ($)	12	12
Total assaying cost ($)	111280	290830
Total labour cost per month ($)	2160	5400
Total sampling cost in terms of assaying and labour ($)	113440	296230

5. DISCUSSION

From the results of the histograms displayed in fig. 4 and fig. 6 respectively for the single channel and triple channel, it can be observed that, the data is highly peaked and skewed to the right. This means that, most of the grade values at the peak interval of 0-12 g/t for both the single and the triple channel recorded higher frequencies. Based on the results obtained from the descriptive statistical estimator, it was realised that, there was no significant difference in the average grades of gold from the two sampling methods. Also the ordinary Kriging estimator proved that, the grades of gold obtained from the single and triple channel methods were close. The implication is that, the accuracy of sampling depends not only on the number of samples but also on the proper distribution throughout the orebody. It would therefore be wrong to sample either the rich parts or the lean parts. However, the triple channel sampling method yielded a relatively higher grade of gold than the single channel method. The total number of samples obtained from the triple channels method (29 083) were significantly higher than the single channel (11 128). The implication is that, a single sample taken at a particular place would not contain the same proportion of metals as does the orebody as a whole. This proves that, as the number of samples increase, the probable error associated with the statistical stability of the system decreases. But this never disappears completely unless the samples are so numerous and so large that, their aggregate is equal to the orebody itself in which case the orebody would be used up in the process of sampling.

6. CONCLUSION

Both the single and triple channel sampling methods yielded very close grades and ounces of gold from the blocks. The cost involved in the single and the triple channel sampling methods were $113 440 and $296 230 respectively. The triple channel method therefore yielded a higher cost than the single channel method. To reduce production cost and increase return on capital employed, the single channel sampling method would be a better channel sampling method in terms of estimation of ore grades.

Acknowledgement

The authors are grateful to the management and staff of Anglogold Ashanti, Obuasi mine for their kind support and assistance.

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