Significance of Sample Repeatability Index in the Mining Industry*

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Abstract

The objective of this research is to establish the importance of Sample Repeatability Index (SRI) as a measure to ensure error minimisation in exploration drilling protocols, during sample preparation of the prospect areas. Almost all the stages entailed in the exploration stages involve sampling. Samples collected and prepared within the field are well checked for a good Quality Assurance and Quality Control (QA/QC) methods. However, samples sent out for testing in the laboratory outside the field are not under the control of the exploration team, hence a measure must be taken to assess the efficiency of the laboratory and accuracy of the laboratory results. Sample Repeatability Index is one of the tools that can be used to ensure the degree of confidence in the laboratory results. To achieve this, QA/QC procedures were employed to monitor precision, accuracy and potential sample contamination in order to ensure confidence in the sampling system. A total of twelve thousand and eighty-one samples taken from eight different deposits, considered within a 4-year period were used in this study. Field duplicate pairs were used to check sample repeatability, Relative Difference and Half Absolute Relative Difference (HARD) plot were used to calculate Sample Repeatability Indexes for the deposits. Results of the study showed that Sample Repeatability Index for all the deposits with exception of deposit 2 fell below the Customer Specification Threshold (CST). Deposit 2 produced somewhat better of 77% at 20% precision as compared to the other deposits. Deposit 3 recorded poorly of 60% at 20% precision. It is advisable to have sampling protocol designed to suit different geological domain on each individual deposit.

Keywords: Sampling, Quality Control, Quality Assurance, Sample Repeatability Index

1 Introduction

Sampling is an inevitable task in the exploration and mining industries (Chieregati and Depositard, 2009), most especially when decisions concerning mineral resource and reserve convention into mineable developmental stage is dependent on the outcome of the sample data. Good sampling requires sampling procedures of Quality Assurance and Quality Control as means of standardising sampling practices (Lyman, 2014; Méndez, 2011). Sampling in the mining industry starts from exploration, laboratory and continues through to grade control, mining, metallurgical processes and ends with the final precious metal extraction (Spangenberg, 2012). The differences between assay values of original samples and their duplicates most often in the mining industry cannot be avoided, however low variability within the threshold of ±2 standard deviations, is statistically acceptable (Gurland and Tripathi, 1971; Abzalov, 2008).

Accuracy, Precision and Bias are statistical terms that well define the state of a data. How close a measured value is to a known value is the accuracy and precision is the reproducibility of a measurement whiles bias is the range at which the outcome of an analysis varies from the certified results.

Repeatability of samples assay is best represented by the coefficient of variations of the sample assays estimated from differences between original samples and duplicates (Abzalov, 2009; Stanley and Lawie, 2007). Abzalov (2011) proposed appropriate levels of precisions for different types of deposits using coefficient of variation. Though coefficient of variation is most commonly used relative index of variation, there are other equally used indices as the Reduced Major Axis (RMA) proposed by Sinclair and Bentzen (1998). This model is useful in identifying bias in paired data and is popularly known among geoscientists (Sinclair and Blackwell, 2002). Relative Different Plot (RDP) has been suggested by Abzalov (2008) as graphic tool for determining factors controlling precision error.

Half Absolute Relative Difference (HARD), as stated by Shaw (1997) is a precision measurement tool, hence precisions measured from the use of HARD are comparable from one deposit to the other. The HARD model is used in this paper to determine the precision within each data set of the deposits and compare repeatability among the deposits. The discrepancy in grade values between the original and the duplicate may be attributed to various factors originating from contamination and procedural errors across exploration, laboratory, production to metallurgical processing stage. In exploration sampling is the first call of analysis in the mineral industry, hence it important to tackle all sampling protocols in order to verify the accuracy of results and ensure reliable geological interpretation of data. Assessment of a mineral resource and its viability is dependent on the quality of the sampling

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and assay data. As such monitoring the quality of laboratory analyses is fundamental to ensure the highest degree of confidence in analytical data and providing the necessary confidence to make informed decisions when interpreting all the available geological data. Increase in sampling error minimises the confidence in the data. A comprehensive quality-control system and sample repeatability index is necessary to monitor various essential elements of the sampling procedure and assaying sequence in an effort to minimise errors which are likely to occur. Sample Repeatability Index is the degree of repeatability of a set of pairs of duplicate assay data. It is convenient for comparison with the repeatability of other duplicate data sets acquired. This research used data from eight different deposits in Belahouro project in the Birimian Djibo Greenstone belt in Burkina Faso (Fig. 1) to establish the significance of sample repeatability index. This would help monitor sampling errors and ensure quality data acquisition.

