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2017

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Quantification of sampling uncertainties

at

grade control decision points

for a platinum mine

Mandi Woollam

A Project Report submitted to the Faculty of Engineering and the Built Environment, University of Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the degree of Masters in Science in Engineering

.

Johannesburg 2017

DECLARATION

In accordance with University Regulation G.28:

I declare that this discourse is my own unaided work. It is being submitted to the Master of Science in Engineering and Build Environment to the University of the Witwatersrand, Johannesburg.

It has not been submitted before for any degree or examination to any other University.

The execution of tasks that generated the data used in this discourse were aided by various people responsible for such tasks within Anglo American / Anglo Platinum.

……

Signature of Mrs. A. M. Woollam (student number 510082)

25th day of August, 2017

Discourse research report, as applicable to Master of Science Engineering

ABSTRACT

The mining industry has been challenged with rising costs and lower ore grades mined, thereby squeezing profit margins. Furthermore, with decreasing ore grades being mined, the PGE grade of interest is edging closer to the capabilities of the available analytical techniques. This is placing more pressure on maximizing the precision and accuracy of data and the importance of the quality of sampling has therefore become elevated. The quality of sampling is affected by all contributing effects that make up the sampling chain.

Grade control sampling assay data is used routinely in conjunction with the geology of the ore to assign a destination for the ore (either to a stockpile or to the mill), based on its grade classification for the platinum mine. The classification of the grade for a particular mining block is made using four key elements (4E). This grade determination is often found to be different to that generated from the exploration sampling process. These differences between assay data obtained using different sampling techniques are due to errors in sampling. These errors were investigated in depth in this study.

In order to understand the possible errors in the assignment of grade to a mining block, the errors at the classification thresholds (referred to as grade control decision points (GCDP)) have been investigated. These errors, comprised of both random and systematic errors and were determined independently in this study. Components that generate these errors include the heterogeneity of the ore, the action of taking a sample, sample preparation and the analytical technique used to analyse the sample.

The *random error* associated with the assignment of grade to a particular mining block is highly dependent on the analytical technique, grade of the ore, as well as the number of assays used. The application of the central limit theorem in calculating the average grade of a block (with n=30 samples analysed in duplicate) reduces the random error by a factor of 7.75. Although this factor reduces the random error sufficiently (< 10 % at all grades) to enhance confidence, the large errors (>> 10 %) assigned to each of the individual thirty samples (at grades less than 1.7 g/t 4E) still present a risk of incorrect classification of the ore below 1.7 g/t 4E.

The effect of s*ystematic errors* are additive and cannot be reduced by averaging more assays (unlike random error). These errors have their origin in the “design” of the sampling protocol. This study highlighted that, in general, the grade calculated for a mine area will be lower when calculated using grade control assay data when compared with the grade calculated if exploration assay data were used. This systematic error was also found to change in magnitude and sign depending on the 4E grade of the ore.

The grade at which mining is viable (pay-limit of the mine) is defined in the 2015 annual report as 2.5 g/t 4E. This study, quantified the smallest systematic error (< ± 2 %) between the two sampling techniques at ore grades equal to 1.7 g/t 4E. Both these grades (2.5 and 1.7 g/t) are significant in that it is the upper and lower grade limit for the very low grade ore (VLGO) category. Ore that is assigned to grade categories higher than 2.5 g/t 4E, will be marked as destined for the milling process in mining. It is at this grade that the error should be minimised so as to minimise financial loss; such loss will occur when ore is stockpiled but should have been processed or when ore is diluted with sub-standard grades, which should have rather been stockpiled.

This study quantified the errors associated with grade control into all its contributing parts; the largest error (- 8 %) was assigned to the sample preparation component of the sampling protocol. All other components were quantified as an average error and this was done at the mine's different ore grades. Sampling design (quality assurance) components that present an opportunity to reduce the systematic errors were identified as:

- Increased sub-sampling, sample mass
- Re-design, sub-sampling sample cups
- Protect the integrity of the analytical sample; through the introduction of a third sample cup to obtain the sample required for geological logging
- Optimize the drilling speed of the reverse circulation drill
- Optimize the rotational speed of the rota-port cone splitter
- Centre the cone splitter perfectly below the falling sample stream
- Increase the analytical sample mass (to a maximum)
- Modification of sample preparation (eliminating the crushing stage)
- Minimise loss of fines during sampling and sample preparation

Additional quality control (QC) activities were recommended; these will reveal "out of (statistical) control", sampling components. The cost of incorrect classification of ore is difficult to quantify but when mining tonnages are considered, it is certain to be significant. Using the average realised basket price ZAR / Pt (oz) for 2016, the value of ore (at 2.5 g/t 4E) from a three hundred tonne truck, is calculated to be around R287,666. Thus if a truck is incorrectly assigned to stockpile instead of processing this value will be lost.

Resources invested in the resolution of these systematic errors will be resources well spent. Management should be commended for investing in heterogeneity and twin-hole test work, both of which provide information that quantify and identify sampling errors. Measuring these errors is the first step towards reduction or elimination of error.

DEDICATION

In loving memory of my mother,

Rita Pieterse (1938 - 1979).

ACKNOWLEDGEMENTS

I would like to acknowledge Anglo American and Anglo Platinum management for supporting this project

In particular:

- Marie Humphries
- Quartus Snyman
- Trust Muzondo

Also special acknowledgement to:

- Professor Minnitt who was the supervisor for my project
- Mine site geologists responsible for the excellent execution of the twin hole program
- Anglo technical and sustainability geology team
- Anglo Platinum team responsible for compiling the proficiency and check data
- Laboratories involved in analysing the samples
- My family for their patience, support and encouragement

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LIST OF SYMBOLS

%	percentage
cm	centimetre
g	grams
g/cm^3	grams per centimetre cubed
g/t	grams per tonnes
kg	kilogram
m	metres
mg	milligram
mm	millimetre
ppm	parts per million
sec	second
sd	standard deviation
df	degrees of freedom

LIST OF NOMENCLATURE

% Diff	Difference, expressed as a percentage
% RSD	Relative Standard Deviation, expressed as a percentage
3E	Sum of Pt, Pd and Au
4E	Sum of Pt, Pd, Au and Rh
Ag	Silver
Au	Gold
AMIS	African Minerals Standards
BE	Best Estimate
BL	Between Lab
BMs	Base Metals
BQ	Diamond drilling with core size 36.5mm
CLT	Central Limit Theorem
CONC	Concentration
CRM	Certified Reference Material
Cu	Copper
CV	Consensus Value
*CV	Coefficient of variation (*only used in the Literature Review)
DD	Diamond Drilling Sampling
DIFF	Difference
DL	Detection Limit
D_N	Nominal top size diameter
Dups	Duplicates
DQOs	Data Quality Objectives
DSA	Duplicate Series Analysis
EXP	Exploration
EXP-LAB	Laboratory used for analysing Exploration samples
GC	Grade Control
GC-LAB	Laboratory used for analysing Grade Control samples
GCDP	Grade Control Decision Point
Ha	Alternative Hypothesis
Ho	Hypothesis
HG	High Grade
HGO	High Grade Ore
ICP	Inductively Coupled Plasma
ICP-OES	Inductive Coupled Plasma, Optical Emission Spectroscopy
IDE	Incremental Delimitation Error
IEE	Incremental Extraction Error
IPE	Incremental Preparation Error
LAB	Laboratory
LGO	Low Grade Ore
LOQ	Limit Of Quantification
LTRM	Long Term Resource Model
MM-CRM	Matrix Matched CRM
MP	Method Precision

n	Number of observations
Ni	Nickel
NQ	Diamond Drilling with core size 47.6mm
Pb	Lead
Pd	Palladium
PL	Paylimit
PGE	Platinum Group Elements
PGM	Platinum Group Metals
PREP	Preparation
PSA	Particle Size Analysis
PSD	Particle Size Distribution
Pt	Platinum
QA	Quality Assurance
QAQC	Quality Assurance and Quality Control
QC	Quality Control
RC	Reverse Circulation
Rep	Replicates
Rh	Rhodium
RMS StdDev	Root Mean Square Standard deviation
RSD	Relative Standard Deviation
SG	Specific Gravity
SMU	Smallest Mining Unit
Std	Standard
TOS	Theory of Sampling
VLGO	Very Low Grade Ore
XRF	X-ray fluorescence

1. INTRODUCTION

CONTEXT

The mining industry is continuously challenged with rising costs and lower ore grades mined thus the profit margins are squeezed. Furthermore, with decreasing ore grades being mined, the grade of interest is edging closer to the capabilities of the available analytical techniques (particular for the PGM deposit where ore grades is in the low ppm range). At very low grades the techniques may become subjected to unusual systematic errors. This is placing more pressure on maximizing accuracy and precision of data and the importance of quality. Carrasco, P., et al. (2003) [(6)], stated that an incorrect sampling and assaying process can lead to bad decisions that can cost billions of dollars during the life of a large mining company.

There is a direct relationship between cost and quality of sampling. It is for these reasons that it is necessary to understand the limitations and benefits of the available analytical and sampling techniques. It has become necessary to clearly understand the weakest link from sample to assay by quantifying the different uncertainties (risk) associated with the different analytical and sampling techniques, as well as the natural variability of the ore itself. A balance between capability and client requirement needs to be reached with the end-use of the data as main focus.

There is an associated error with any measurement system, with three main types of errors namely: gross errors (outliers or mistakes); random errors, and systematic errors. Random errors and systematic errors can be measured and are a function of the measuring system e.g. the analytical and sampling method in use. This investigation will quantify the relevant random and systematic errors for the sampling techniques in use at the grade of the grade control decision points (GCDPs) for the mine. The laboratory puts in place preventative measures to control gross errors. These errors should then be minimal with the use of good laboratory practices and a good QAQC program.

Due to the cost of sampling, it is imperative to use the data for as many purposes as possible (Minnitt, Pitard 2015)[(17)]. That being said, samples collected for one purpose may be worthless for another [(17)]. The temptation is to expand the use of data beyond its initial intended use. In many cases, the end-user of the data may not fully appreciate the associated uncertainties and its implication to the end-use of the data. For the data to remain meaningful, a clear understanding of the limitations are necessary. Money and resources are also wasted if unrealistic requests for accuracies and precisions are forced (outside the original intent) beyond the capabilities of the techniques and this should be avoided.

Furthermore, the analytical chemist will likely not understand the data processing steps that are required before the data is used to solve an estimate or decision problem. Data quality objectives (DQOs) link sampling (and analytical methods) and data processing steps to the *purpose and reason* for undertaking the exercise.

Reconciliation data quality objective targets, used to compare the difference between the resource model and the grade control model are defined below in table 1-1.

Table 1-1 Business objectives for the reconciliation between the average resource and grade control model

Reconciliation relationship		Target
Resource model to Grade control model	Acceptable	-10 % to +10 %
	Warning	-20 % to +20 %
	Action	<- 20 % to >+20 %

The rand uncertainty equivalent for one, three hundred tonne truck at a ± 20 % uncertainty (using the averaged 2016 ZAR / Pt (oz) realized prize) is calculated as R287,666 ± R54,284.

The *grade control model* is established from grade control samples (> 80 %) obtained using reverse circulation (RC) sampling, with lead (Pb) fire assay, Spark excitation, ICP-OES finish, analysed at the GC-Lab. Less than 20 % of the samples (only where RC sampling access is not possible) is obtained from blast hole sampling. The grade control model informs the short term mine plan which determines the grade and tonnes delivered to the mine.

The *resource model* is established from exploration samples obtained using BQ diamond drilling sampling, with Pb fire assay (Ag and Pd as co-collectors), ICP-OES finish, analysed at the EXP-Lab. The resource model informs the long term mine plan which determines what resource is available for exploitation.

Grade control sample assays are also used for mine decision making, whether to stockpile ore, or feed the ore to the plant. Table 1-2 below with different decision points for grade control, two important decision points to note are < 1 g/t 4E (waste), > 2.5 g/t (ore to the mill).

Table 1-2 Ore classifications groups used for grade control at the platinum mine

Classification:	4E (g/t) Grade From:	4E (g/t) Grade To:
Waste	0	0.99
Very low grade ore (VLGO)	1	1.69
Low grade ore (LGO)	1.7	2.49
Medium grade ore (MGO)	2.5	4.0
High grade ore (HGO)	4.0	above

The objective of a DQO equal to ± 10 % error limit (Samrec code, 2009) [26] is very common in literature. Minnitt and Pitard, (2005) [17] refers to this as the safety line. This error is assumed to be expressed in ± % RSD (percent relative standard deviation) terms. No information could be obtained with respect to DQOs for grade control across the grade control decision points for the mine.

In order to determine if the business objective stated in table 1-1 can be achieved across the 4E grades of the mine, the individual errors encountered when assigning grade to a mining block are quantified in this study.

THE PURPOSE OF THE STUDY

The purpose of the study is to quantify the sampling uncertainties for the combined platinum group metals grade (Pt + Pd + Au + Rh) for the mine at the grade control decision points (GCDPs) to determine if the suggested ± 10 % DQO is achievable across the PGE grades.

The grade control (GC) information is used for multiple purposes, some of which are listed below:

- Grade control is an estimation (4E (g/t) grade of the mining block) as well as a decision problem (block to be marked for stockpiling or mining)
- Mine ore delivered to plant is an estimate problem (mass (tonnes) delivered to the mill)
- Short term grade control model is an estimate problem (4E (g/t) grade of resource delivered to the mill)

The RC hole represents a 10 m (length) x 10 m (width) x 15m (depth) block of ore. An RC sample is taken every 2.5 m (a historical convenient number linked to the 15 m and 10 m benches mined at the mine) giving six vertical samples. Each RC sample represent 775 tonnes of ore (see figure 1-1). Some sample chips are taken for each sample to record the geology of the sample. For blast hole sampling, an ore production blast can be (3.8 m x 4.2 m) or (4.8 m x 5.5 m) or (6.2 m x 7.2 m) ore block. For grade control, grades are assigned to a mining block of 6.5 m (length) x 6.5 m (width) x 15 m (depth).

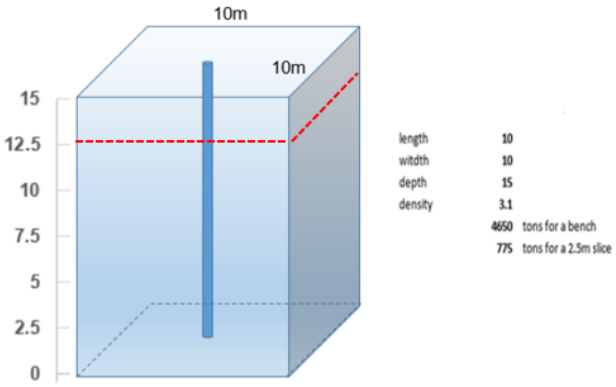


Figure 1-1 Schematic presentation of a RC block with RC drill hole where each sample represent a mass of 775 tonnes of ore

The table below presents the calculation of the theoretical mass of a RC drill hole bulk sample.

Table 1-3 Theoretical mass calculation a RC primary bulk sample

RC Drill diameter		RC radius	length		GS	recovery	mass	mass	ml/cm^3
inch	cm	cm	cm	r cm sq	g/cm^3	%	g	kg	volume
5.50	13.97	6.99	250.00	48.79	3.10	95.00	112,852	113.00	38,319.75

For grade control the analytical splits (samples) are analysed for Pt, Pd and Rh using lead collection fire assay, with Spark-ICP finish. Cu, Ni are analysed by XRF and SG by pycnometer on each sample. The primary laboratory cannot analyse for Au, therefore an estimation of the Au is calculated and added to Pt, Pd and Rh to make up the 4E grade sum. The Au is estimated using regression parameters obtained from the analysed Pd grade content.

The 4E grade values are used in a kriging process (domain parameters obtained from the signed-off long term resource model) to estimate the grade content of the 6.5 m x 6.5 m (x, y location) mining block for a particular bench (15 m in height). In the kriging process, thirty analytical samples (n = 30) closest in proximity to the centre of the mining block are used in the estimation (weighted by distance away from the central point of the block).

The planned mining area is marked on a map, with areas designated as destined to be processed (truck load to be taken to the mill, generally grades > 1.7 g/t) or stockpiled (as waste or low grade ore (VLGO or LGO)). The mine ore is classified into five categories of 4E grade (g/t) as specified in table 1-2.

The grade classification groups for stockpiling and mining are based on paylimits (annual report) [(2)] . The paylimit (PL) for stockpiling is 1 g/t 4E and for processing is 2.5 g/t 4E grade. No technical information could be obtained for the origin or basis of design of the 1.7 g/t and 4 g/t 4E decision points; likely based on known grade distributions at the time. It is the aim of

this investigation to define the error uncertainties and associated risk at these decision points (table 1-2), for the purpose of grade control.

The error uncertainties and risk are influenced by many factors. This project work would aim to investigate and quantify as many of these factors as possible.
Some factors that were investigated (at the GCDPs as specified in table 1-2) are mentioned below:

- Analytical technique capability
    - Systematic error: analytical accuracy (measured as systematic error)
    - Random error: analytical precisions (method precision)
    - Analytical detection limits (DL) and limit of quantification (LOQ)
- Sampling techniques used
    - RC drilling
    - BQ diamond drilling
    - NQ diamond drilling
- Sample preparation
- Sampling protocol
    - Sample size
    - Particle size of the sample
    - Heterogeneity of the ore
    - Geological logging
- The process of grade estimation of the mining block
    - The kriging process
    - The number of samples used

The platinum group metals (4E = Pt + Pd + Au + Rh) are the main focus of this study, although where it is reasonable to extrapolate the investigation to base metals (Cu and Ni) and SG; these are included.

HYPOTHESIS

H_o: A ± 10% 4E error is applicable to all grade classification groups for the mine

H_a: A ± 10% 4E error not applicable to all grade classification groups for the mine

RESEARCH AIM

The aim of this study was to document the uncertainty and risk associated with the current sampling (and analytical) techniques at the grade control decision points (GCDPs) for the mine. This information was used to establish whether the defined DQOs (table 1-1) are applicable to the GCDPs at the mine.



Figure 1-2 Reverse circulation drill rig used for grade control sampling at the platinum mine [13]

RESEARCH CONCERNS

The concerns are that:

- the error at the mine's low grade decision points are so large that effective grade control at low grades is not possible using the current analytical and sampling techniques
- the sampling error is so large that it does not warrant a change in analytical technique
- the error is not fully understood by the end-user of the data
- unrealistic requests for accuracies and precisions are forced beyond the capabilities of the techniques
- inadequate QAQC practices at the point of sampling will inevitably compromise the samples

RESEARCH MOTIVATION

The research will document the random and systematic errors at the GCDPs (for the sampling technique used) at the mine.

Mine's heterogeneity nomograms will be extended to 4E grade nomograms (currently only individual element nomograms exist for the mine).

Improvements to sampling will be recommended where appropriate.

PROBLEM STATEMENT

With decreasing ore grades being mined, the grade of interest is edging closer to the capabilities of the available analytical techniques (particularly for the PGE deposit where ore grades are in the low ppm range). It is for this reason that the sampling and analytical uncertainties need to be quantified at the GCDPs grades. These individual (Pt, Pd, Au_{Reg}, Rh) uncertainties need to be converted to a combined 4E grade. Literature suggest that a maximum of 10 % error (Samrec code,2009) [26] at the decision points is permissible. The actual error will be compared with the maximum suggested error.

RESEARCH QUESTIONS

- What is the uncertainty of the block classification at or near the GCDPs?
- Are the systematic errors predictable and consistent between the GCDPs?
- What is the error profile (random and systematic) over the grade range of the ore?
- How many samples are used in an estimation of a block?
- What is the smallest mining unit (SMU) at the mine and how does the SMU affect the random error estimated for the block?
- What is the appropriate analytical acceptance criteria for grade control samples at the GCDP grades?
- What QAQC practices are in place for sampling (that is analytical and sampling)?