1.1 Geology of the Study Area

The Belahouro Gold Project is situated approximately, 220 km north-northeast of Ouagadougou, Burkina Faso in the western part of the Birimian Djibo Greenstone Belt. The terrain is extensively deformed and metamorphosed. Metamorphic mineral assemblages are indicative of low-grade regional metamorphism to greenschist facies (McCuaig *et al*., 2016; Baratoux, *et al*., 2011). However, in Belahouro, kyanite-bearing mica schist and pelite indicate a higher-grade metamorphic regime.

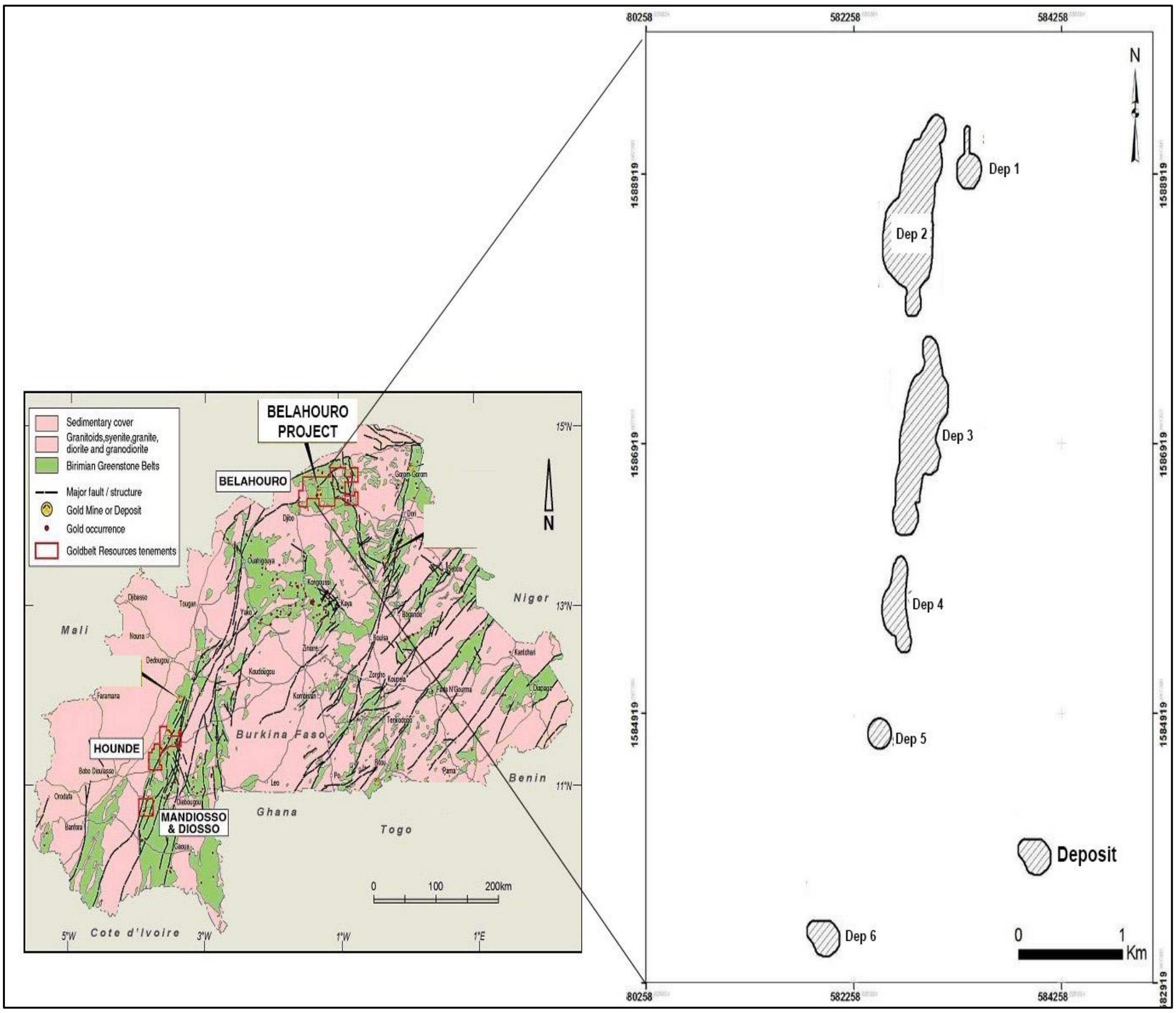

Fig. 1 Location of some of the Deposits and Geology of the Belahouro Gold Project, (Modified after Sako, 2014). (Dep. = deposit)

The succession is strongly affected by polyphase deformation displaying recumbent folding and a strong sub-vertical dominant schistosity with transposed bedding planes in some areas. The entire stratigraphy has been intruded by massive post-Birimian dolerite dykes and sills with higher magnetic susceptibility than the surrounding host rock (McCuaig *et al*., 2016). Gold mineralisation is commonly associated with stockwork and sheeted quartz–carbonate–sulphide veining, stockworks of albite-carbonate-sulphide veinlets, or as sulphidic haematitic breccia. Pyrite is the dominant sulphide species, present as discrete poikilitic euhedral ranging from a fraction of a millimeter in size, largely confined to vein margins or disseminated within alteration selvedges. Traces of other sulphides, principally chalcopyrite, galena, pyrrhotite, arsenopyrite, bornite, tennantite, linneite and m ackinauwite are present as veins, fracture fillings and localised disseminations adjacent to veins.

2 Resources and Methods Used

2.1 Resources

The exploration team utilises contract Reverse Circulation (RC) drill rigs equipped with a sample collection system and 5.5" RC hammer. The drilling is conducted on a 12.5 m by 6 m pattern along strike with holes inclined generally at 60° (determined by local geology) against the dip of the ore body. The vertical depth covered varies between 20 m and 25 m dependent on the nature of the ground being drilled.

Sample collection is at 1 m interval into plastic bags. A 2 m composite sample weighing about 2.0 kg is prepared from the samples collected by using a riffle splitter at every eighth to tenth meters. Surveyors stake the planned RC coordinates in the field prior to drilling and also pick the coordinates after drilling is completed.