RESEARCH METHODS

Eight different data sets were used to quantify the sampling, sample preparation and analytical uncertainties, as an average estimation of error, as well as the error at the grade control decision points (GCDPs) for the mine namely:

- Data set 1: Three-way twin drilling program
- Data set 2: Laboratory proficiency test program on feed and tail grade material
- Data set 3: Four-way laboratory exploration pulp check program
- Data set 4: Two-way laboratory grade control pulp check program
- Data set 5: Laboratory pulp replicates at the GC-Lab

- Data set 6: RC sub-sampling field duplicate data
- Data set 7: Nomogram test data
- Data set 8: “Blind” QC performances at the GC-Lab

HYPOTHESIS TEST

The hypothesis test of this research:

- H_o: If the achieved data quality is less than ± 10 % error (safety line), it will be concluded that the DQO (as stated in table 1-1) *are* also applicable at the GCDPs.
- H_a: If the achieved quality is greater than ± 10 % error (safety line), it will be concluded that the DQO (as stated in table 1-1) *are not* applicable at the GCDPs.

2. LITERATURE REVIEW

Holmes (2010)[10] claims that "despite the availability of training courses, conferences and standards on correct sampling practices, many examples of poor sampling practices can still be found in industry." As part of this project work, all sampling and sample preparation practices related to grade control at the mine were assessed using best practice guides published (e.g. Holmes (2010)[10]).

Gy (1995) and Pitard (1989) [8,22] suggested that for each ore type, there is a minimum sample mass required for a particular sampling methodology (e.g. particle size). For this purpose the heterogeneity test work available for unaltered pyroxenite ore will be re-visited to obtain the uncertainty related to RC drilling samples for the combined PGMs.

Stanley and Lawie (2007)[29] submitted a plea for consistency to the geoscience fraternity. They suggested that the coefficient of variation (*CV) should be used when measuring the average relative error. They define the different measures of average relative error as:

- CV (coefficient of variation)
- RP (relative precision)
- RV (relative variance)
- ARD (absolute relative difference)
- HARD (half absolute relative difference)
- PARD (percentage absolute relative difference)

In their work, each statistical term, formula and relationship to the coefficient of variation is defined. In this study, the CV expressed as a % (that is CV x 100 = % relative standard deviation (% RSD)) will be used to describe the average relative error.

According to Stanley (2006)[28], the conventional standard deviation formula when applied to duplicate pairs (n=2), when simplified to a function of absolute difference between pairs is: $\sigma = \frac{IX_1 - X_2 I}{\sqrt{2}}$. This equation for duplicates will be used in the test work to quantify random error using duplicate pairs.

Spangenberg and Minnitt (2014)[27] suggest that "correct" sampling be linked to the concept of the "lot". The "lot" refers to a mass of material from which a representative sample is to be extracted. The in-situ rock that needs to be sampled for grade control purposes is a two-dimensional lot. The dimension of the lot needs to be reduced as far as possible, to a dimension of "zero", e.g. a falling stream. A zero dimensional lot is when there is no restriction to access of the increment lot. RC drilling (primary sampling) cannot obey the basic rule for

correct sampling because an in-situ block of ore is a two-dimensional lot (position of the sample is defined in two dimensions) and samples are extracted in a 3rd dimension. Drilling is the only means of obtaining estimates of the grade at a given locality, thus an in-situ measurement is made. The cylinder shape of the drill rod is the correct geometry for two dimensional sampling. The cylinder / drill must penetrate the entire thickness of the bench. The correctness of the "from" "to" location measurement of the drill sample should be correctly noted.

For the sample to be "correct", each and every fragment in the lot has to have the same statistical chance as every other fragment of being sampled. Thus, although not "correct", the only reasonable way to recover the material from the drill hole would be by using a reverse-circulation (RC) rig as the primary sampling method. For the mine, secondary sub-sampling of RC clippings are collected per increment via a cyclone and then divided using a cone splitter. The code of practice (COP) should specify design, installation, operation, and maintenance requirements according to theory of sampling (ToS). In this study, the COP, standard operating procedures (SOPs) and planned tasked observations (PTOs) for grade control sampling at mine[11,12] were investigated and compared with best practice found in literature.

The in-situ nugget effect (INE) which is considered to be characteristic of the reef, was quantified for 3E g/t using the heterogeneity test data done by Barr, J., et al. (2016)[5].

Spangenberg and Minnitt (2007b)[19] believe that it is difficult for management to accept the cost of new sampling equipment but if made aware of the hidden cost incurred due to poor sampling practices, they will ensure that sampling equipment is installed, operated and maintained at appropriate levels. It is envisaged that this test work will aid to highlight (and quantify) the risk associated with sampling (specifically in the area of grade control).

Thompson and Howarth [31-34] suggested that if a large number of duplicate measurements are available (n > 50), a linear measurement-error function may be obtained via regression. They compiled the duplicates into consecutive groups of 11, based on their means. When the number per samples in the group is large (> 11), the number of groups are fewer but the estimates of the means and standard deviation to regress with are more accurate; smaller number of samples per group result in less accurately estimated statistics. This study, used the same strategy of groups of 11 (or more), to reduce the random error sufficiently in order to quantify the systematic error.

Stanley and Lawie (2007)[29,30] used the average means and root mean square, (RMS) standard deviation of the duplicates after grouping. Plotting each group on a Thompson-Howarth scatter plot. It was noted that ordinary least square regression of the group RMS standard deviation against the average group means, yields a linear measurement-error relationship. Using the expected RMS measurement errors for the samples to estimate the functional relationship between concentration and error. This approach, was used to establish the method precision of the analytical method used in this study.

Thompson-Howarth error analysis[31-34] has been the standard technique used to assess the precision of geochemical data. This error analysis used the differences between duplicates and assumes that measurement error is distributed normally. Stanley 2006[28] suggested a modification to the procedure. Instead of using differences, the standard division of the duplicate pairs were used.
Stanley mathematically derived the formula for the standard deviation for duplicates as:

$$s = \frac{|x_1 - x_2|}{\sqrt{2}}$$

The data was sorted in ascending grade and the group root mean square (RMS) standard deviations were used as the measure of measurement error. This modification removes systematic error, even if the error distributions are not normal. Suggesting that the RMS of the eleven pairs convert these values into mean standard deviations. In this way, the assumption of normally distributed errors is avoided. Thus the unsystematic errored estimate of the relationship between measurement error and concentration can be deduced.

Stanley 2006[28] also noted that determination of measurement errors in grade control assays from low grade, high tonnage ore deposits is now extremely important because of the small profit margins associated with the mining of ores with concentrations close to cut-off grade. In this paper[28], Stanley also points out that the group of eleven duplicates is arbitrary and that any number of pairs could be used. The more duplicates placed in a group, the better the estimate of the mean and standard deviation. The regression function will also become more stable. However, if too many duplicates per group are used only a small number of group statistics will be available with which to calculate a regression function, degrading its quality Thus, a trade-off between the number of replicates in the group vs. the number of points used for the regression should be made in order to obtain the best possible regression fit. Stanley suggests that rare elements such as platinum are not likely to be normally distributed because these commodities occur in rare grains (nuggets). Suggesting that “nugget” ores are more likely to have a poisson distribution. It is for this reason that Stanley’s 2006[28] work is very relevant. In this study, the above modification to the Thompson-Howarth error analysis was

used to quantify the analytical method precision at the GCDPs. The formula derived for duplicates was also used to calculate the regression function for sub-sampling field duplicates for the mine.

The guidance document from the USA environmental protection, by Gerlach, et al. (2003)[7] summarises Pierre Gy sampling theory and its implication on sampling in very simplistic terms. Unless a heterogeneous population (block of ore) can be completely and exhaustively analysed, sampling is the first physical step in any measurement process of that population. The characteristics of collected samples are used to make estimates of the characteristics of the population. Thus, samples are used to infer properties about the population in order to implement decisions about the population, Gerlach, et al. (2003)[7]. In most cases it is assumed that samples are an accurate and precise representation of the population. Gerlach, et al. (2003)[7], state that without special attention to this assumption; sampling could be the weakest link leading to the largest errors in the measurement process or the experimental study. In this study, grade control sampling was given extensive attention and was tested against Gy's sampling theory.

In the US environmental guide(2006)[35]; it is stated *that "any lot (e.g. a site, a section from a site, or a batch) of particulate material consists of particles having diverse characteristics with respect to size, shape, density, distribution, as well as physical and chemical constitution. This diversity in the particle properties, the lot-specific uniqueness of the distribution of the analytes of interest, and the uncertainties due to the subsampling techniques in the field and the laboratory, often lead to a large variability among the analytical results of the samples that are supposed to represent the lot ".*

Gerlach, et al. (2003)[7] suggest that a sample assessment be conducted for each sample purpose. The properties of particulate material being sampled and its effect on sampling variances has been investigated. Particle properties that may affect the variability (directly or indirectly) were defined by Gerlach, et al. (2003)[7] as:

- Colour (hue and intensity)
- Composition
- Concentration
- Density
- Friability
- Hardness
- Mass (weight)
- Mineral type
- Moisture (and other liquid) content
- Mottling
- Opacity

- Porosity
- Shape
- Size
- Structure
- Texture
- Variegation pattern (stripes, streaks, or speckles)

Table 2-1 presents a useful way to translate the nomograms so as to better understand the fundamental constitutional and distributional error for mine ore.

Table 2-1 Relationship of particle diameter, analyte concentration and desired uncertainty level compared to the sample mass for low concentration samples of average density (2.7 g.cm^{-3}). Sample sizes in column 3 through to 6 are shown to 2 significant figures in units of grams

Maximum Diameter (cm)	Analyte Proportion	% Relative Standard Deviation			
		M_s = 5 g	M_s = 10 g	M_s = 25 g	M_s = 50 g
0.01	0.1	0.0043	0.0011	0.00017	0.000043
	0.05	0.097	0.0024	0.00039	0.00097
	0.01	0.053	0.013	0.0021	0.00053
0.05	0.1	0.54	0.14	0.022	0.0054
	0.05	1.2	0.30	0.049	0.012
	0.01	6.6	1.7	0.26	0.066
0.10	0.1	4.3	1.1	0.17	0.04
	0.05	9.7	2.4	0.39	0.10
	0.01	53	13	2.1	0.53
0.5	0.1	540	140	22	5.4
	0.05	1,200	300	49	12
	0.01	6,600	1,700	260	66
1.0	0.1	4,300	1,100	170	43
	0.05	9,700	2,400	390	97
	0.01	53,000	13,000	2,100	530

Table 2-1 is an extract from the USA environmental protection guidance document[35]. Gerlach, et al. (2003)[7] state that a bold horizontal line may be drawn in on the nomogram to represent the maximum relative variance of the fundamental error that is tolerated, as set by the study objectives (e.g. DQOs). In this study, the maximum line was set to the safety line, of 10 % RSD.

Minnitt (2010)[16], noted that the sampling nomogram is an essential tool in the optimization of a sampling protocol and allows the operator to track the change in relative variance of the fundamental sampling error during steps of comminution and mass reduction in the process of recovery of the aliquot for analysis. The data required for the compilation of the nomogram is centred on the sampling constant K and the exponent alpha of the nominal fragment size. The duplicate series analysis method (DSA) described by Minnit(2010)[16] was used in this study to compile the nomogram for 3E g/t.

Minnitt (2007)[14], noted that in order to confidently answer questions about the sampling procedure a sampling nomogram is required to describe and summarise the relationship between the fragment size, the mass of the sample relative to the mass of the lot and the

relative variance that can be anticipated. In the same paper, Minnitt also states that "*a good look at correct sampling protocols can improve closer reconciliation between mineral inventory estimated which in turn leads to better cash flows, enhanced profits and added share value*". Minnitt, highlights that in order to understand the total variability, the variance needs to be split up into its component parts and evaluated individually; this study attempts to do exactly that.

Minnitt (2007a)[18], noted that the total sampling variance is a measure of the total sampling error, but disaggregating the variance into its component parts is problematic.

Schouwstra, R., et al (2013)[25], suggested that changes in concentrate grade or recovery could be expected as a result of change in ore type. They note that the diversity of the Platreef is much greater than the rest of the Bushveld complex mainly due to extensive reaction of the pyroxenite magma with footwall sediments. They identified four major rock types for the mine namely, parapyroxenite, pyroxenite, feldspathic pyroxenite and serpentinite. The most abundant rock type being pyroxenite. In this study pyroxenite rock type was used to quantify the error associated with the intrinsic heterogeneity of the ore. It is suggested that the other three rock types as identified by Schouwstra, should also be tested using the DSA method described by Minnitt (2010)[16].

The slope and intercept defined in table 6-1 quantify the method repeatability limit. The AOCS procedure M1-92[3] defined the method precission limit as the absolute difference between two independent single test results, obtained with the same method on identical test material in the same laboratory by the same operator using the same equipment within a short interval of time.

The AOCS procedure M1-92[3] defined the between laboratories precision as the reproducibility limit calculated as the absolute difference between two single single test results, obtained with the same method on identical test material with different laboratories by a different operator using different equipment. In this study the reproducibility data is data set 3.

Carrasco, P., et al. (2003) [6], stated that an incorrect sampling and assaying process can lead to bad decisions that can cost billions of dollars during the life of a large mining company. Reasons for the incorrect sampling process were listed as:

- Lack of awareness of the hidden costs associated with incorrect sampling process
- Focus on effects rather than causes of problems
- Sources of variability not known and understood
- Low synergy in the mining industry
- Isolated sampling community unable to communicate the relevance of sampling to top management

- Rarity of courses and research programmes in the field of sampling
- Cryptic books on sampling theory that makes the subject difficult to understand

This study identifies and quantifies the sources of variability for grade control RC sampling at the mine.

The Atlas Copco, *An introduction to reverse circulation drilling*[4] describes the RC drilling process as follows: The RC method employs double wall drill rods that comprise an outer drill rod, with an inner tube located inside the drill rod. These inner tubes provide a continuous sealed pathway for the drill cuttings to be transported from the bit face to the surface. High pressure air enters the annulus between the rod and the tube. The air travels down the annulus to the RC hammer. The air powers the drilling tool and the exhaust air carries the cuttings through the inner tubes in the drill string. The air and cuttings (sample) discharge through a sample hose into the cyclone. There are two main components to the sampling system: the cyclone and the splitter. The cyclone reduces the speed of the sample and separates it from the air, allowing it to be collected. The cyclone should be efficient enough to collect 99% of the sample with the remaining dust and air going to the dust collector. *In this study it was found that the efficiency of the cyclone is not measured on a regular basis.* The cyclone holds two sample intervals without contamination. An area of the cyclone called a dump box is equipped with a door that separates the two samples. One sample is being drilled while the other is held in the dump box. The door then opened and the sample released from the bump box for splitting. The purpose of splitting is to divide the sample down to a smaller size that is an accurate representation of the complete sample. The entire sample is dropped over the point of an inverted cone. The assay sample is taken as it runs off the edge of the cone. The segment size can be adjusted to collect the required percentage cut of sample. Cone splitters can give a more accurate split but are more sensitive to set up than a riffle splitter. *In this study it was found that the percentage sample cut is not measured on a regular basis.* Both the above mentioned quality control measures should be implemented to monitor the quality of sampling at the mine site.

Minnitt (2017)[15] highlights the fact that only by minimizing bias, there is the possibility of minimizing the adverse effect of dilution and lost ore, both of which cost the mining company money that can never be accounted for.

3. THEORETICAL CONCEPTS

3.1 STATISTICAL CONCEPTS

Statistical concepts relevant to this report are defined and discussed below.

3.1.1 MEASUREMENT

Measurement is the assignment of a number to a characteristic (e.g. physical quantity like grade) of an object (e.g. a block of ore). The complete mining block of ore cannot be measured thus a sample of the block is taken and inference is made about the block of ore with the information obtained from the sample.

3.1.2 UNCERTAINTY

A parameter, associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurant, Amira P754 (2004)[(1)] .

3.1.3 MEASURING SYSTEM

The measuring system for grade control at the mine consists of seven sampling components:

I. Reverse circulation *primary sampling* to obtain a bulk sample containing chipped ore fragments
II. *Sub-sampling* to obtain the analytical sample by passing the sample under influence of gravity through a rota-port rotating cone splitter.
III. Automated *sample preparation (crushing, milling and splitting)* at the grade control laboratory (GC-Lab)
IV. *Analyses* at the GC-Lab using a Spark analytical method;
    Lead fire assay with Spark excitation, with optical emission spectroscopy finish, to determine the individual grade of platinum (Pt), palladium (Pd) and rhodium (Rh)
V. Importing assays into the *database*
VI. The *calculation of the 4E grade*; gold (Au) grade are estimated from the analysed Pd grade using regression parameters. The sum of Pt plus Pd plus $Au_{(Reg)}$ plus Rh are then added to obtain a 4E g/t total
VII. *4E grade assignment* to the centre (x, y, z) location of the 6.5 m x 6.5 m x 15 m mining block using a kriging process

This report focuses quantifying errors associated with components I to IV for grade control at a mine.

3.1.4 MEASURANT

When a specific problem needs to be solved it is important to clearly state the measurant. The measurant is the *physical or chemical parameter and its unit of measure*, examples below;

- Grade (e.g. 4E g/t)
- Mass of ore delivered (as tonnes (t))
- Content (as ounces Pt)
- Random error (as ± % RSD)
- Random error (as ± g/t 4E)

The mine measure for its process of controlling the grade to the mill (grade control) is in terms of 4E grade in units of g/t, thus the measurant is 4E g/t.

In this study, the uncertainty in 4E is measured in terms of error.

3.1.5 UNIT OF MEASURE

A parameter can be measured using different units of measure e.g. the parameter “distance” can be measured in miles, kilometres, or metres.

In the case of grade control at the mine the unit of measure is grams per tonnes (g/t).

When the uncertainty of a measurement is stated, it is very important to state which unit of measure was used.

The parameter “error” can be described in various units of measures:

- Variance (Std dev^2)
- Difference (A - B)
- % Difference = ((Difference (A-B))/Average (A,B)) x 100
- Standard deviation (Std dev)
- Coefficient of variation (CV)
- Relative Standard Deviation (±% RSD)
- Standard Variance

The convention of using CV % (same as % RSD) as a measure of average error is used here (Stanley and Lawie (2007a)[29].

3.1.6 ERROR

Error can be described as the difference between the obtained grade and the “true” value of the sample. Error is a single value for example 2 %. Error is an idealized concept and errors cannot be known exactly.

Any measurement is subject to three types of errors namely:

- Gross errors (mistakes)
- Random errors (“signature” of the measurement system)
- Systematic errors (consistent errors related to the “design” of the techniques used)

Gross errors are mistakes that can be avoided. In reality systematic and random errors are superimposed. In the investigation of errors, different techniques can be used to separate the random and systematic components, so as to obtain a better understanding of these errors. Resources can then be employed to address errors that have the largest contributing factor. When contributing errors are *compared* it is best to convert these errors into a standard variance $\left(\frac{StdDev^2}{Ave\ Grade^2}\right)$, this allows the parameters to be positive and without unit. These errors are then additive and can be compared.

3.1.6.1 Gross errors

Gross errors (outliers) are caused by an unforeseen event e.g. the sample solution in the laboratory was not made up to the correct volume or the inserted “blind” standard is not assigned the correct identification. These type of errors are mistakes.

Preventative measures should be put in place to eliminate these type of errors.

Examples of such preventative measures are:

- The laboratory introduces a copper (Cu) pattern (green colour resulting from the addition of copper) to the flux before fusion. This preventative measure highlights gross errors that may have occurred during the fusion process e.g. samples out of sequence. If the Cu pattern obtained after fusion is different from the Cu introduced before fusion, a gross error occurred and the process needs to be repeated.
- Samplers should weigh the sample mass obtained for sub-sample “A” and sub-sample “B” at the RC rig. The difference between mass “A” and mass “B”, calculated as a % is an indication of the splitting efficiency of the rota-port cone splitter. If the splitting difference is larger than the excepted difference, a gross error occurred in the splitting procedure and the sample will be biased.