2.2 Methods

A comprehensive and well-structured quality control quality assurance programme was designed to monitor sample quality during operations. Control samples such as blanks, standards and field duplicates are inserted at regular interval within the sample batches before sample submission to the laboratory. Every 10^{th} sample is a duplicate and every 20^{th} sample is a standard sample. The laboratory receives all the samples as a whole package from the exploration programme and has no idea of the arrangement of the check samples.

2.2.1 Collection of Field Duplicates

Grade Control samples are taken from the drill rig. Samples are collected at a 2 m interval. The samples are collected by geologist and ~~his~~ sampling crew. The field duplicates were collected at the drill rig by splitting a 1 m drilling interval through a three-tier freestanding riffle splitter for the original sample and resplitting the reject through a three tier riffle splitter to obtain the duplicate sample.

Fig. 2 Sampling by means of a Three-stage Riffle Splitter

2.3 Data Acquisition

The field duplicate sampling was carried out from 12 081 2 m composite RC samples collected by the exploration team from 8 different gold deposits between the periods 2010 to 2014. All samples were analysed by Avocet laboratory. The field duplicate data obtained, only 5799 representing approximately 48% of the total data were used in the data analysis (when the original samples were filtered), because any original sample assay value below 0.2 g/t was not considered. This is necessary because any value below 0.2 g/t is regarded as waste as it will not have any influence on the grade modeling. However, information on the rest of the control sample types were not considered in this project work.

2.3.1 Sample Preparation and Assaying

The exploration prospecting team implements a dedicated QA/QC program on sample preparation, handling, laboratory processes and assay reporting.

A control sample (standards and field duplicates) is inserted as one in every tenth (10^{th}) in a sample batch before submitting to the laboratory. The Reference Standard Material (RSM) used as control samples are supplied by Rocklab and Geostat laboratories. Representative samples are periodically analysed to ascertain the gold barren property.