Preventative measures are quality control (QC) measures put in place to monitor quality in a particular part of the sampling chain (7 components described in 3.1.3).

3.1.6.2 Random errors

Random errors (generally also referred to as precision); these type of errors are as a result of the type of measuring system used. These arise when a system of measurement is extended to its maximum sensitivity. If one were to measure a desk with a tape measure in decimetres (1 dm = 10 cm = 100 mm), repeat measurement will be in complete agreement but if one were to measure the same distance in mm, repeat measurement would vary randomly around a mean. Random errors are a direct consequence of numerous *uncontrollable variables* that inevitably exist in every chemical or physical measurement. Random errors always have a ± (plus and minus) sign. It describes the normal distribution that can be expected using the particular measuring system of choice e.g. analysis at a specific laboratory, analytical method and ore type. This normal distribution of the measuring system can be compared with (in simplistic terms) the fingerprint of a person, meaning that it is unique to the measurement system. The normal distribution of a measuring system is the statistical property that allows the end user of the data to predict the population distribution ("true" grade of the ore block) from the student t-distribution (measured grade of the ore block).

In many cases the end user of the data assumes that if the limits (assigned to describe the random error) of the measurement are tightened, the laboratory will deliver better quality assay results, where in fact the opposite is true. The purpose of assigning random error limits to a measurement system is to ensure that the "measurement system" does not drift out of statistical control. Thus outlier results (gross outliers) are highlighted if a measured result is outside the control lines and the sample can be repeated. If the random limits are not following the "signature" of the measuring system or put differently: is not a true representation of the random distribution of the measuring system, the results will be systematically errored (artificially made to be too high or made to be too low). It is in the interest of the end user of the data to ensure that the "natural" distribution of the data is protected; meaning the limits applied represent the true distribution of the data.

3.1.6.2a Central limit theorem

A very important property of random error is described in the *central limit theorem (CTL).* Minnitt and Pitard (2005)[17], state that "*the CLT describes the characteristics of the means of a sufficiently large number of independent random variables with a mean (μ) and variance (σ^2). In such cases the sampling distribution of the means approaches a normal distribution with a mean (μ) and variance* $\frac{\sigma^2}{n}$ *with n, the sample size*".

Thus due to the CLT, the method precision of the laboratory can be used to estimate the random error in the grade of the block by dividing the method random error (at the grade of ore) by the square root of the number of samples used in the "estimate".

Thus if thirty samples (analysed in duplicate) are used to calculate the grade of the mining block, then the random error can be estimated as equal to the laboratory method precision (at the grade of the block) divided by the square root of sixty.

The CLT can also be used to create graphs that separate random errors from systematic errors. This concept will described in section 3.1.7.2.

3.1.6.2b Method precision

Random errors of an analytical method can be quantified using multiple replicate pairs (n=2, of the same pulp split of the sample). The methodology used is described in literature as the "Thomson Howard" duplicate method.

The method precision (MP) of a laboratory is the best precision that a laboratory is able to achieve using a specific analytical method for a particular element, specific grade and sample matrix. MP can be expressed as 1x % RSD or at a specific confidence interval such as a 99.7 % (± 3 % RSD) or a 95 % (± 2 %RSD) confidence. For the purpose of this report MP is expressed in terms of (one) ± % RSD.

The MP error close to the *detection limit* of the analytical technique is described by a regression formula (y = mx + c) and not by a single number. The regression is a linear relationship between concentration (x-axis, concentration in g/t) and random error (y-axis, absolute error in g/t standard deviation). The error can then be translated into a % error (expressed as ± % RSD) against the grade of the element (e.g. in g/t Pt). Laboratories that are ISO accredited are enforced to fully describe its random error in their method validation reports. The end user of the data has a right to request this information.

The formula used to calculate the MP of a laboratory is given by:

MP (as %RSD) = ((intercept / grade) + slope)

MP (as 2 x %RSD) = ((intercept / grade) + slope) x 2…….at 95% confidence

MP (as 3 x %RSD) = ((intercept / grade) + slope) x 3…….at 99% confidence

The MP limits can be used to determine if paired replicates are within statistical control. This involves calculation of the % error (as 1 x % RSD) between the paired data points and if the % RSD is greater than 3 x % RSD limit, then the error between the replicate pairs can be regarded as an outlier result that did not follow the expected random error of the method.

It should be noted that this MP should be translated into a measurant that makes sense to the end user of the data e.g. 4E g/t.

If the analytical procedure is well established, its standard deviation (random error) is well known and based on a sufficient large number of degrees of freedom (df), we may assume that the MP standard deviation is equal to the population standard deviation σ (see 3.1.6.2).

3.1.6.3 Systematic errors

Systematic errors are *determinate errors*, because they have a definite value which can be measured.

Systematic errors are *uni-directional (one direction, "-" or "+")* and may affect the final result in two ways:

- *independent* of sample size or analyte concentration
- *proportional* to sample size or analyte concentration

Exact classification of the origin of systematic errors can be quite problematic and any type of classification will suffer from overlap of classes.

Systematic errors can generally be assigned to:

- The sampler or analyst
- The equipment
- The procedure

3.1.6.3a Independent systematic error

If the absolute error's magnitude (g/t 4E) is both constant and independent of the sample size and / or the analyte concentration, the relative error (%) will vary in magnitude.

Example: An analytical balance having a weighing error that leads to all masses being 10 mg too low. The absolute error would then be "-" 10 mg irrespective of the sample weighed out. The "-" 10 mg error is obviously more serious if only 100 mg of sample is weighed out than if 1000 mg of sample had been weighed. Thus the relative error (%), will be larger (a bigger %) at 100 mg weighing, and smaller (a smaller %) at 1000 mg weighing.

3.1.6.3b Proportional systematic error

Errors that are proportional to the sample size or analyte concentration's magnitude is directly proportional to the size of the sample and/or analyte concentration; the relative error (as a %) will remain constant.

Example: If the matrix of the instrument calibration standards does not match the matrix of the samples. The calibration graph's sensitivity or slope will not be applicable to the analysis of the sample material being analysed. The absolute error (g/t) will increase as the concentration increases but the relative error (%) will remain constant.

In order to eliminate systematic errors, it is important to understand its dependency and proportionality on sample size and analyte concentration as well as its magnitude absolute terms (g/t) and in % terms. It is for this reason that the researcher has expressed errors in this study in units of both g/t and %.

3.1.7 CONTROL CHARTS

Control charts can be used to monitor the systematic error (accuracy) or random error (precision) of the measuring system mentioned in 3.1.3.

3.1.7.1 Control charts to measure random error

An example of control charts that measure random error would be Shewhart control charts. A laboratory uses Shewhart control charts to monitor the analysis of each assay of the quality control (QC) standard. If the QC measurement is within the ± 3 sd control lines, it is assumed that the laboratory process of analyzing the samples under the same conditions are within statistical control. The consensus value (CV) that the laboratory uses in control charts that is designed to measure random error, should be the laboratory's established CV for the standard in use. These control charts makes no statement with the respect to any systematic errors. The process that the laboratory uses to establish its lab-CV for the standard and the acceptability of the lab-CV when compared to the CV certified by the certification body of the standard, is outside the scope of this study.

Many laboratories use the CV as stipulated in the certificate to monitor whether their process is in statistical control. If the difference between the lab-CV and the CV as stated on the certificate is sufficiently large, a systematic error is present and the laboratory will repeat the analysis when resources should rather be used to eliminate the systematic error present. When a QC (and samples) is repeated when it is not out of statistical control, chances are that the repeat QC will fall within statistical control. The results obtained are now probably

systematically errored due to the laboratory repeating when it should not have repeated (introducing a selection systematic error). No real improvements are made although an apparent improvement is shown.

3.1.7.2 Control charts to measure systematic error

Control charts designed to measure systematic error, must use the best estimate of the "true" value, which is mostly the CV as stipulated on the certificate of analysis for the standard in use. In very rare cases will the laboratory be able to present sufficient evidence that contradicts this assumption. The preparation of the bulk material and the process of certification used by certification bodies are normally regulated by best practices.

A Shewhart chart presenting the assay of each instance of QC can be used to measure the systematic error, however a 5 or 10 point moving average superimposed on the actual assays (maintaining the same x-axis) presents a clearer view of the systematic error. Each individual QC result will be subject to random and systematic error. The individual results need to be averaged, in order to "strip" the systematic error from the random error (using the CLT property of random error). The random error in the average is reduced by a factor of $\sqrt{n}$ (with n = number of assays that are averaged). This averaging, reduces the random error sufficiently in order to measure the systematic error more accurately. This principle, in line with the CLT, is used throughout the measurement of systematic errors in this study.

3.1.8 DATA QUALITY OBJECTIVES

3.1.8.1 Business quality requirement (business objectives)

Business objectives are regarded as the error tolerances that a business places on a specific measured parameter. Table 1-1 is the business objective used in the reconciliation between the long term model and the grade control model. The business objective is normally *independent* of the measuring system. It could be error tolerances set by the finance department where these are set based on risk tolerances in terms of rand value.

3.1.8.2 Technical quality achieved (technical objectives)

These technical objectives are error tolerances that were technically derived to monitor if a specific measured parameter is in control. An example of this type of objectives are the quality control limits for a specific standard used by the laboratory. These objectives are *dependent* on the measuring system.

3.1.8.3 Fit for purpose

A measuring system is said to be “fit for purpose” if the technical objectives match or are within the business objectives.

If the technical objectives are much “tighter” than the business objectives, then an opportunity exists to save cost by using a “cheaper” measuring system with larger errors.

If the technical objectives are larger than the business objectives, then the measuring system is not “fit for purpose” and the company needs to invest in obtaining a better measuring system or accept the larger errors and associated risks in the measuring system in use.

Data quality objectives (DQOs) address the question of why and with what purpose the samples are collected[21]. DQOs link the business quality requirement to the quality that can be achieved using available analytical and sampling techniques. If there is a match, the techniques can be regarded as “fit for purpose”. If there is a miss-match, alternative solutions need to be found or the business needs to accept the uncertainty and associated risks.

The USA Department of Energy (2006)[35] compiled a 111 page document, specifying the procedure that needs to be followed to document DQOs. In it, it is stated that a planning team of technical experts is required to develop the DQO with input from all stakeholders. It is a strategic planning approach based on a scientific method of documenting the data requirements [35].

The USA Department of Environment, Gerlach, et al. (2003) [7] state that “the primary reason for taking samples is to make some determination about the lot (e.g. a block of ore). The DQOs determine the acceptable statistical characteristics for the study. If a decision is dependent on the analytical results, then the first issue is to determine what type of measurements are needed and how accurate and precise it should be.

Many cannot grasp the purpose of investing technical expert’s time to document DQO’s. These DQOs technically answer the question: “Is the data fit for purpose?”. No literature was found where the mining industry used this formal approach of documenting data quality requirements.

This study, focuses on sample information used for the purpose of grade control and errors (technical quality achieved) are quantified at the GCDPs.

3.2 QAQC CONCEPTS

A good QAQC program covers the measuring system (3.1.3) as a whole; that is covering all components within the sampling chain (sampling, sample preparation, analytical, data importing into a database, calculation of the composite 4E grade and assigning 4E grade to the mining block). This section will focus only on QAQC components within sampling, sample preparation and analytical.

Figure 3-1 below present the overall design components of a QAQC program. The program can be divided into components of design (these components give assurance of quality: QA) and components of control (these components monitor quality: QC). The different QAQC components in this study, are discussed from a grade control sampling perspective.

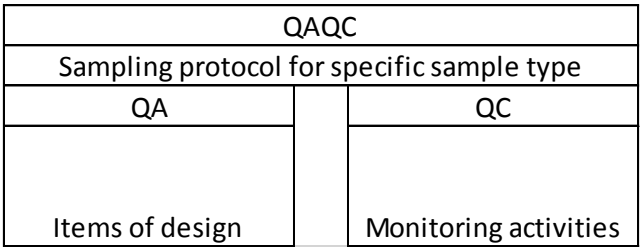


Figure 3-1 Schematic diagram of the high level QAQC components for a sampling protocol

In order to improve the quality of measurements, it is important to first quantify all sources of error. To recap: random errors are the “finger print” of the measuring system. The effect of random error can be reduced by averaging more samples used in the final decision point e.g. when assigning a grade to a block, averaging more samples (increase n). Systematic errors originate from “design” error; these have a magnitude and sign. These errors cannot be reduced and are cumulative. These can only be changed if the parameters of the measuring system is changed e.g. introduction of a new flux in the fire assay process. Resources should be focused on reducing these type of errors. Systematic errors can be dependent or independent on grade and sample mass.

3.2.1 SAMPLING (THE ACTION OF TAKING A SAMPLE)

3.2.1.1 Sampling “design” components (QA - quality assurance):

Sampling Protocol is a summarised description of the mass and comminution (particle size reduction) steps from lot-to-aliquot. For grade control, the lot is the mining block for which the grade is being estimated and the aliquot is the analytical sample aliquot analysed. The larger the mass and the smaller the particle size of the sample, the smaller the variance. The frequency of the sampling events (sample cuts) should be specified in the sampling protocol (the larger the number of sampling events the smaller the variance (group segregation error

(GSE)). The sampling protocol (highlighted in the red square in table 6-9) can be plotted on a nomogram if the sampling constants K and alpha are known; Minnitt, et al. (2007b)[19]. The sampling constants can be derived from heterogeneity test experiment for a particular ore type. It involves the calibration of particle size against variance for the particular ore type. It is recommended that the residual fundamental error be below a ± 10 % one RSD. This reference line is referred to as the safety line. A nomogram for the mine was established using the duplicate sample analysis (DSA) method described in the literature[19]. Note the nomogram excludes Rh; it is assumed that the effect of Rh will be insignificant due to the very low grades of Rh.

To reduce the error related to the intrinsic heterogeneity of the material, the heterogeneity test work Barr, et al. (2016) recommended that:

- Redesign of the RC sub-sample cup:
  The RC sample taken at the RC rig needed to be increased from 500 g (a mass of 900 g was chosen as it is just below the laboratory mass design criteria of 1 kg). For a sample mass larger than 1 kg, the laboratory will have to make significant design modification to its automated procedure.
- Modification to the analytical sample fusion mass:
  The analytical sample needed to be increased from 40 g to 60 g (maximum mass : flux ratio that can be accommodated using the current fire assay fusion pot sizes)

The effect of making these small changes reduced the intrinsic heterogeneity errors for platinum and palladium from > 10 % to < 10 %. Test work at the laboratory also indicated that better precisions and fewer failures were achieved with the larger analytical sample aliquots.

These changes fall in the “design” component (QA) of a QAQC program.

During a visit to the mine site it was observed that 6 m drill rods were used. This makes it difficult for the operator to control the drill rod at 2.5 m intervals. It was recommended that 5m drill rod-lengths be used instead. Implementation of 5 m drill rod lengths are components of “design”.

Secondary sub-sampling of the RC rock clippings is done by a rota-port cone splitter. The clippings are presented to the cone in a falling stream as a zero dimensional lot.

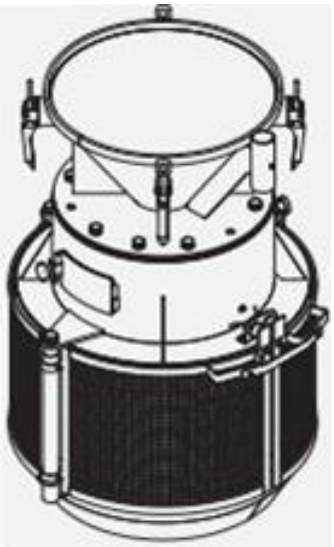


Figure 3-2 Schematic diagram of the RC sampling drill rig rota-port cone splitter

The *sample equipment design* components need to be tested against theory of sampling (ToS) and best practice recommendations; this aspect covers the quality assurance (QA) component in a QAQC program.



Figure 3-3 Reverse circulation drilling rota-port splitter, sample cups and samples used for grade control

The *golden rule of sampling*, “Every sample fragment must have an equal chance of being selected as the chosen sample” must be tested i.e. equiprobability for sampling.

In order for the *cutter blades* to have the best chance of being “correct”, the following best practice *design* criteria must be honored:

- The cutter blades:
  - must not be worn or bend
  - must intersect the complete stream, overshooting the stream with 5 cm on both sides
  - move at a constant speed, some literature suggest < 0.45 cm / sec and others suggest < 0.6 m / sec (Holmes, R. (2010)[10])
  - must have 45 degrees edging, facing the stream
- The increments of which the sample are made up should be as small as possible and as many as possible (> 30).
- The interaction between the cutters and the material stream, needs a specific minimum opening, defined as:
  - opening of the cutter must be 3 d (where d is the nominal top size) plus 1 cm, (Holmes, R. (2010)[10]).

For RC drilling the nominal top size (d_n) is 1 cm. The cutter blade opening should be uniformly at least 4 cm to ensure no preferential exclusion of specific size fractions. Thus the cutter geometry must be correct. Incorrect cutter blades will result is an *increment delimitation error* (IDE) error; that is, there is a difference between the *correctly defined* increment and the *actual* increment extracted.

The *capacity of the sample cups* must be large enough to receive increments from the complete full stream. It must not fill up before the complete bulk sample has passed the sample cups. The sample cups must not overflow, thus fragments that should be part of the sample must not be lost by means of spillages. *Incremental extraction error* (IEE) arises if the sample volume expected is not the same as the sample volume obtained. Thus there is a difference between the *intended* increment and the *actual* increment extracted.

During a visit to the mine site, the observed sub-sample cups were overflowing. The sample cups were re-designed to obtain the maximum required analytical sample (± 900 g). In reducing the size of the sample cups the sample obtained does not follow this ToS best practice principle.



Figure 3-4 RC drill rig rota-port sampling cutter blades

The receiving *sample cups must be positioned* below the cone splitter so that it will be able to take fragments falling that are closest to the cone splitter as well as furthest away from the cone splitter in an equal manner. Thus an increment from the complete falling stream must be taken without any sample loss.

During a visit to the mine, the position and design of the sub-sampling cups were inspected to ensure this assumption is true. The sampling cups contained a “lip” on the outside of the cup, facing inward. The “lip” was used as a handle to remove the cup from the splitter unit. The “lip” restricted sample falling into the cup, thus an incremental delimitation error (IDE) occurred. *The sub-sampling cups for RC drilling need to be re-designed. Handles of the cup* must be positioned to the outside or “up” so as not to obstruct falling fragments from entering the cup.

The *shape of the sample cups* must be radial with the smallest opening closed to the center and not smaller than 4 cm. The *“lips” of the cup* must not be worn or bend and must have 45 degrees edging. During a visit to the mine site it was observed that the sample cups do not have a clean radial design and the “lips” of the cups were worn and skew.



Figure 3-5 RC sub-sampling sample cups with cup handles (highlighted with the red arrow) that restricting the fall of sample

The *integrity of the sample* must be maintained. The complete sample must be transferred to the bag without any *sample loss* during the transfer process. During a site visit to the mine it was observed that the sampler took some chips out of the analytical sample for geological logging. This practice compromises the integrity of the sample.

Loss of fines during RC drilling is a real problem clearly visible when observing the sampling process. Due to the nature of RC drilling it is very difficult to prevent all loss of fines i.e the falling sample creates a dust cloud when falling through the rota-port splitter. PGMs are concentrated in the fines thus this loss of fines will affect the quality of the samples, generating a low systematic error ("-" systematic error).

The sampling system must be flushed with compressed air after every sample to avoid *contamination*. The complete sampling system must be cleaned out regularly to remove build-up of sample, this should be done at least at the start of every shift.

Site sampling standard operating procedures (Langa, Z. (2014 a & b)[11,12]) were inspected and inadequate reference to theory of sampling and quality assurance aspects are addressed in these procedures.

3.2.2.2 Sampling "control" components (QC – quality control):

Proportionality of the samples, the % cut needs to be measured for each sample. This can be done by weighing the bulk sample (this can be done once a day) from which the sample originate and weighing the split sample (mass of each analytical sample). The weight of the split sample as a percentage of the bulk sample will be an indication of the consistency of the sample cut.

Recovery of the bulk sample, the calculation of the theoretical mass of the bulk sample in comparison to the actual weight of the bulk sample gives an indication of the delimitation (IDE) and extraction (IEE) error of the sample. IEE arises if the sampling tool is selective, e.g. coarse cuttings stay at the bottom of the drill hole. Thus, if the sampling tool preferentially collects fine material because it cannot collect large fragments IEE is introduced.

Primary sampling *field duplicate reproducibility (precision)* are normally not routinely monitored but this random error should be measured. It is a costly exercise and should probably be done every 2 years. A twin hole exercise was introduced during 2016 at the mine to establish the error between twin holes collared within 1 m. The results of the program was reported in section 4 and 5 of this report.

Secondary sampling *field duplicates* of the rota-port cone splitter should be submitted to the laboratory (e.g. % of the samples). Results should be used to calculate the sub-sampling field duplicate random errors (sampling & analytical precision). Monthly comparisons will monitor any deviation from the established baseline performance. Sub-sampling field duplicate acceptance limits are calculated for each element. The field duplicate data should be checked against the acceptance limits and the percentage of data outside these limits should be monitored for trends. Field duplicate outliers can also be used to highlight possible compromised assay results or samples.

Regular *particle size analysis* should be done to ensure the RC drill is performing optimally. Drill bits made of tungsten steel are attached at the end of the drill hammer. These have metal nodules attached at the end to allow cutting through rock. With wear and tear these nodules become flattened which create finer particulate material which eventually do not cut the rock anymore but rather grind the rock into a fine powder. When the nodules are completely flat the drill bit gets stuck and RC drilling production is held up. With regular particle size analysis, optimal drill bit performance can be measured.

The drilling speed and rock type (hardness) have a direct effect on the particle size of the sample clipping. The slower the drilling speed the more effectively the rock is cut, producing less fines. The creation of fines during RC drilling, should be avoided where possible. PGMs are liberated in the fines, creating preferential PGM losses where fines are lost.

The number of increments (*rotations of the sample cups under the falling stream*) should be monitored; the number of rotations (sample cuts) should be more than 30.

3.2.2 SAMPLE PREPARATION

Sample preparation is the process of mass reduction and comminution (particle size reduction). These are the steps, from taking a field sample at the RC rig to the analytical aliquot ready to be analysed at the laboratory.

Increment preparation error (IPE) may occur during subsequent sample preparation procedures, such as drying, transport, crushing and grinding.

Possible causes of IPE are

- Contamination
- Sample loss during preparation
- Alteration of physical and chemical composition of the sample
- Negligence in handling the sample
- Deliberate

During a mine site visit, is was observed that the sampler took a coarse chip out of the sample bag intended for the laboratory for geological logging purposes. Such practice compromises the sample and may introduce a systematic error. Under no circumstances must a chip be taken out of the sample bag that is intended for the laboratory. Instead, it should be taken from the bulk reject sample or unused duplicate sample.

3.2.2.1 Sample preparation design (QA)

The sample preparation steps are part of the sampling protocol. Thus the mass and comminution steps need to be checked using a sampling nomogram to ensure variances are below the safety line (10 % error). The RC samples are analysed at the GC-Lab. The sample input to the laboratory was designed to split samples with a mass > 1kg using a rotary splitter, after a comminution step of crushing the sample to < 0.2 cm. Particle size test work on RC samples revealed that the 90 % of the RC samples has a particle size of < 0.8 cm.

All sample preparation steps create an opportunity for sample loss. The particle size of RC sample cuttings are small enough to be fed directly to the mill, instead of first being crushed. Test work is underway to quantify the benefits of eliminating the crushing step during sample preparation at the GC-Lab.

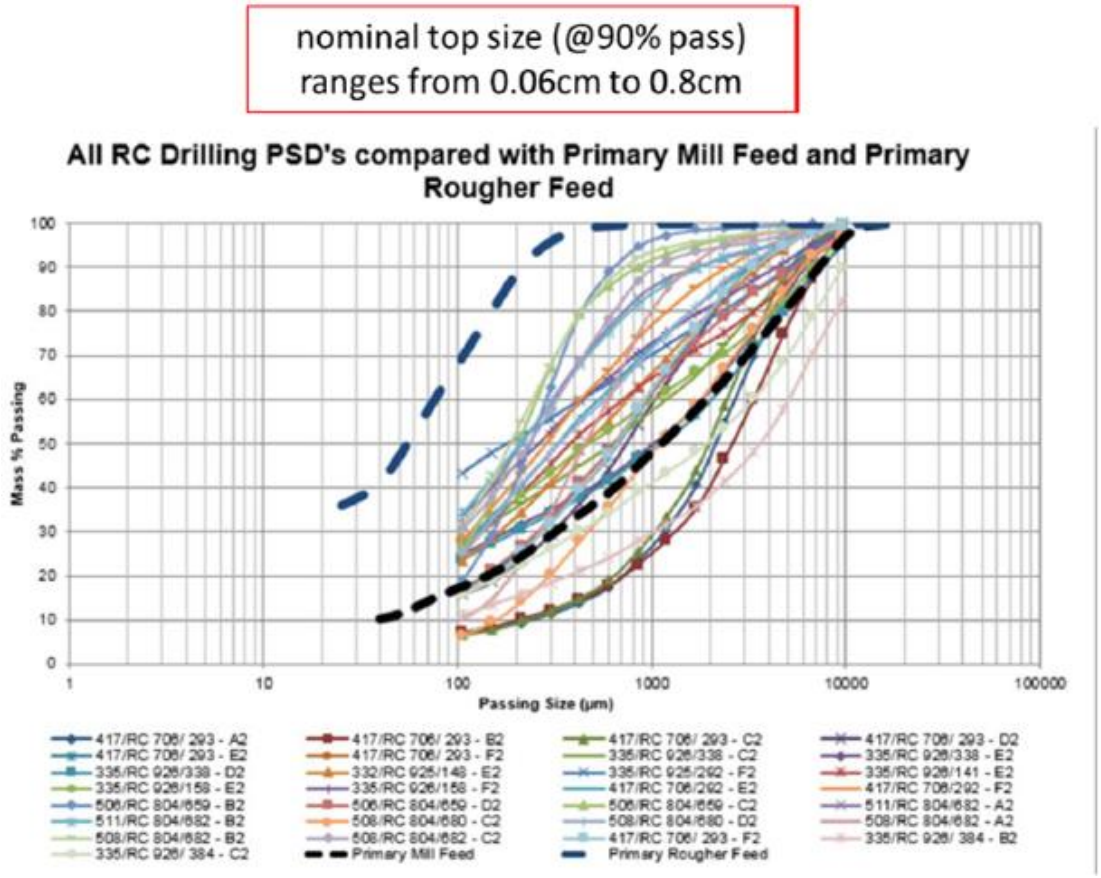


Figure 3-6 RC sampling particle size distributions diagram expressed as % mass passing on the y-axis and passing size in micrometre on the x-axis

RC sampling particle size analysis (figure 3-6) was obtained from W.Ware, Geologist, per.comm.,Oct 2016.

3.2.2.2 Sample preparation quality control (QC)

The following quality control parameters need to be monitored:

- *Proportionality* of the samples need to be measured if the sample is split using a rotary splitting device
- *Mass loss* during crushing and milling
- *Milling efficiency*

3.2.3 ANALYTICAL

Analytical QAQC components relevant to the end user of the data will be discussed in this section with relevance to mine grade control. Internal laboratory QAQC is the responsibility of the laboratory and those components are not discussed in this report.

3.2.3.1 Analytical quality assurance components (QA)

The analytical capability needs to be documented; this is normally reported by the laboratory in a method validation report. The requirements for method validation are outside the scope of this report. Below are the minimum quality assurance (QA) components that need to be defined by the end user of the data to ensure the correct analytical method is used.

Detection limit (LOD)

Many different definitions and calculations exist in literature, the most useful being: the detection limit is the concentration at which the precision (expressed as ± 2 x %RSD, thus 95 % confidence levels) is equal to 100 %. Laboratories quote the limit of detection (LOD) in the laboratory method validation report. The end user of the data can calculate the LOD for their samples using laboratory replicate data (results from the same pulp samples).

Detection limit is the grade where ± 2 x % RSD = 100 %

- 2 RSD = (Intercept / grade) + slope) x 2
- 100 = (Intercept / grade) + slope) x 2
- Grade at LOD = Intercept / (50 – slope)

Intercept and slope used are the parameters calculated to determine the method precision (6.1.1) at a specific grade. Using MP parameters the LOD for GC samples are calculated as:

LOD for the Spark method used at the GC-Lab = 0.34 g/t 3E (0.36 g/t 4E)

Limit of Quantification (LOQ)

Many different definitions and calculations exist in literature, the most useful being; the grade at which the results are regarded as quantitative, normally 10 x the detection limit of the analytical method. Using MP parameters the LOQ is calculated as:

LOQ for the Spark method used at the GC-Lab = 3.4 g/t 3E (3.6 g/t 4E)

Grade at which a 10 % error is achieved

The grade at which 10 % RSD is achieved, is an important grade to note. That is the grade corresponding to the safety line (10%) is achieved.

- 2 RSD = (Intercept / grade) + slope) x 2

- 10 = (Intercept / grade) + slope) x 2
- Grade (at 10 % RSD) = Intercept / (5 – slope)

Using MP parameters the 10 % error line is calculated at: 1.88 g/t 3E (2.0 g/t 4E)

Method Precision (within laboratory precision)

The laboratory method precision for a particular material type can be determined using a large set of replicate data (Thompson-Howarth[31-34] method for duplicates). At lower grades the method precision is dependent on the grade of the samples. Higher grade samples have better precision and lower grades closer to the detection limit of the method have poorer precision. When precision of the method does not improve with increased grade, the limit repeatability grade of the method is reached.

Method precision can be used to calculate:

- Appropriate QC limits
- Method detection limit
- Limit repeatability grade (minimum precision is reached)
- Grade at which a 10% error is achieved

Accuracy capability (industry accuracy baseline)

Results from *proficiency test programmes* can be used to calculate the best accuracy that is achievable by the laboratories for a specific grade and material type. For the platinum interchange program, each monthly bulk sample is well mixed and rotary split to produce a representative split for all participating laboratories. Each laboratory analyses the sample using their routine method and reports the results. Results are inspected for gross outliers, these are results that fall outside 3 z-scores of the average of all results.

$$\text{Z-score} = \frac{xi-\mu}{\sigma}$$

Where:

x_i = results of the individual laboratory average

μ = the consensus value of the month's interchange

σ = the standard deviation of the month's interchange

Industry accuracy base line limits can be calculated by calculating the average root mean square standard deviations from all the monthly between laboratory standard deviations.

Appropriate CRMs

The laboratory standards as well as the client “blind” CRMs:

- Need to be sufficient in quantity to last at least for 12 months
- Matrix of the standards must match the matrix of the samples
- Must cover low, median and high grade range of the samples
- Certificate consensus values (CVs) must be traceable
- Preparation and certification must be of sufficient quality

Note that the “blind” CRM identification and grade should be kept confidential; that is it should not be disclosed to the analysing laboratory.

3.2.3.2 Analytical quality control components (QC)

Various quality control measures are in place to ensure analytical quality of the method, used for grade control analyses. QC components are discussed from a client perspective while the QC components that the laboratory implement are not in scope of this study.

Replicate pulp analysis

The intra-laboratory (within-laboratory) precision is measured by conducting replicate analysis on each sample for Pt, Pd and Rh. Intra-site limits calculated by the laboratory are used to control the within-laboratory precision. All replicate results (rep1 and rep2) are imported into the sable warehouse and the averages (of rep1 and rep2) are reported into the MRM database.

The reported replicate data is checked against the established method precision limits and the percentage of data outside these limits are monitored for trends.

“Blind” MM-CRMs (matrix matched certified reference materials)

MM-CRMs are used to check the accuracy of assays. The manufacturing of these standards consists of preparation and certification. The aim is to have at least three MM-CRMs (low, medium and high) to be used as “blind” CRM inserts. That is a CRM is inserted in-between the routine samples for analyses. The identity of the CRM is kept confidential, thus the analyses of the CRM is “unknown” to the laboratory.

The accuracy performance of the laboratory at the grade of the CRM, must be monitored over time. The performance can be superimposed on the check assay comparison graph e.g. see

figure 7.26b. If the performance of the “blind” standards falls on the systematic errors quantified using the 4-way check lab data, then the quantified systematic error is verified as a “true” estimation of the error.

The method precision as well as the between laboratory standard deviation from the certificate (BL Std dev) should be investigated to determine the control limits for the “blind” standard. The greater of the two (that is the MP standard deviation at the grade of the std or the BL Std dev) should be used to derive limits for determining failures.

“Blind” Blanks

“Blind” blanks are submitted in-between the routine samples to measure contamination at sample preparation stage. “Blind” blanks should be less than three times the detection limit of the method.

Au Regression

GC-Lab does not analyse for Au, as the detection limit for Au is too high for the low grade Au in mine ore. Au is estimated from the reported palladium using a regression formula. The regression formula should be verified at regular intervals.

Analytical method comparison

Table 3-1 compares the analytical method used for grade control with the method used for exploration samples.

Table 3-1 Analytical method comparison for methods used for grade control vs. exploration

Method:	Spark	Ag prill
Sample Type:	Grade Control	Exploration
Analyses:	Analysed for Pt,Pd,Rh. Au(Reg) is estimated from Pd grade	Analysed for Pt,Pd,Au. Rh can be estimated from Pt grade
Replicate protocol	Duplicate (2 x), This is required to improve precision.	Single, with 25 % Replication
Detection Limit, calculated grade at 50 % 1 x RSD	0.36 g/t 4E	0.08 g/t 4E
LOQ	3.6 g/t 4E	0.8 g/t 4E
Grade at which Precision = 10%	2.0 g/t 4E	0.45 g/t 4E
Cost	Similar to Ag prill method	Similar to Spark method
Turnaround time	24 hours	5 - 7 days
Capacity Mine requirement	10,000 sample/month	Can be designed to requirement
Restrictions	Mass < 900 g	No mass restriction
Gross Outlier (%) Feed proficiency test	10 % outside 3 z-scores	1 % outside 3 z-scores
Gross Outlier (%) Tail proficiency test	10 % outside 3 z-scores	0 % outside 3 z-scores

4. DATA SETS USED TO QUANTIFY UNCERTAINTIES

Eight different data sets used to quantify the sampling, sample preparation and analytical uncertainties, these being:

- Data set 1: Three-way twin drilling program
- Data set 2: Laboratory proficiency test program for feed and tail grades
- Data set 3: Four-way laboratory - exploration pulp check program
- Data set 4: Two-way laboratory - grade control pulp check program
- Data set 5: Laboratory pulp replicates at the GC-Lab
- Data set 6: RC sub-sampling field duplicate data
- Data set 7: Nomogram test data
- Data set 8: “Blind” CRM inserts

The uncertainties were calculated as an average as well as at the grade control decision points (GCDPs). The eight sections below describe the QAQC programmes that generated these data sets.

4.1 THREE-WAY TWIN DRILLING PROGRAM – Data set 1

Three-way twin holes were drilled at the mine with the aim of quantifying sampling uncertainties. The designated area for drilling was chosen using the long-term resource model information in order to ensure the grades intersected across the reef, represent typical ore grades for the mine.

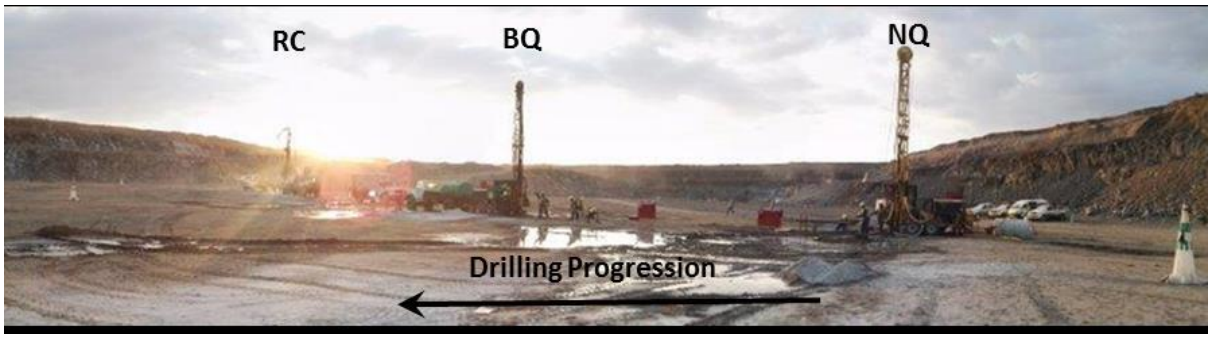


Figure 4-1 Twin hole drilling site at the platinum mine [13]

The sampling techniques investigated were;

- Diamond drilling with NQ diameter (NQ)
  NQ hole diameter (outside) 75.7 mm, core diameter (inside) 47.6 mm
- Diamond drilling with BQ diameter (BQ) – used routinely for exploration sampling
  BQ hole diameter (outside) 60 mm, core diameter (inside) 36.5 mm
- Reverse circulation drilling (RC) – used routinely for grade control sampling
  Outside diameter 139.7 mm, inside diameter 136.5 mm

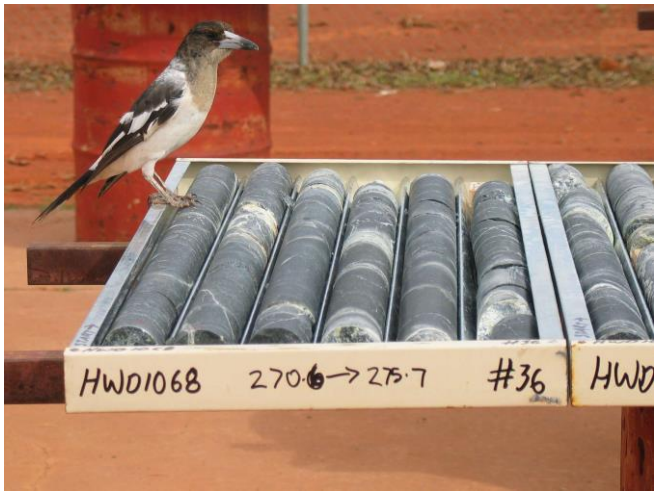


Figure 4-2 Diamond drill core samples in core boxes



Figure 4-3 Reverse circulation samples prepared in the pit

Twelve (three-way) paired drill holes were drilled using the three different sampling techniques collared 1 m apart to a depth of 45 m. For the RC drill holes, samples were taken every 2.5 m, while for BQ and NQ drill holes samples were taken every 1.25 m. Two sample results (1.25 m x 2) for BQ and NQ, respectively, were averaged and matched with the corresponding RC depth of the hole, sampled every 2.5 m. For each hole/depth paired set, 13 different streams/results were obtained; each stream representing a different combination of sampling, sample preparation and laboratory protocol.

Sampling protocols were established (figure 4-4) to compare three sampling techniques (RC, BQ and NQ) and two laboratories (EXP-Lab and GC-Lab).