A sample preparation protocol currently employed by Avocet Laboratory (AL) is as follows:

(i) Dry entire sample
(ii) Crush to 70% passing nominal 2.0mm

(iii) Riffle split 250 grams and pulverize to 85% passing 75 microns
(iv) Sub sample 50 gram for Fire Assay analysis
(v) ASS reading at detection limit of 0.01ppm

Table 1 Summary Statistics of Original and Duplicate Samples

Statistics	Sample	Duplicate
Mean	0.70	0.70
Standard Error	0.02	0.02
Median	0.11	0.11
Mode	0.02	0.02
Standard Deviation	2.02	2.05
Sample Variance	4.08	4.19
Kurtosis	247.44	288.66
Skewness	11.37	12.01
Range	68.45	71.26
Minimum	0.00	0.00
Maximum	68.45	71.26
Sum	9 650.74	9 725.56
Count	13 825.00	13 825.00
Confidence Level (95.0%)	0.03	0.03

2. 3.2 Data Processing

The Half Absolute of Relative Difference (HARD) plot method was used to calculate the precision of the assay value of original samples and field duplicates. The precision or repeatability value indicates the level of repeatability of a set of pairs of duplicate assay data. Parameters used are:

(i) a - b, thus the difference

(ii) a + b, their summation

(iii) Mean, $\frac{(a+b)}{2}$

(iv) Relative Difference, (a-b) / (Mean)

(v) ARD, Absolute of the RD

(vi) HARD, Half Absolute of Relative Difference.

where, a is the original sample and the b representing duplicate or the assay check (Abzalov, 2009).

The Absolute of Relative Difference for single duplicate pair is expressed as:

$$ARD = 2\frac{|a-b|}{a+b}$$

Whilst HARD for single duplicate pair is expressed as:

$$HARD = \frac{|a-b|}{a+b} \times 100$$

Average HARD for several duplicate pairs is expressed as:

$$\overline{HARD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{|a_i-b_i|}{a_i+b_i}\right)^2}$$

3 Results and Discussion

HARD plots and Relative Difference (RD) plots were used to assess the precision and sample repeatability index of the various deposits as mentioned earlier. The samples from the field duplicates collected by Avocet from the various deposits were used.

3.1 Sample Repeatability Index

Sample repeatability index is a single numerical index to indicate the degree of repeatability of a set of pairs of duplicate assay data. In the exploration industry, this is one of the accepted quality control and quality assurance method which allows convenient and rapid comparison with the repeatability of other duplicate data sets. It is routinely done during grade control drilling campaign from month to month, project to project, and deposit to deposit or between different sampling methods.

Sample repeatability index is defined by the following:

%MAPD (Mean Absolute Paired Difference) = RPHD (Relative Percent Half Difference) = %HARD (Half Absolute Relative Difference)

%HARD are ranked and the rank percentage of sample pair is calculated. %HARD data is plotted on the y axis and the ranked percentile on the x axis. The HARD plots of the various deposits are presented in Figs. 3 to 10. The sample repeatability index is determined or calculated from where the percentile-%HARD curve intersects the Customer Specification Threshold (CST). This is the percentage of data at or below the CST. The sample repeatability indexes calculated are all below the CST of 90 % at 20 % HARD as tabulated in Table 2.

In Fig. 11, all the points of inflexion of all the curves do not pass through the recommended customer specification threshold of 90 % level at 20 to 25 % HARD.