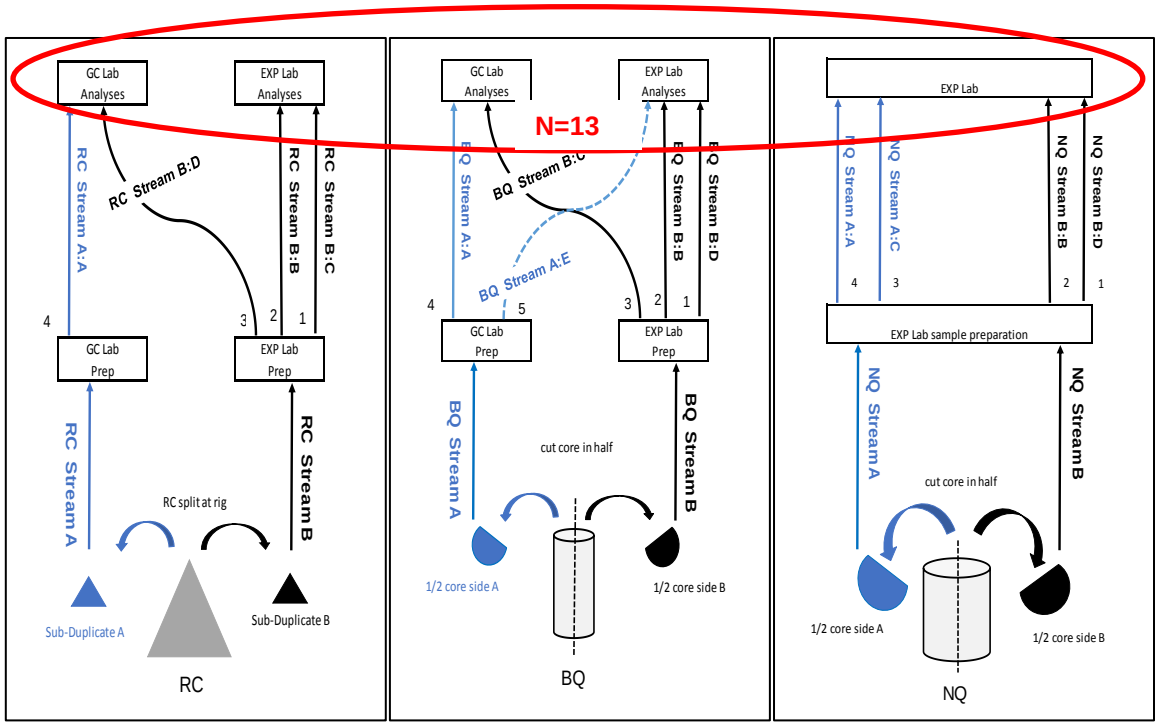


Figure 4-4 Twin hole program sampling protocols (RC,DD-BQ and DD-NQ), n = 13

- Diamond drilling with BQ diameter is routinely used for exploration sampling using the EXP-Lab
- RC drilling used for grade control makes use of the GC-Lab

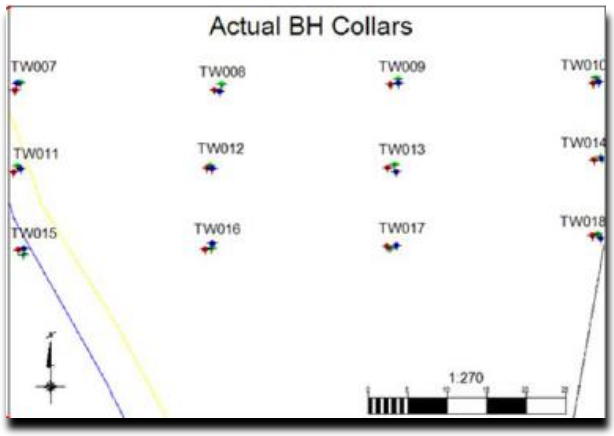


Figure 4-5 Borehole collar locations mapped for the twin hole drilling program [13]

The different protocols are described below in:

- figure 4-6 for the RC sampling campaign
- figure 4-7 for the BQ sampling campaign
- figure 4-8 for the NQ sampling campaign

For each sampling campaign, the primary drill hole sample was split into two sub-samples labelled sample “A” and sample “B”. Samples that originated from sample “A” were referred to as the “A” stream samples. Samples that originated from sample “B” were referred to as the “B” stream samples.

The PGMs, Cu, Ni and SG elements were evaluated; these will not be presented in this report due to the volume of information. To give a summarised perspective, 4E (Pt + Pd + Au + Rh) was also evaluated and the results are discussed in this report.

GC-Lab with its Spark technique, does not analyse for gold (Au) but in order to ensure a likewise comparison, the EXP-Lab median for Au were assigned to the GC-Lab, Au results. It is believed that this will have an insignificant effect because the Au grades are very low. Excluding the Au grade for the GC-Lab will create an artificial “systematic error” and the results would not be comparable. For the mine’s routine grade control results, the Au is estimated using regression parameters based on the correlation between palladium and gold. The 4 way check data set 3, can be used to obtain and ratify the regression formulae for Au used at the GC-Lab.

The three sampling campaign protocols are discussed in detail below.

4.1.1 RC SAMPLING CAMPAIGN

Each 2.5m RC sample was split in two at the RC rig using two identical cups beneath the rota-port, into a sample “A” and sample “B”.

Sample “A” was crushed and milled at the GC-Lab creating a pulp sample “StreamA:A”.

- This sample was analysed at the GC-Lab (highlighted in blue in figure 4-6)
- This sample represents the *routine grade control protocol* under investigation.

This protocol is outlined in red in the figure 4-6.

Sample “B” was crushed and milled at the EXP-Lab creating one pulp sample that was split into three splits; sample “StreamB:B”, sample “StreamB:C”, sample “StreamB:D”.

- Sample “StreamB:D”,was analysed at the GC-Lab
- Samples “StreamB:B” and “StreamB:C” were analysed at the EXP-Lab

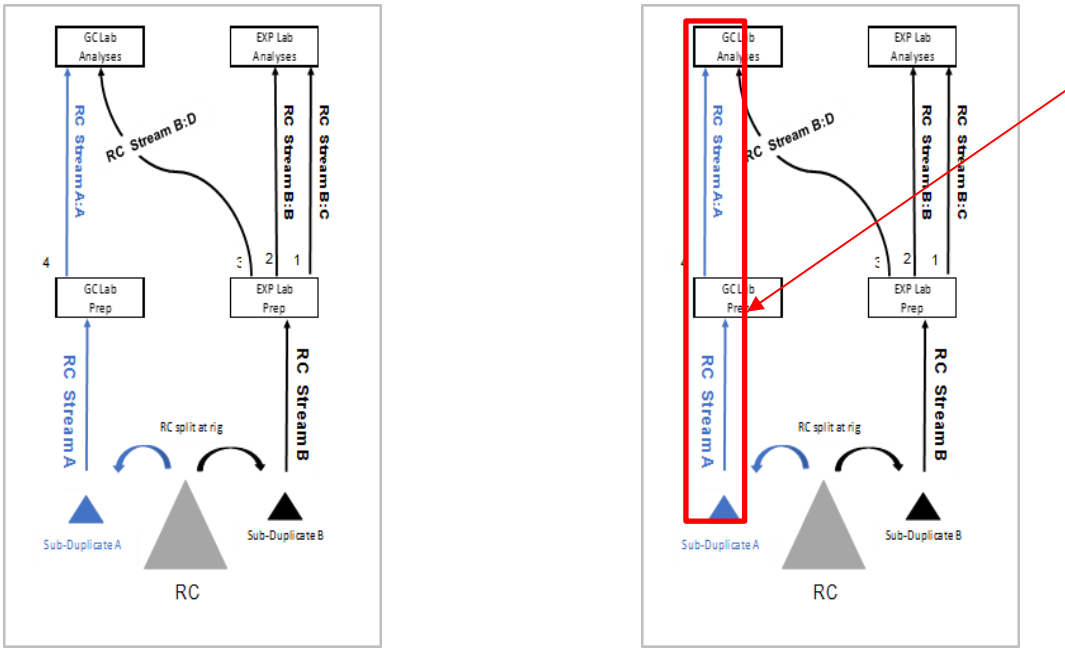


Figure 4-6 Diagram of the twin hole program’s RC sampling campaign streams (4 Streams, numbered 1 to 4), with the routine grade control protocol outlined in red, in the diagram on the right

4.1.2 BQ SAMPLING CAMPAING

Each 1.25 m BQ core sample interval was cut in two half cores, using a diamond saw, resulting in a sample “A” and a sample “B”.

Sample “A” was crushed and milled at the GC-Lab creating a pulp sample that was split into two splits; sample “StreamA:A” and “StreamA:E” (highlighted in blue in figure 4-7).

- Sample “StreamA:A” was analysed at the GC-Lab
- Sample “StreamA:E” was analysed at the EXP-Lab

Sample “B” was crushed and milled at the EXP-Lab creating a pulp sample that was split into three splits; sample “StreamB:B”, sample “StreamB:D”, sample “StreamB:C”.

- Sample “StreamB:C” was analysed at the GC-Lab
- Samples “StreamB:B” and “StreamB:D” were analysed at the EXP-Lab

This sample represents the *routine exploration protocol* outlined in red in the figure 4-7.

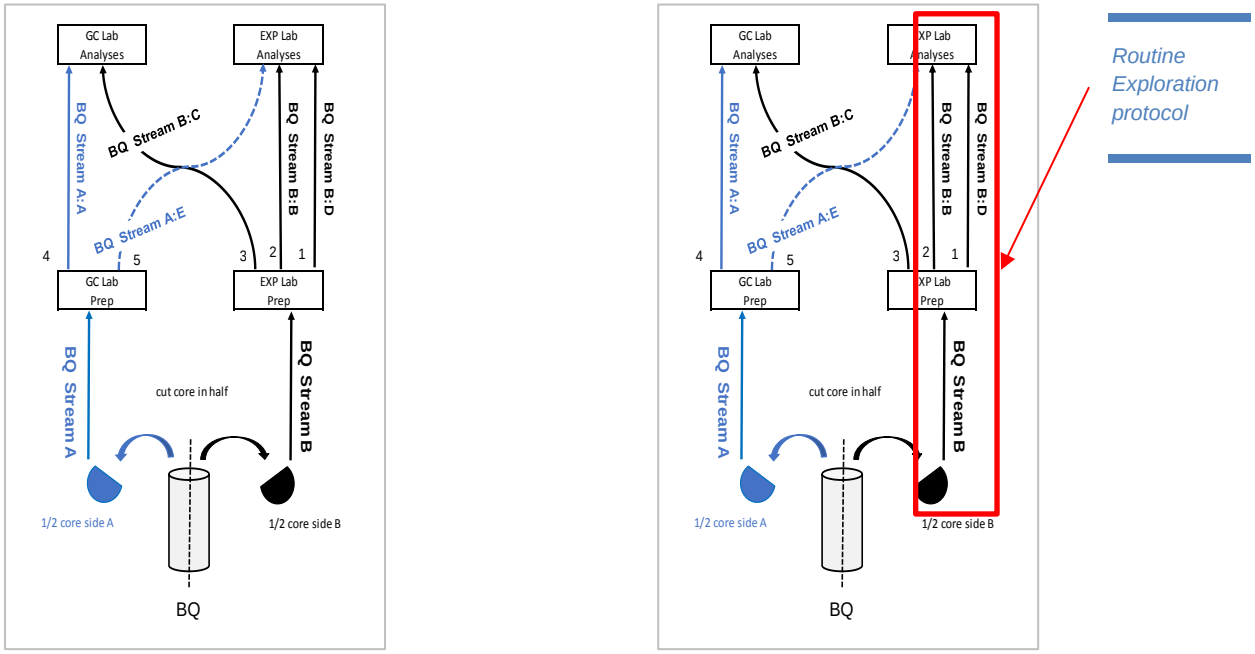


Figure 4-7 Diagram of the twin hole program’s BQ sampling campaign streams (5 Streams, numbered 1 to 5), with the routine exploration protocol outlined in red, in the diagram on the right

4.1.3 NQ SAMPLING CAMPAIGN (4 STREAMS)

Each 1.25 m NQ sample was cut in two half cores, using a diamond saw, giving a sample “A” and a sample “B”. Both samples were crushed and milled at the EXP-Lab.

Pulp sample “A” was split into two splits; sample “StreamA:A” and sample “StreamA:C” (highlighted in blue in figure 4-8). These samples were analysed at the EXP-Lab.

Pulp sample “B” was split into two splits; sample “StreamB:B” and sample “StreamB:D” (in black in figure 4-8). These samples were also analysed at the EXP-Lab.

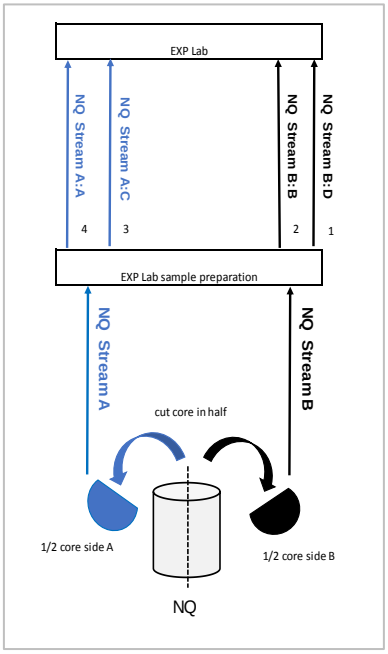


Figure 4-8 Diagram of the twin hole program’s NQ sampling campaign streams (4 Streams, numbered 1 to 4), NQ drilling (not routinely used at the mine)

Three way twin program – outliers:

The 3-way twin program drilling generated a set of 13 samples for each drill depth. Where results were not available for the full 13 samples, the complete data set was excluded. In addition, three sets were excluded where PGM nuggets were present (table 4-1) and gave distorted results. The final comparative data set contained 164 matched hole/depth paired (n=13) results, each representing a 2.5 m bulk sample.

Table 4-1 Three-way twin program outliers that were excluded from the dataset (data set 1)

sample ID	**RC Me 4E**	**RC Me Pt**	RC Me Pd	RC Me Rh	RC Me Au	RC Me Cu	RC Me Ni	RC Me SG
OYRCDDTW009/014	3.68	1.49	1.85	0.11	0.23	0.14	0.28	3.05
OYRCDDTW009/007	5.63	2.41	2.75	0.19	0.29	0.18	0.35	2.93
OYRCDDTW012/019	2.6	1.09	1.26	0.1	0.16	0.10	0.24	2.89
sample ID	BQ Me 4E	BQ Me Pt	BQ Me Pd	BQ Me Rh	BQ Me Au	BQ Me Cu	BQ Me Ni	BQ Me SG
OYRCDDTW009/014	10.48	8.21	1.56	**0.52**	0.19	0.19	0.34	3.04
OYRCDDTW009/007	1.64	0.72	0.76	0.05	0.11	0.07	0.13	2.99
OYRCDDTW012/019	0.11	0.04	0.04	0.02	0.01	0.01	0.01	2.69
sample ID	NQ Me 4E	NQ Me Pt	NQ Me Pd	NQ Me Rh	NQ Me Au	NQ Me Cu	NQ Me Ni	NQ Me SG
OYRCDDTW009/014	3.32	1.23	1.67	0.21	0.21	0.10	0.26	3.08
OYRCDDTW009/007	0.53	0.22	0.27		0.04	0.02	0.06	2.98
OYRCDDTW012/019	0.45	0.17	0.25		0.03	0.03	0.06	2.72

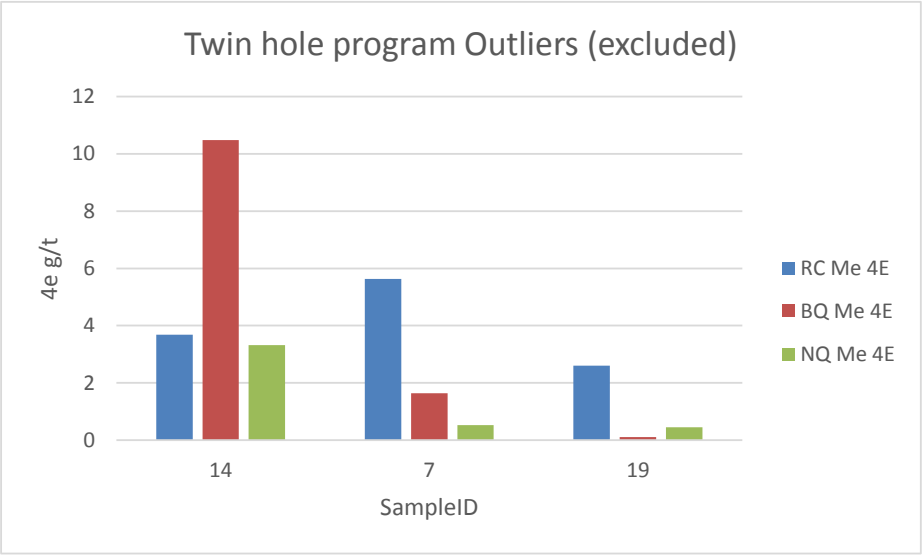


Figure 4-9 Bar chart of three-way twin program outliers, with 4E g/t grade on the y-axis and sample identification on the x-axis

4.2 LABORATORY PROFICIENCY TEST PROGRAM – Data set 2

The second data set, used to quantify uncertainties (in particular the analytical uncertainties), were obtained from two proficiency test programmes:

- one at typical tail grade (0.72 g/t 4E)
- one at typical feed grade (3.5 g/t 4E)

Seventy four proficiency test rounds form part of data set 2. For each proficiency round (distributed monthly) a bulk material was blended and then split using a rotary splitter. Each participating laboratory received a representative split of the bulk sample. Each bulk sample (on average) was analysed by ten different laboratories using the different PGM methods available.

Methods used in the proficiency program were:

- Nickel sulphide collection-fire assay, ICP-OES finish
- Lead collection-fire assay (with silver and palladium as co-collectors), ICP-OES finish
- Lead collection-fire assay, with gravimetric mass measurement
- Lead collection-fire assay, Spark-OES finish

The GC-Lab uses the lead collection-fire assay, Spark-OES finish method. The EXP-Lab uses the lead collection-fire assay (with silver and palladium as co-collectors), ICP-OES finish.

The median for each proficiency test round (paired results from a particular bulk sample) were calculated as the *consensus value* (best estimate of the bulk sample grade). Thus, a different consensus value was calculated for each paired data set (where the number of laboratories were around ten; n = ~10). Each month's data set was inspected for gross outliers (results outside 3 z-scores). These outlier results were excluded from the calculation of the month's consensus value. The outliers did not have a significant influence on the consensus value (CV) because the median and not the average were used as the CV.

The *between laboratories variances* were calculated for each proficiency test round. Each proficiency test round representing a single month. Using these 74 variances, the best estimate standard deviation (RMS StdDev) for that particular grade (tail and feed grade) were calculated. This was done using the square root of the average variance to give the best estimate standard deviation (called the root mean square standard deviation – RMS StdDev). From this RMS StdDev, the best estimate analytical (between laboratories) error were calculated (as $\frac{RMS\ StdDev}{Ave}$ x100) in units of ± % RSD (percent relative standard deviation).

4.3 FOUR WAY EXPLORATION CHECK PROGRAM – Data set 3

The third data set used in this study is the 4-way exploration check program, using pulp splits of the same sample. For routine exploration drilling, where diamond drilling with BQ diameter is used, samples are taken every 1.25 m. The total sample is milled to 80 % less than 75 micrometres. For 5 % of the primary samples, the sample is split into four representative samples, named here split 1 to split 4.

Split 1 is sent to the EXP-Lab for routine primary analysis. Split 2 is sent to the GC-Lab and split 3 is sent to the Check-Lab for analysis. Split 4 is kept back and submitted after 2 weeks to EXP-Lab to check on the laboratory long-term reproducibility. This 4-way comparison is used to check systematic errors between the laboratories over the grade range of the samples.

Data processing:

The results of all four splits are matched with the ID of the original sample. The EXP-Lab re-submit (split 4) is not included in the calculation of the median; that is done so as not to give EXP-Lab the advantage of contributing twice to the median.

The PGMs, Cu, Ni and SG elements were evaluated; these will not be presented in this report due to the volume of information. To give a summarised perspective 4E, (Pt + Pd + Au + Rh) was also evaluated and the results are discussed in this report. In the case of the GC-Lab, the median calculated for Au is used to make up the 4E g/t results for the GC-Lab. It is believed that this will have an insignificant effect because the Au grades are very low. Excluding the Au grade for the GC-Lab will create an artificial “systematic error” and the results would not be comparable. For the routine mine’s grade control results, the Au is estimated using regression parameters based on the correlation between palladium and gold. This 4-way check data set on pulp splits can be used to obtain or confirm the Au regression formulae used routinely in the calculation of 4E g/t at the mine.

In the case of the Check-Lab, the calculated Rh median is used to make up the 4E g/t for the Check-Lab. This is done because the check laboratory does not routinely analyse for Rh. The analyses of Rh requires an additional fire assay; this is not done in order to save costs. To check the quality of Rh, the EXP-Lab is directly compared with the GC-Lab; thus only a 2-way comparison is available (this data set is not discussed in this report).

For each check sample, the laboratory % systematic error (or rather % difference from the median) was calculated using the formula:

$$\textit{Lab \% difference} = \frac{(Lab\ result - median)}{median}\ x\ 100$$

The g/t systematic error (or rather g/t difference from the median) was calculated using the formula:

$$\textit{Lab g/t difference} = \frac{(Lab\ result - median)}{median}$$

Where median is assumed to be the best estimate of the "true" value (CV).

The complete data set is then sorted by the 4E median grade. For each laboratory and analyte, a group average is calculated using the lab *% difference* for results 1-11 as record 1. Next, the group average for results 2-12 is calculated as record 2. Next the group average for results 3-13 is calculated as record 3, etc. This is done for the complete data set. The process of calculating the group averages are repeated using the *Lab g/t differences*. These group averages are then plotted on the y-axis, against the median grade on the x-axis for the particular element (see figure 7-28, 7-29). Table 4-2 describes the 4-way check program.

Table 4-2 Exploration 4-way check program protocols for the platinum mine

Purpose	Exploration	Grade Control	Quality Control	Re-submit to Exploration Lab
Samples identified for quality control purposes				
Split at prep	Split 1	Split 2	Split 3	Split 4
Number of samples	100 %	5 %	5 %	5 %
Lab	EXP-Lab	GC-Lab	Check-Lab	EXP-Lab
Sampling	Diamond drilling-BQ			
Analytical method	Pb Fire assay Ag&Pd prill, ICP-OES	Pb Fire assay Spark-OES	Pb Fire Assay Ag prill ICP-OES	Pb Fire assay Ag&Pd prill ICP-OES
Analytes PGMs	Pt, Pd, Au Rh where Sum of 3E > 1.5g/t	Pt, Pd, Rh	Pt, Pd, Au	Pt, Pd, Au Rh where Sum of 3E > 1.5g/t
Replication rate for PGMs	Single with 25% replication	Duplicate (100%)	Duplicate (100%)	Single with 25% replication
Base Metal method	Cu, Ni by XRF pressed powder	Cu, Ni by XRF pressed powder	Cu, Ni by fusion ICP finish	Cu, Ni by XRF pressed powder
Replication rate for BMs	Single with 10 % replication	Single	Single with 10 % replication	Single with 10 % replication
SG by pycnometer replication	Single with 10 % replication	Single with 10 % replication	Single with 10 % replication	Single with 10 % replication

4.4 TWO WAY GRADE CONTROL CHECK PROGRAM – Data set 4

The fourth data set used in this study is the 2-way grade control check program using pulp splits. For routine RC drilling (used for grade control purposes), samples are taken every 2.5 m. The primary samples gravity fall through a rotating rota-port splitter where an analytical sample is collected at the bottom of the cone splitter. The total sample is submitted to the laboratory where it is milled to 80 % less than 75 micrometres. After the analysis of the primary samples, the laboratory select a specific number of samples (n = 75) and submit these to the Check-Lab. As an internal check the laboratory also re-analyse a split of these samples again. The primary results from the GC-Lab are compared with the results from the Check-Lab to quantify the difference between the two laboratories. If the difference is small (< ± 5 %), it is assumed that the systematic error at the GC-Lab is under control. It should be noted that the GC-Lab select the monthly check batch of samples that are submitted to the Check-Lab. Table 4-3 describes the 2-way lab grade control check program.

Table 4-3 Grade control 2-way check program protocols for the platinum mine

Purpose	Grade Control	Quality Control
Split after primary analyses	Split 2	Split 3
Number of samples	100 %	75 samples
Lab	GC-Lab	Check-Lab
Sampling	RC Drilling	
Analytical method	Pb Fire assay Spark-OES	Pb Fire Assay Ag prill ICP-OES
Analytes PGMs	Pt, Pd, Rh	Pt, Pd, Au
Replication rate for PGMs	Duplicate (100 %)	Duplicate (100 %)
Base Metal method	Cu, Ni by XRF pressed powder	Cu, Ni by fusion ICP-OES finish
Replication rate for BMs	Single	Single with 10 % replication
SG by pycnometer Replication	Single with 10 % replication	Single with 10 % replication

Data processing:

The results from the two laboratories are matched with the ID of the original sample. For each analyte / sample the average of the two laboratories is calculated for the particular sample. For each laboratory the % difference and g/t difference from the average is calculated. The data set is sorted by the average grade and plotted as % difference and g/t difference from the average.

The Pt, Pd, Cu, Ni and SG were evaluated but due to the volume of information only Pt and SG are presented in this report.

4.5 LABORATORY PULP REPLICATE DATA – Data set 5

The GC-Lab pulp replicate data (obtained from routine grade control analyses) were used to calculate the random error of the analytical method (also referred to as the method precision). The standard deviation of the pulp replicates are plotted against the grade of the samples to obtain regression parameters. These regression parameters (slope and intercept) are used to calculate the random error of the method at a particular grade, using the formula below.

$$\pm \%\text{RSD} = \left(\left(\frac{Intercept}{Grade}\right) + slope\right)$$

4.6 RC SUB-SAMPLING FIELD DUPLICATE DATA – Data set 6

For RC sub-sampling duplicates, samples are taken at a particular depth; these are split with an in-line rota-port cone splitter into “A” and “B” samples. The field duplicate results from sample “A” and sample “B” can be used to calculate the sub-sampling random error. RC sub-sampling field-duplicates are analysed at a different time, thus a longer time range (reproducibility) are applicable. These samples are normally called field duplicates but it should be noted that it is not “true” field duplicates but should be rather called sub-sampling field duplicates. True field duplicates would be two holes collared within a 1m spacing, referred to as twin holes.

The random error for sub-sampling field duplicates were also calculated at the GCDPs.

4.7 NOMOGRAM TEST DATA – Data set 7

The *sampling protocol* is a summarised description of the mass and comminution (particle size reduction) steps from lot-to-aliquot. The larger the mass and the smaller the particle size of the sample, the smaller the variance. The frequency of the sampling events (number of sample cuts) should be specified in the sampling protocol. The larger the number of sampling events the smaller the variance; grouping and segregation error (GSE) is minimised. The sampling protocol can be plotted on a nomogram if the sampling constants K and alpha are known. The sampling constants can be derived from a heterogeneity test experiment for specific ore types. It involves the calibration of particle size against variance of the ore type being tested. It is

recommended that this residual fundamental error should be below 10 % 1 x RSD line. In literature this reference line is referred to as the safety line.

A heterogeneity test for the mine's major rock type was done to calculate the overall variance related to the intrinsic heterogeneity, for the grade control sampling protocol; Barr, et al. (2016)[5]. These nomograms plot the residual uncertainty (total - analytical) against different sample masses. The analytical work for the test work was done at the Check-Lab using lead fire assay, with Ag as co-collector with ICP-OES finish for Pt, Pd and Au. In order to establish the overall variance related to the intrinsic heterogeneity for the collective PGMs, a nomogram for 3E (that is the sum of Pt + Pd + Au) were established in this report. Note that Rh was not analysed (due to the significant cost related to the analysis of Rh). The concentration of Rh is very low and the additional cost for the Rh analysis could not be justified for this test work.

In addition, the analytical uncertainty for the GC-Lab was calculated at the grade of the heterogeneity bulk sample and replaced with the Check-Lab's analytical uncertainty. This was done to demonstrate the effect of higher method detection limit on such test work.

The intrinsic heterogeneity error was calculated for the major rock type at the mine at typical ore grade.

4.8 "BLIND" STANDARDS – Data set 8

"Blind" standards (standards inserted without the laboratory knowing the identity of these standards) are used to determine the analytical systematic error of a laboratory. Although this practice is the best methodology to determine accuracy, it has its shortcomings. One shortcoming is that, it is not possible to check the analytical systematic error of a laboratory over the grade range of the ore. "Blind" standards give a snapshot of the systematic error at the grade of the standards. Another shortcoming, is that the accuracy of the systematic error determined with "blind" standards is only as good as the "blind" consensus value (CV) which is dependent on the process of certificate and the quality of the preparation of the standards.

5. OVERALL UNCERTAINTIES

The overall sampling uncertainty includes systematic as well as random errors.

5.1 BETWEEN SAMPLING TECHNIQUES – Data set 1

Using the three-way twin drilling program:

The three-way twin hole program allowed for the overall sampling uncertainty between sampling techniques to be quantified, included ore sampling, sample preparation as well as analytical errors. Differentiation between random and systematic error is not possible due to the fact that multiple sampling techniques and more than one laboratory were used in the 13-streams data set. The variance for each depth set was calculated using all 13 streams (figure 7-1). The root mean square variance of all the depth-of-hole sets (n = 164 “samples”) were used to calculate the best estimate of the overall sampling uncertainty. This uncertainty was expressed in terms of %RSD (referred to as the overall sampling error). This error can be back-translated into a variance because the average grade of the 164 depth/hole samples are known.

Overall sampling uncertainty = ~ 30 % RSD

The average overall sampling uncertainty error includes random and systematic errors from sample preparation, analytical as well as the process of taking the sample.

In order to determine if this error is reduced when only two sampling techniques are compared (and not three), the error between (NQ & BQ), (NQ & RC) and (BQ & RC) were quantified.

It was found that the between sampling (technique) errors remained constant where only two sampling techniques were compared. Error (systematic and random) between sampling techniques NQ & BQ ~= NQ & RC ~= RC & BQ ~= 30 % RSD

The average overall errors (systematic and random) are presented in an uncertainty table, table 5-1.

Table 5-1 Uncertainty table summarising the average error between sampling techniques, highlighted in red

4E g/t Uncertainty Table			Systematic & Random error		
as % Error	4E g/t		All	Analytical	
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)
Waste	0	0.99	30%		
Very low grade ore (VLGO)	1	1.69			
Low grade ore (LGO)	1.7	2.49			
Medium grade ore (MGO)	2.5	4			
High grade ore (HGO)	4	above			

5.2 BETWEEN ANALYTICAL TECHNIQUES – Data set 2

Overall analytical uncertainty includes random and systematic errors but exclude sample preparation and sampling errors.

Using the laboratory proficiency test program data:

The proficiency test data set 2 was used to quantify the overall analytical errors (random and systematic errors). Differentiation between analytical random and systematic error is not possible due to the fact that multiple analytical methods and multiple laboratories are used in a proficiency test program. It should also be noted that any sample preparation and sampling errors are eliminated because each bulk sample used was subjected to best practice sample preparation (that is comprehensive milling and multistage splitting using rotary splitting). The between laboratory errors are presented on the graphs below for feed (figure 5-1 and 5-2) and tail (figure 5-3 and 5-4) grade proficiency programmes. These errors were sorted in chronological order (figure 5-1 and 5-3) and then again according to grade (figure 5-2 and 5-4).

From the graphs it is clear that the errors do not vary within the tail grade or feed grade program but do vary between the tail and feed grade program.

The best estimate of the overall analytical (between laboratories) errors achievable using an average of ten laboratories is:

- *± 7.6 % error at 3.5 g/t 4E (feed grade)*
- *± 12.5 % error at 0.72 g/t 4E (tail grade)*

The performance of the GC-Lab in the proficiency programmes are quantified below.

The best estimate of overall analytical error achieved by the GC lab is:

- *± 17 % error at 3.5 g/t 4E (feed grade)*
- *± 27 % error at 0.72 g/t 4E (tail grade)*

Thus the Spark-OES technique used at the GC-Lab has a 2.5 x poorer precision at low grade when compared with the EXP-Lab that uses Ag and Pd collection with ICP-OES method.

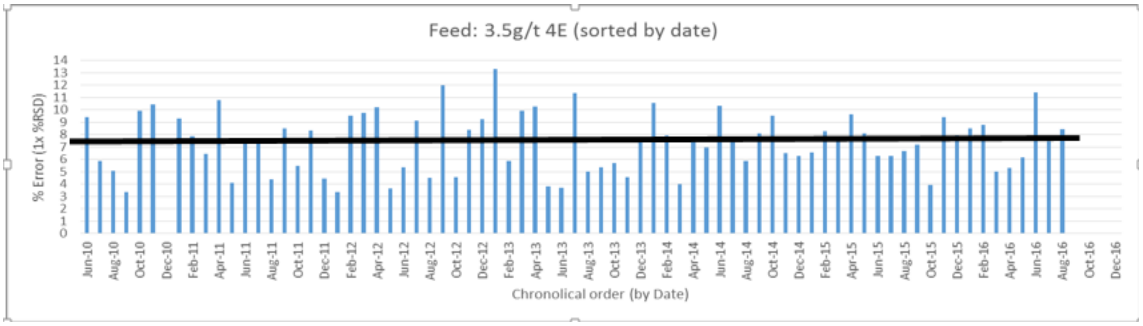


Figure 5-1 Between laboratories analytical error (as %RSD) sorted by increasing date for the feed grade samples

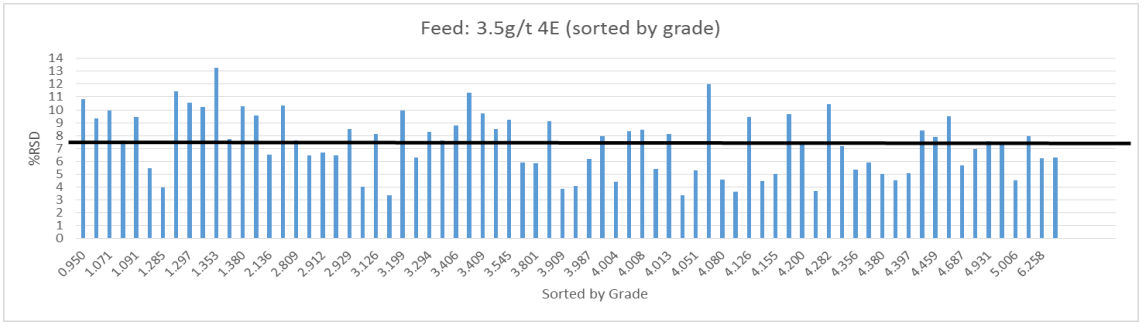


Figure 5-2 Between laboratories analytical error (as %RSD) sorted by increasing grade for the feed grade samples

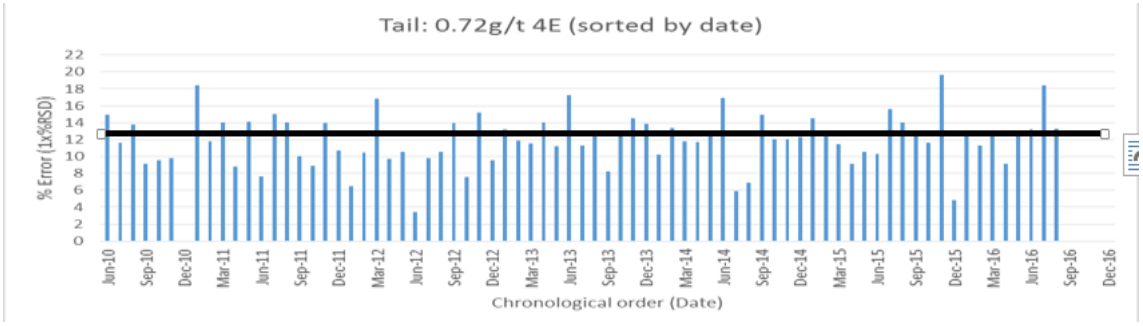


Figure 5-3 Between laboratories analytical error (as %RSD) sorted by increasing date for the tail grade samples

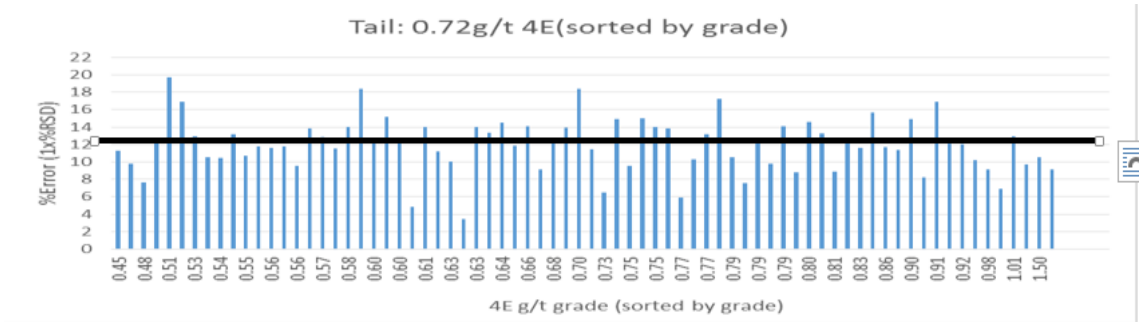


Figure 5-4 Between laboratories analytical error (as %RSD) sorted by increasing grade for the tail samples

The estimated error at the GC-Lab, is plotted against the industry best performance (referred to as industry standard on the graph, figure 5-5). Most laboratories use analytical techniques other than the Spark-OES method.

Table 5-2 Analytical average error obtained from all participating laboratories compared to the GC-Lab analytical error for the proficiency test investigated

Analytical error (random and systematic) % error (calculated as ± % RSD)			
Tail grade 0.72 g/t 4E		Feed grade 3.5 g/t 4E	
Proficiency test average (IE) ♦	GC Lab performance (RC Lab-E) ■	Proficiency test average (IE) ♦	GC Lab performance (RC Lab-E) ■
Various methods	Spark-OES	Various methods	Spark-OES
± 12.5 % error	± 27 % error	± 7.6 % error	± 17 % error

The errors obtained from the GC-Lab (Spark-OES analytical method) are approximately 15 % worse at tail grade and approximately 10 % worse at feed grade, when compared with various other analytical techniques.

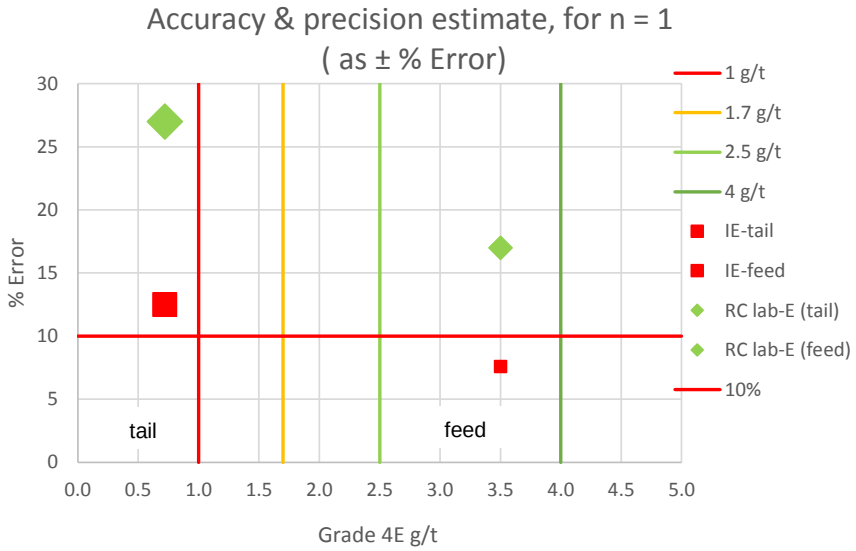


Figure 5-5 Analytical error for a proficiency test program comparing two analytical techniques, namely ICP-OES (average for all laboratories) vs. Spark-OES (GC- Lab)

In figure 5-5:

"IE-tail" or "IE-feed" is the estimate for the average analytical error expected at particular grade (calculated using mostly plasma ICP-OES methods), where n = 1 (single analyses).