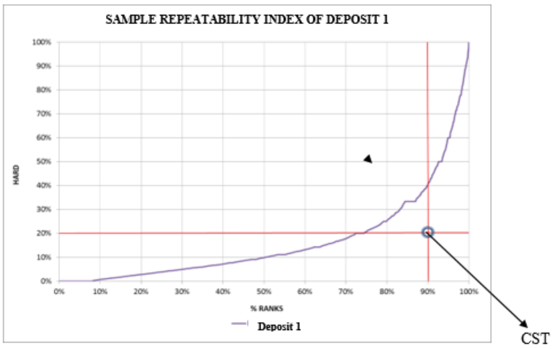

Fig. 3 HARD Plots of Duplicate Samples in Orebody of Deposit 1

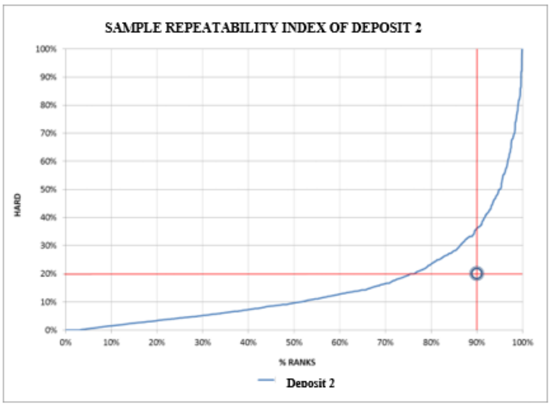

Fig. 4 HARD Plots of Duplicate Samples in the Orebody of Deposit 2

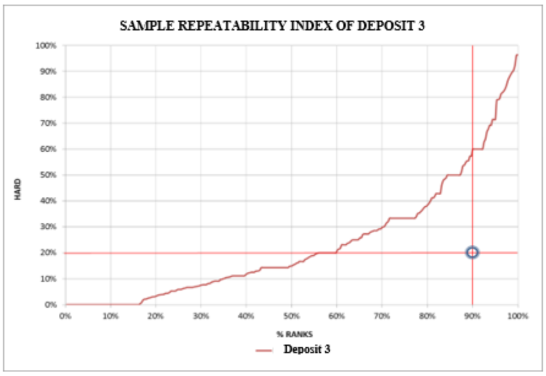

Fig. 5 HARD Plots of Duplicate Samples in Deposit 3

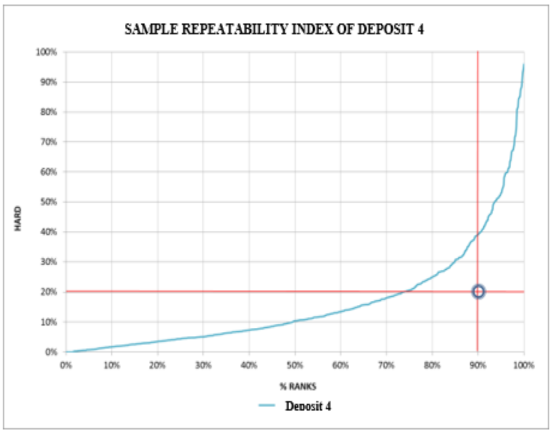

Fig. 6 HARD Plots of Duplicate Samples in Deposit 4

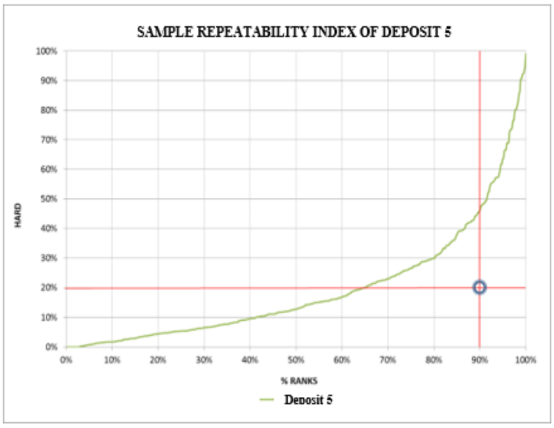

Fig. 7 HARD Plots of Duplicate Samples in Deposit 5

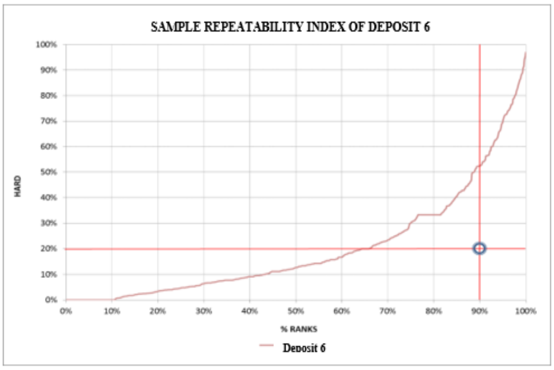

Fig. 8 HARD Plots of Duplicate Samples in Deposit 6

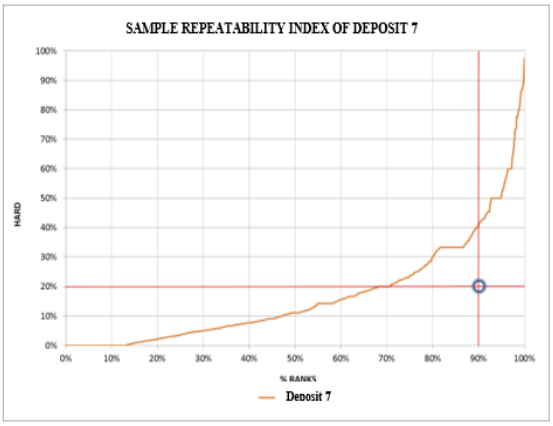

Fig. 9 HARD Plots of Duplicate Samples in Deposit 7.

Table 2 Summary of Sample Repeatability Index Analysis for Field Duplicates

Deposit	< 10%	<15%	<20%	No. of Samples
Dep. 1	51	65	73	5,270
Dep. 2	52	67	77	2,635
Dep. 3	35	50	60	321
Dep. 4	51	64	75	863
Dep. 5	43	56	65	536
Dep. 6	43	56	66	693
Dep. 7	47	60	71	1,176
Dep. 8	42	53	64	587

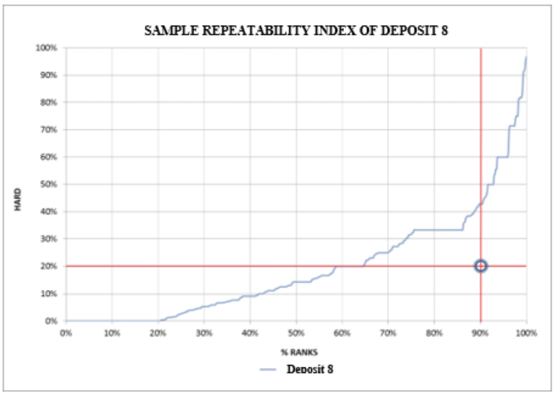

Fig. 10 HARD Plots of Duplicate Samples in Deposit 8

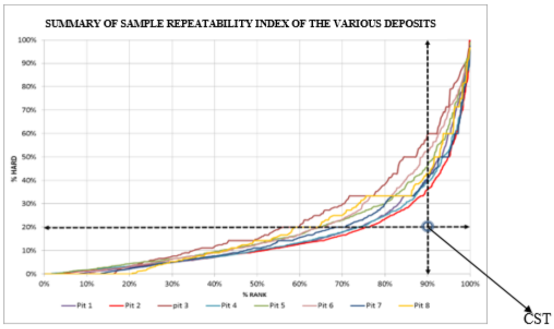

Fig. 11 HARD Plots of Duplicate samples of all the 8 Deposits.

3.2.1 Establishment of Customer Specification Threshold (CST)

It is acceptable or appropriate to have 90 % of data having a repeatability of 20 % to 25 % of %HARD or more. This repeatability level is accepted by Joint Ore Reserves Committee (JORC) Compliant resource statement (Apau *et al*., 2014). The 90 % data level is determined from the inflection point on a typical Percentile - %HARD plot. This may be interpreted as 10 % of the data fall outside precision level and this is expected because of various unavoidable conditions such as geological variability. Achieving 100% perfection is not feasible.

3.3 Relative Difference Plots

The sample repeatability index for Deposit 1 which is the deepest Deposit (about 5270 samples) among them was further studied based on RL. This time HARD was ranked by depth and grade. It was observed that, grade had no significant difference in HARD with depth, but HARD or precision level was consistent until markedly changed from depth 250 and below with precision level as low as 43 % at 20 % precision level as shown in Fig. 12. Since the precision is the reproducibility of a measured value.