"RC lab-E" is the average analytical error at the GC-Lab at particular grade using GC-Lab performance in the proficiency program, where n = 1 (single analyses). Tail grades are indicated with larger square points, feed grades with the smaller square points.

The industry estimate (IE) for analytical error includes random and systematic error because multiple laboratories are used in the estimation (e.g. 7.6 % for feed grade ore).

This % error (7.6 %) is as expected and more than the 5 % analytical error (random error only). The GC-Lab error (random and systematic) was quantified at feed grade as 17 %.

The average analytical errors (systematic and random) at feed and tail grade ore are presented in an uncertainty table, table 5-3.

Table 5-3 Analytical systematic and random error comparison for the GC-Lab when compared with all other laboratories using the proficiency test data investigated

4E g/t Uncertainty Table			Systematic & Random error		
as % Error	4E g/t		All	Analytical	
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)
Waste	0	0.99	30%	27%	12.5%
Very low grade ore (VLGO)	1	1.69			
Low grade ore (LGO)	1.7	2.49			
Medium grade ore (MGO)	2.5	4		17%	7.6%
High grade ore (HGO)	4	above			

The best estimate single analyses error (expressed as ± % RSD) for analytical industry was also quantified for all other elements of interest, presented in figure 5-6.

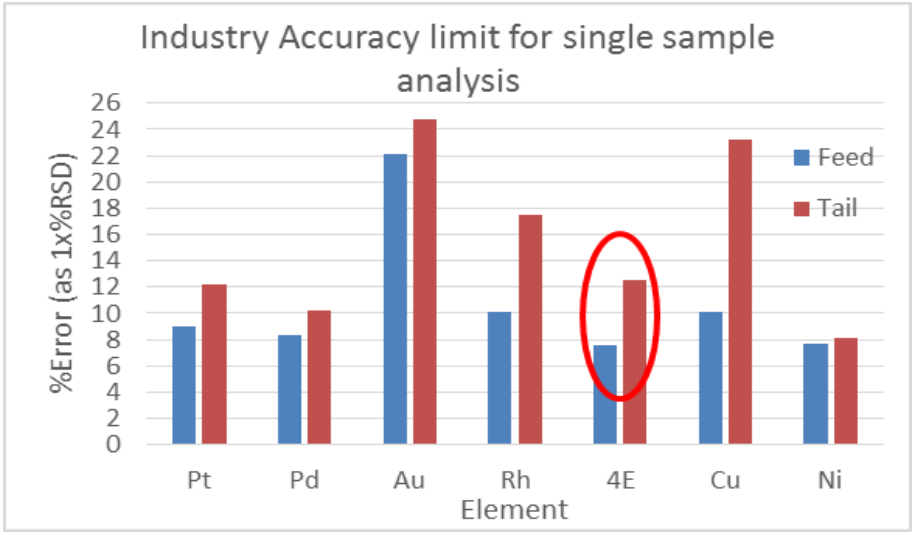


Figure 5-6 Analytical errors (for all participating laboratories, excluding GC-Lab) for feed and tail material for PGMs and base metals using the proficiency test data set under investigation

The best estimate error can be regarded as the average error that can be expected from an analytical laboratory. Some laboratories will perform worse and others will perform better. The GC-Lab used for grade control performs worse for 4E, mainly due to the detection limit for the method being higher than the Pb fire assay, Ag prill, ICP-OES finish method (see figure 5-5).

The above best estimated errors, can be used to create limits on a Shewart chart at 2 x and 3 x standard deviation error limits. For 2 x error limits, 15.2 % for feed grade (3.5 g/t 4E) and 25 % for tail grade (0.72 g/t 4E). The laboratory performance can then be measured against these limit lines to give perspective on the laboratory performance and method ability compared to the “analytical best estimate error limit” for single analyses. This is an analytical quality control measure that can be put in place to monitor the laboratory performance against best possible expected error.

The laboratories are monitored in this manner. Note that the Au consensus value (CV) for each comparison was used to make up the full 4E grade for the GC-Lab. This was done because the GC-Lab does not analyse for Au.

GC-Lab technique performances are the black lines in figure 5-7 and 5-8.

5.3 SUMMARY OF FINDINGS

Overall sampling uncertainty includes random and systematic errors, with components from sampling (the action of taking samples), sample preparation, analytical techniques and methods as well as the heterogeneity of the ore. Using the twin hole program data, (where three sampling techniques were compared) the overall error was 30 %. This error remained constant when only two sampling techniques were compared.

Overall analytical uncertainty includes random and systematic errors. The feed (3.5 g/t 4E) proficiency test program data was used to quantify this Analytical error for the GC-Lab (Spark-ICP) at 17 % error and at laboratories using ICP-OES the error was closer to 8 %.

The first step in reducing these errors is to quantify and split the overall uncertainty into random and systematic errors for the individual components (3.13) of the sampling chain.

Note the y-axis scale difference between feed and tail graphs.

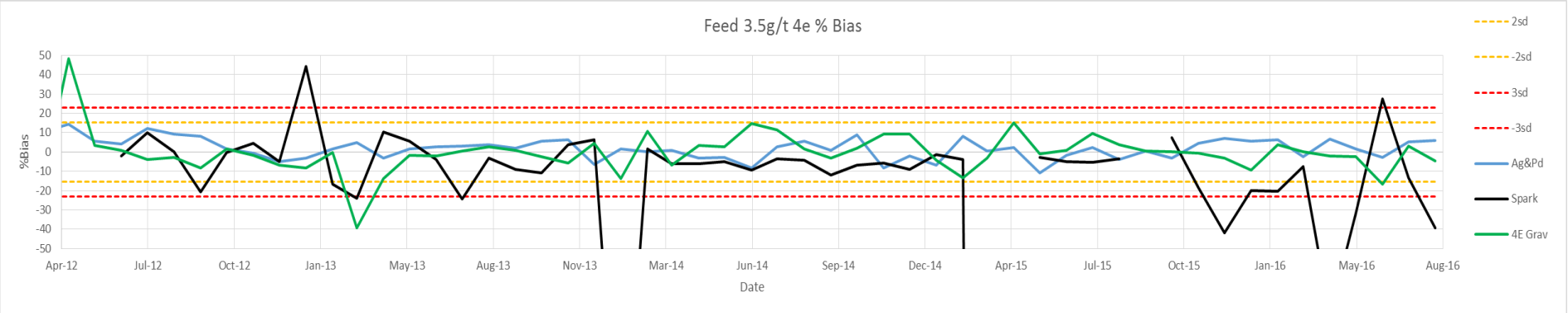


Figure 5-7 Proficiency test data for feed grade 3.5 g/t 4E, three analytical methods presented

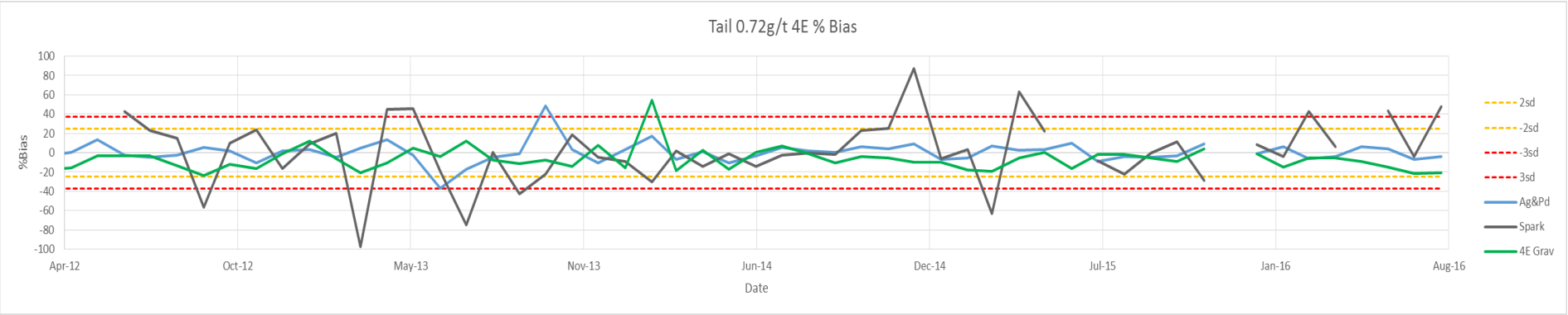


Figure 5-8 Proficiency test data for tail grade 0.72 g/t 4E, three analytical methods presented

6. RANDOM ERROR

To re-cap: Random errors are the “finger print” of the measuring system. Random errors are a direct consequence of numerous *uncontrollable variables* that inevitably exist in every chemical or physical measurement. Random errors always have a ± (plus *and* minus) sign. It describes the *normal distribution* that can be expected using the particular measuring system of choice e.g. analysis at a specific laboratory, analytical method and ore type.

6.1 ANALYTICAL RANDOM ERROR, within a laboratory

Analytical random error excludes systematic error. Two separate data sets were used to quantify the analytical random error.

6.1.1 LABORATORY METHOD RANDOM ERROR - Data set 5

The errors measured between the laboratory pulp replicates (referred to as “Ana reps” in figure 6-2) are the short range variability (also called method precision or method random error) within the same laboratory. The methodology to calculate the laboratory method precision is described in section 3.1.6.2b. Pulp replicate results are two assay values from the same pulp-analytical sample, analysed within a short period of time at the same laboratory.

Table 6-1 Regression parameters for the precision of the method (random error) used for grade control samples analysed at the GC-Lab

Method Random error, Slope and Intercept for GC sampling				
GC Lab	**Pt**	**Pd**	**Rh**	**Au**
Intercept	12	8	1.5	n.d
Slope	2.3	2	1.5	n.d

The slopes and intercepts were applied to the GCDP’s grade in order to calculate the expected random error for the laboratory at those specific grades. It can be seen from the table 6-2, that the errors are highly dependent on the grade. This is because the grades measured are close to the analytical method’s detection limit and are not at the grade where the precision cannot be further improved (limit repeatability grade range). Errors less than the safety line (± 10 %) are highlighted in shaded green in the table 6-2. The variances of the individual elements were added and then back-translated to ± % RSD to obtain the overall random error for 3E. The GC-Lab does not analyse for Au.

At grades > 1.7 g/t 4E, the analytical random errors is less than ± 10%.

Table 6-2 Pulp replicate random error at the GC-Lab for the individual PGM elements as well as for the combined 3E expressed as ± % RSD

Method Precision at GC-Lab, Random error as ±%RSD = Intercept / grade + slope											
Ore	4E grade g/t		Pt		Pd		Rh		Au		4E (as 3E)
Type	From	To	g/t	%RSD	g/t	%RSD	g/t	%RSD	g/t	%RSD	%RSD
Waste ↑	**0.00**	0.99	0.41	31.6	0.50	18.0	0.03	51.5	0.06	n.d	16.9
VLGO ↑↓	**1.00**	1.69	0.70	19.5	0.85	11.4	0.05	30.9	0.10	n.d	10.5
LGO ↓↑	**1.70**	2.49	1.03	14.0	1.25	8.4	0.08	21.5	0.15	n.d	7.6
MGO ↑↓	**2.50**	3.99	1.64	9.6	2.00	6.0	0.12	14.0	0.24	n.d	5.3
HGO↓	**4.00**	higher	2.26	7.6	2.75	4.9	0.17	10.6	0.33	n.d	4.2

The analytical random errors at the GCDPs are presented in an uncertainty table, table 6-3.

Table 6-3 Analytical random error for pulp replicates at the GCDPs, for 3E g/t highlighted in red

4E g/t Uncertainty Table			Systematic & Random error			Random error					
as % Error	4E g/t		All	Analytical		Sampling		Analytical	Sampling	Sub-Sampling	Analytical
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Between 1/2 NQ core	Within sampling technique	Between pulps	Intrinsic Heterogeneity	Field dups (at GC Lab) for 3E	Between reps (at GC Lab) for 3E
Waste	0	0.99	30%	27%	12.5%						± 16.9%
Very low grade ore (VLGO)	1	1.69									± 10.5%
Low grade ore (LGO)	1.7	2.49									± 7.6%
Medium grade ore (MGO)	2.5	4		17%	7.6%						± 5.3%
High grade ore (HGO)	4	above									< ± 5%

6.1.2 USING THE THREE-WAY TWIN DRILLING PROGRAM – Data set 1

In order to calculate the *analytical uncertainty* within a sampling technique, the variances for all streams within a particular sampling protocol, sent to the EXP-Lab (for RC n = 2; for BQ n = 2; for NQ n = 4) were calculated for each hole/depth set (or "sample").

- For RC, Stream B, samples BB and BC were used ("RC-StreamB")
- For BQ, Stream B, samples BB and DB were used ("BQ-StreamB")
- For NQ Stream A, samples AA and AC were used ("NQ-StreamA")
- For NQ Stream B, samples BB and BD were used ("NQ-StreamB")

The root mean square variances of all the depth/hole sets (n = 164, "samples") were used to calculate the best estimate error in terms of ± % RSD (or % error). This is presented in figure 6-1 as "RC-StreamB", "BQ-StreamB" and "NQ-StreamA, NQ-StreamB".

Analytical random error (within a sampling protocol) was calculated as:

- NQ = ~ ± 4 % RSD between pulps, thus a ~ ± 4 % analytical error
- BQ = ~ ± 5 % RSD between pulps, thus a ~ ± 5 % analytical error
- RC =~ ± 6 % RSD between pulps, thus a ~ ± 6 % analytical error

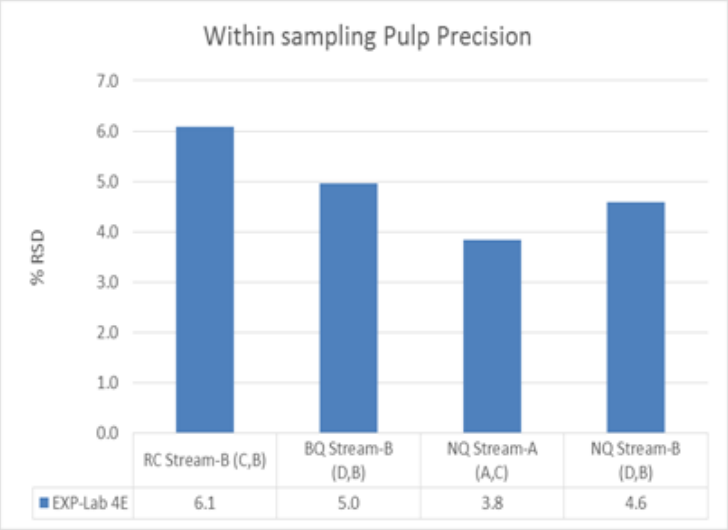


Figure 6-1 Graphical presentation of the average analytical random errors within the different sampling techniques using the twin drilling program – data set 1

It is noted that the analytical random error is the largest for RC and smallest for NQ sampling technique. These errors are defined as analytical random errors (within the same sampling technique and same laboratory).

Analytical random error (within a sampling protocol, 4E) were calculated as for the EXP-Lab:

- *BQ = ~ ± 5 % error*
- *RC = ~ ± 6 % error*

Analytical random error (using MP, 3E) was calculated as for the GC-Lab at the average grade of the 3-way twin hole data set:

- *RC = ~ ± 8 % error*

The average analytical random error is presented in an uncertainty table, table 6-4.

Table 6-4 Average analytical random error quantified within a sampling technique for the EXP-Lab

4E g/t Uncertainty Table			Systematic & Random error			Random error					
as % Error	4E g/t		All	Analytical		Sampling		Analytical	Sampling	Sub-Sampling	Analytical
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Between 1/2 NQ core	Within sampling technique	Between pulps	Intrinsic Heterogeneity	Field dups (at GC Lab) for 3E	Between reps (at GC Lab) for 3E
Waste	0	0.99	30%	27%	12.5%			± 6%			± 16.9%
Very low grade ore (VLGO)	1	1.69									± 10.5%
Low grade ore (LGO)	1.7	2.49									± 7.6%
Medium grade ore (MGO)	2.5	4		17%	7.6%						± 5.3%
High grade ore (HGO)	4	above									< ± 5%

Note that the average analytical random error for the GC-Lab was quantified as ± 8 %.

6.2 SUB-SAMPLING RANDOM ERROR, between field duplicates – Data set 6

Sub-sampling random error obtained from field duplicates taken at the RC rig, includes sample preparation, analytical and sub-sampling components (excluding systematic error).

Using RC sub-sampling field duplicate data:

The paired precision methodology (described in section 3.1.6.2) was also used to calculate the random error between RC sub-sampling field duplicates taken at the reverse circulation (RC) rig. This random error is applicable to single analyses (n = 1).

Table 6-5 Regression parameters for the precision of sub-sampling field duplicates (random error) used for grade control samples analysed at the GC-lab

Slope and intercept values for mine RC field duplicates, GL-Lab				
RC sub sampling Precision	Pt	Pd	Rh	3E
Intercept	13	13	2	15
Slope	4	4	1	6

The slopes and intercepts were applied to the GCDP's grade in order to calculate the expected random error (table 6-5) for sub-sampling field duplicates at those specific grades. The variances of the individual elements were added and then back translated to % RSD to obtain the overall random error for 3E.

On average, the random error between sub-sampling field duplicates are 1.4 times greater than the analytical pulp replicate (method precision) random error.

The average sub-sampling field duplicate random error is presented in an uncertainty table, table 6-6.

Table 6-6 RC sub-sampling duplicate random errors at the GCDPs, highlighted in red

4E g/t Uncertainty Table			Systematic & Random error			Random error					
as % Error	4E g/t		All	Analytical		Sampling		Analytical	Sampling	Sub-Sampling	Analytical
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Between 1/2 NQ core	Within sampling technique	Between pulps	Intrinsic Heterogeneity	Field dups (at GC Lab) for 3E	Between reps (at GC Lab) for 3E
Waste	0	0.99	30%	27%	12.5%			± 6%		±22.4%	± 16.9%
Very low grade ore (VLGO)	1	1.69								±14.3%	± 10.5%
Low grade ore (LGO)	1.7	2.49								±10.6%	± 7.6%
Medium grade ore (MGO)	2.5	4		17%	7.6%					±7.7%	± 5.3%
High grade ore (HGO)	4	above								< ± 7 %	< ± 5%

In figure 6-2, the proficiency test data results are graphically superimposed on the sub-sampling field duplicates and GC-Lab method precision. The squares in the graph represent the proficiency test data (green for GC-Lab, red for all labs). The lines on the graph represent the analytical replicates (green line) and field duplicates (blue line).