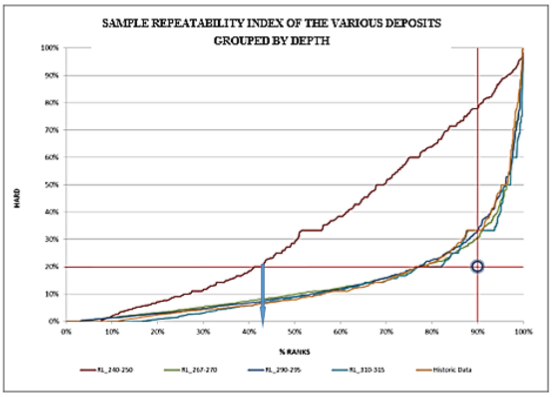

Fig. 12 HARD Plots of Duplicate Samples in Deposit 1 with Reduce Levels

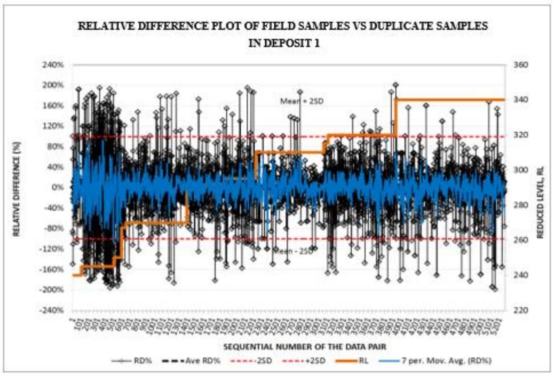

Fig. 13 Relative Difference Plot (RDP) of Deposit 1 with Depth

Ideally, repeatability of 20% to 25% HARD of 90% of data is acceptable. Repeatability levels of <10%, <15% and <20% were recorded for all the deposits (Table 2). Deposit 1 had precision of 20% of 73% of 5,270 duplicate samples and 40% precision for 90% of data (Fig.3). Deposit 2 had 77% of 2,635 sample data fell within 20% precision and 90% of the field duplicates have precision of 37% (Fig.4). Deposit 3 had the 20% precision for 60% of the data and 60% of precision for 90% of the field duplicates (Fig.5). Deposit 4 recorded 75% of data fell within 20% precision and 90% of the data with 40% precision (Fig.6). For deposit 5, 65% of the data had 20% precision and 48% precision for 90% of the duplicates (Fig. 7). Deposit 6 recorded 20% precision for 66% of the data and 52% precision for 90% of the data (Fig. 8). Deposit 7 had 20% precision for 71% of the data and 90% of the data had a precision of 41% (Fig. 9). Deposit 8 recorded 20% precision for 64% of the data and 42% precision for 90% of the data (Fig.10). From the results and analysis, it is inferred that, deposits 1, 2, 4 and 7 recorded above 70 % of data at 20 % precision level with deposit 2 having a better SRI of 77%. Deposits 3, 5, 6 and 8 recorded below 70 % at 20 % precision level with deposit 3 having the lowest SRI of 60% Ore bodies from deposits 1, 2, 4 and 7 belong to the main geological domain whilst the ore bodies from other deposits belong to offset mineralization with different geological characteristics.

Generally, the poor SRI for all the Deposits were mainly due to inherent geological sampling factors, (e.g., nugget effect) and also maintain the same sampling crew for all the sampling protocols. Drastic change of SRI in deposit 1 at 240 to 250 m is likely due to change in geological characteristic of the ore body.

4 Conclusions and Recommendations

4.1 Conclusions

From the discussion, it may be concluded that the Sample repeatability index for all the deposits fell below the customer specification threshold (CST).

Based on grade and depth for deposit 1 (deepest deposit), it was observed that precision level was consistent with depth until the 240 m to 250 m depth where the precision changed. Hence, SRI once established for any ore body can be used to monitor sampling errors in the field.

4.2 Recommendation

From the research it can be recommended that:

(i) The existing sampling protocols for deposits 1, 2, 4 and 7 can be maintained up to the 240 m depth.
(ii) Detailed heterogeneity studies should be conducted to help design sampling protocols to suit the other deposits especially deposit 3.
(iii) Beyond the 240 m depth, heterogeneity studies should be conducted to design different sampling protocols for all the deposits.
(iv) Repeatability or reproducibility test should be conducted periodically on all the 8 deposits to confirm this preliminary study and establish the actual sample repeatability index for each orebody.

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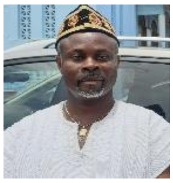

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