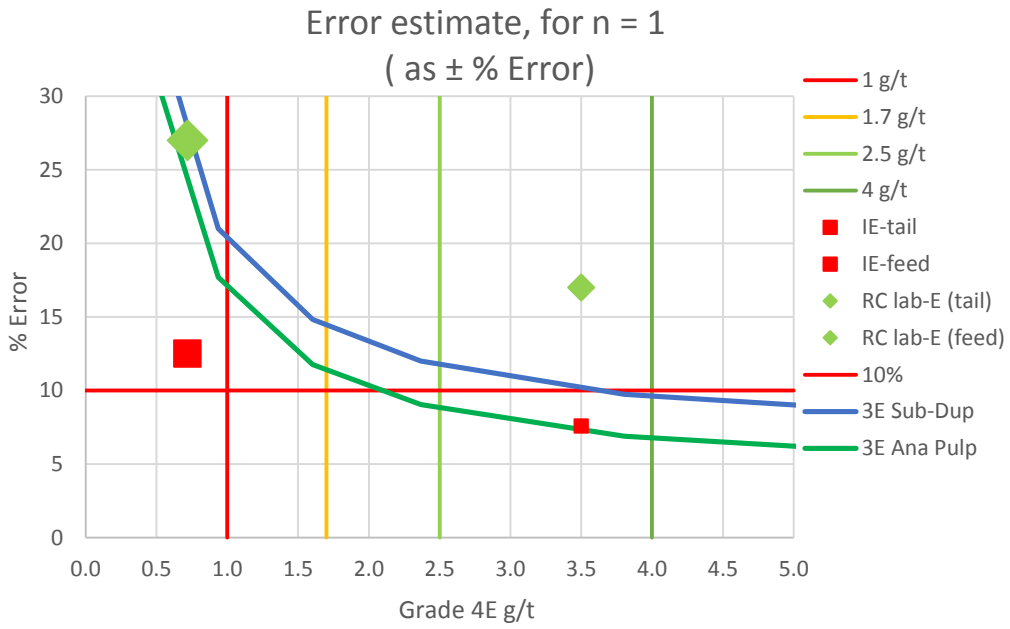


Figure 6-2 Analytical error for a proficiency test program comparing two analytical techniques, as well as laboratory replicates (green line) and sub-sampling field duplicates (blue line)

At grades > 2.5 g/t 4E, the sub-sampling random errors is less than ± 10 %.

6.3 SAMPLING RANDOM ERROR, within a sampling technique – Data set 1

Using the three-way twin drilling program:

In order to calculate the *within sampling uncertainty*, the variance for all streams within a particular sampling protocol (for RC n = 4; BQ n = 5; NQ n = 4) was calculated for each hole/depth set (or "sample", n = 164). The error calculated here will include the random error within the sampling technique being investigated.

The root mean square variance of all the depth/hole sets (n = 164 "samples") were used in the calculation. From this, the best estimate error was calculated in terms of ± % RSD (or % Error). This is represented in (figure 6-3) as "RC", "BQ" and "NQ"; the within sampling technique errors.

- NQ = ~ ± 12 % RSD (4 streams, same Lab, between ½ cores); = ~ ± 12 % error;
- BQ = ~ ± 10 % RSD (5 streams, both Labs); = ~ ± 10 % error;
- RC = ~ ± 10 % RSD (4 streams, both Labs); = ~± 10 % error;

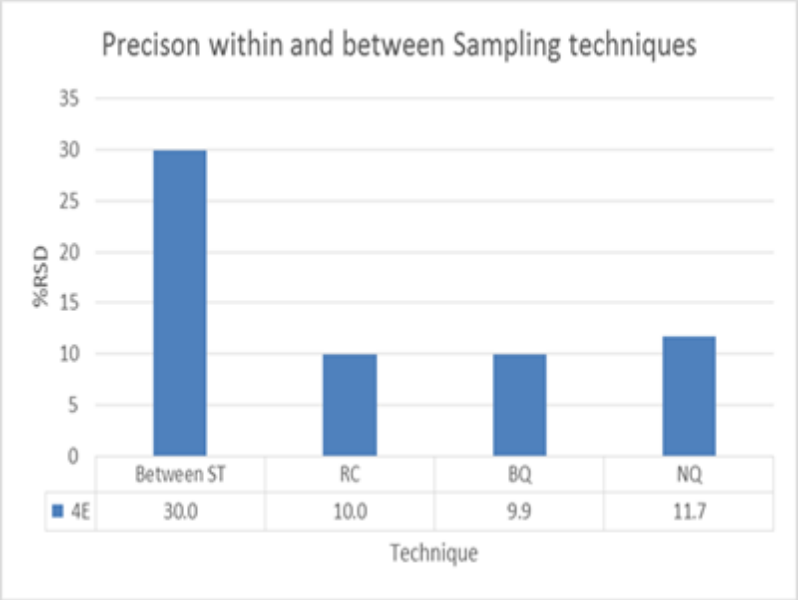


Figure 6-3 Bar chart of within and between sampling techniques (NQ, BQ and RC) errors as quantified using the 3-way twin drilling program data

It is noted:

The random error is the largest within the NQ sampling technique.

The random error within the sampling technique (RC or BQ) is ~ ± 10 % RSD.

The average sampling (within) random error for BQ or RC sampling is presented in an uncertainty table, table 6-7.

Table 6-7 Random error within RC and BQ sampling techniques using the 3-way twin drilling program

4E g/t Uncertainty Table			Systematic & Random error			Random error					
as % Error	4E g/t		All	Analytical		Sampling		Analytical	Sampling	Sub-Sampling	Analytical
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Between 1/2 NQ core	Within sampling technique	Between pulps	Intrinsic Heterogeneity	Field dups (at GC Lab) for 3E	Between reps (at GC Lab) for 3E
Waste	0	0.99	30%	27%	12.5%		± 10%	± 6%		±22.4%	± 16.9%
Very low grade ore (VLGO)	1	1.69								±14.3%	± 10.5%
Low grade ore (LGO)	1.7	2.49								±10.6%	± 7.6%
Medium grade ore (MGO)	2.5	4		17%	7.6%					±7.7%	± 5.3%
High grade ore (HGO)	4	above								< ±7 %	< ± 5%

6.4 SAMPLING RANDOM ERROR, between ½ cores – Data set 1

Using the three-way twin drilling program:

Sampling uncertainty referred to here is the sampling random errors between NQ half cores.

The 12 holes were drilled using a NQ diamond drilling sampling technique. The core was cut in half to create an “A” and “B” sample (stream). The complete “A” and “B” samples were respectively milled to 80 % less than 75 micrometres and then each sample was split into two pulps, see figure 4-8.

- The average random error between ½ core sampling was calculated using the variance between the average of StreamA (A:A&A:C) and the average of StreamB (B:B&B:D)) (n = 2), for all samples – referred to as “NQ between half core” in figure 6-4.

  Random error between ½ cores for NQ diamond drilling sampling protocol:

  between ½ cores = ~ 14 % RSD (between Stream A & Stream B)

- The average random error between all 4 NQ streams was calculated using stream AA, AC, BB and BD; (n=4) – referred to as “NQ all” in figure 6-4.

  Random error within NQ diamond drilling sampling protocol:

  between and within ½ cores (all 4 streams) = ~ 12 %RSD (A:A, A:C, B:B, B:D)

- The average analytical random error using the pulp replicates, calculated in section 3.1.3 for the NQ sampling technique is also presented in the barchart – referred to as “NQ Stream B (D,B) and NQ StreamA (A,C)” in figure 6-4.

  Random error within NQ diamond drilling sampling protocol:

  between pulp replicates = ~ 4 % RSD (D,B & A,C)

All NQ sampling streams were analysed at the EXP-Lab.

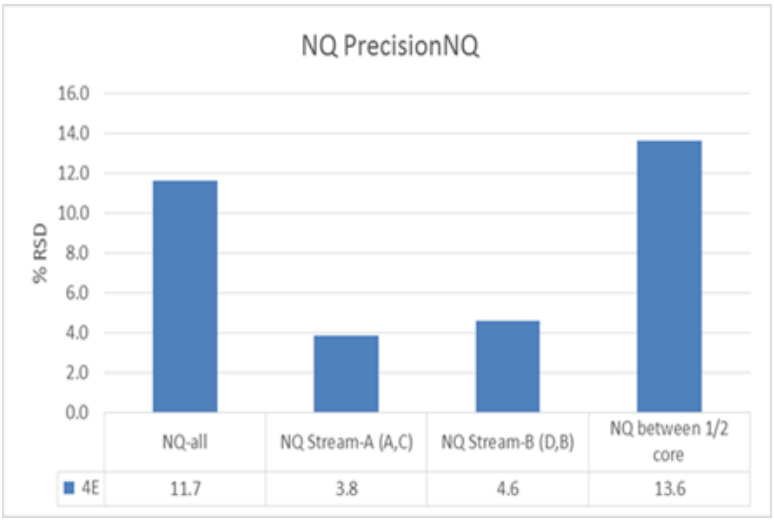


Figure 6-4 Random errors "within" NQ sampling technique using the 3-way twin drilling program

The "NQ all" % error (± 11.7%, n = 4) is < than the " NQ between ½ core" % error (± 13.6 %, n = 2).

The average sampling random error between ½ cores for NQ sampling is presented in an uncertainty table, table 6-8.

Table 6-8 Random error between ½ core random error using the 3-way twin drilling program

4E g/t Uncertainty Table			Systematic & Random error			Random error					
as % Error	4E g/t		All	Analytical		Sampling		Analytical	Sampling	Sub-Sampling	Analytical
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Between 1/2 NQ core	Within sampling technique	Between pulps	Intrinsic Heterogeneity	Field dups (at GC Lab) for 3E	Between reps (at GC Lab) for 3E
Waste	0	0.99	30%	27%	12.5%	± 14%	± 10%	± 6%		±22.4%	± 16.9%
Very low grade ore (VLGO)	1	1.69								±14.3%	± 10.5%
Low grade ore (LGO)	1.7	2.49								±10.6%	± 7.6%
Medium grade ore (MGO)	2.5	4		17%	7.6%					±7.7%	± 5.3%
High grade ore (HGO)	4	above								< ±7 %	< ± 5%

The random error between ½ cores is ± 14% Error.

6.5 HETEROGENEITY RANDOM ERROR – Data set 7

Intrinsic heterogeneity error relates to the matrix of the material being sampled (excluding analytical and sampling error).

Using nomogram test data:

A heterogeneity test for the mine's major rock type was done to calculate the variance related to the intrinsic heterogeneity, for the grade control sampling protocol; Barr et al., (2016)[5].

In order to establish the overall variance related to the intrinsic heterogeneity for the collective PGMs, a nomogram for 3E (that is the sum of Pt + Pd + Au) was established. Note that Rh was not analysed (Rh is very low and the additional cost for the Rh analysis could not be justified for this test work). At 3 g/t 3E, the expected grade for Rh is 0.1 g/t.

The intrinsic heterogeneity error calculated for the major rock type at the mine at typical ore grade (3.1 g/t 4E), was 6.12 %, see table 6-9.

Table 6-9 RC sample nomogram for unaltered pyroxenite ore at the mine

3E (Pt+Pd+Au)	DSA				
Nomogram for Mogalakwena RC Sampling			Standarised Relative Variance		
Sample	Size [cm]	Mass [g]		Rel. Std. Dev.	%RSD
Lot = In-situ Block (10x10x2.5m)	1.00	775 000 000	0.0000	0.000064	0.01
Primary RC Bulk Sample	1.00	112 852	0.0000	0.005321	0.53
Secondary Cone split at RC rig	1.00	900	0.0035	0.059578	5.96
Pulverisation at Laboratory	0.0075	900	0.0000	0.003289	0.33
Analytical Aliqout	0.0075	60	0.0002	0.012738	1.27
		Incremental variance	0.0038	0.061245	6.12
		Alpha=	1.18		
		K=	3.19		
		% Error=	1.3		
		% Maximum Stage Error	6.0		
		R^2	0.9765		

The average intrinsic heterogeneity error for the mine's major rock type is presented in an uncertainty table, table 6-10.

Table 6-10 Random error related to intrinsic heterogeneity for unaltered pyroxenite ore at the mine

4E g/t Uncertainty Table			Systematic & Random error			Random error					
as % Error	4E g/t		All	Analytical		Sampling		Analytical	Sampling	Sub-Sampling	Analytical
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Between 1/2 NQ core	Within sampling technique	Between pulps	Intrinsic Heterogeneity	Field dups (at GC Lab) for 3E	Between reps (at GC Lab) for 3E
Waste	0	0.99	30%	27%	12.5%	±14%	±10%	±6%	±6.12	±22.4%	±16.9%
Very low grade ore (VLGO)	1	1.69								±14.3%	±10.5%
Low grade ore (LGO)	1.7	2.49								±10.6%	±7.6%
Medium grade ore (MGO)	2.5	4		17%	7.6%					±7.7%	±5.3%
High grade ore (HGO)	4	above								<±7%	<±5%

The nomograms are used to plot the residual uncertainty (total - analytical) against different sample masses. The analytical work for the test work [5] was done at the check laboratory using lead fire assay, with Ag as co-collector with ICP-OES finish for Pt, Pd and Au. In order to establish and compare the analytical variance at the GC-Lab (black bar chart, figure 6-5)

with that of the Check-Lab (orange bar chart, figure 6-5). The GC-Lab method precision at the grade of the bulk sample (3.1 g/t 4E) was used to calculate the black bar chart presented in figure 6-5. The variance due to the heterogeneity of the sample is presented using the blue bar chart, figure 6-5.

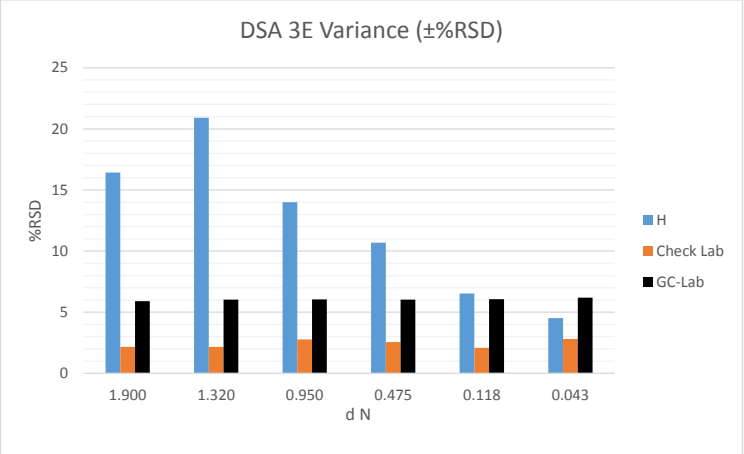


Figure 6-5 Effect of higher detection limit of the Spark method used at the GC-Lab (black bar chart) when compared with the Pb fire assay method used at the Check-Lab (orange bar chart) presents a significantly variance at the grade of the bulk material used in the heterogeneity test work

The analytical variance subtracted from the residual variance, equivalent to ± 2.5 % RSD, was used in the test work. If the GC-Lab was used for the test work, a variance equivalent to ± 6 % RSD would have been used. This is significant when compared to the overall intrinsic heterogeneity calculated (as ± 6 % at particle sizes where d_n <0.475cm).

- *The Spark variances at ore feed grade are too high for heterogeneity test work*
- *It is recommended that for PGM heterogeneity test work, the ICP-OES analytical methods are used*

6.6 SUMMARY OF FINDINGS REGARDING RANDOM ERROR

6.6.1 FINDINGS

Average random errors were quantified at the mine's typical ore grade:

- *Sampling error between NQ ½ cores (± 14 %)*
- *Sampling error within a particular sampling technique (± 10 %)*
- *Intrinsic heterogeneity for the major ore type at the mine (± 6.1 %)*
- *Sub-sampling RC field duplicates (± 10 %)*
- *Analytical error*
    - *Within RC sampling, at the GC-Lab (± 8 %)*
    - *Within RC sampling, at the EXP-Lab (± 6 %)*
    - *Within BQ sampling, at the EXP-Lab (± 5 %)*

Figure 6-6 represent these errors on a bar chart in two different unit of measures namely Relative variance (Rel Var) and as a %RSD.

From this, it is clear that the random error:

- *between ½ cores > between RC sub-sampling field duplicates*
- *for RC sampling > BQ sampling (using the same laboratory)*
- *at the GC-Lab > at the EXP-Lab*
- *at the GC-Lab > Intrinsic heterogeneity for the major ore type*

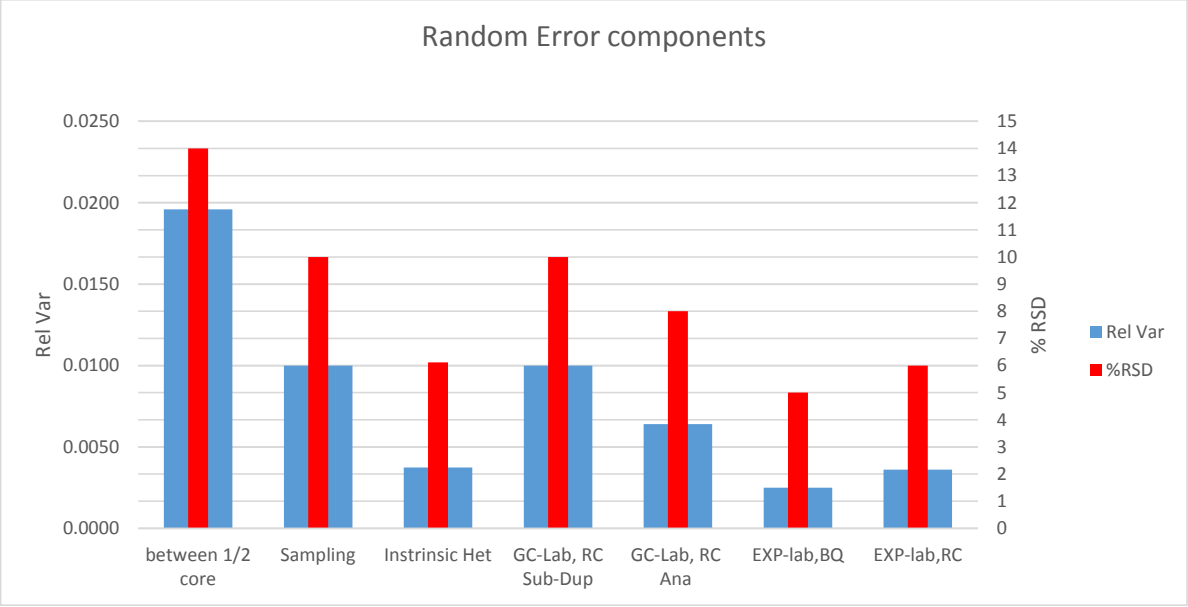


Figure 6-6 Graphical representation of random error components identified and expressed as % RSD and Rel var

The random errors quantified are presented in an uncertainty table, table 6-11.

Table 6-11 Various random error components identified at the GCDPs

4E g/t Uncertainty Table			All	Analytical		Sampling		Analytical	Sampling	Sub-Sampling	Analytical
	4E g/t		Systematic & Random error			Random error					
Classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Between 1/2 NQ core	Within sampling technique	Between pulps	Intrinsic Heterogeneity	Field dups (at GC Lab) for 3E	Between reps (at GC Lab) for 3E
Waste	0	0.99	30%	27%	12.5%	± 14%	± 10%	± 6%	± 6.12	±22.4%	± 16.9%
Very low grade ore (VLGO)	1	1.69								±14.3%	± 10.5%
Low grade ore (LGO)	1.7	2.49								±10.6%	± 7.6%
Medium grade ore (MGO)	2.5	4		17%	7.6%					±7.7%	± 5.3%
High grade ore (HGO)	4	above								< ± 7 %	< ± 5%

Note that the analytical random error between pulps analysed at the GC-Lab is ± 8%, while at the EXP-Lab it is ± 6 % (as quoted in table 6-11).

Table 6-12 is a summary of the random errors quantified at the grade control decision points of the mine. Ideally, errors should be less than ± 10 %, errors less than ± 10 % are highlighted in table 6-12 in green. The calculated random errors for the pulp replicates (GC- Lab, analytical errors) and field duplicates (sub-sampling error) for RC sampling are listed in columns 2 and 3, respectively. The random error for pulp replicates (EXP-Lab, analytical errors) for exploration sampling are listed in column 4, for comparative purposes. From table 6-2 it is clear that the ICP-OES analytical method used at the EXP-Lab for exploration samples have lower analytical random errors than the Spark-ICP method used at the GC-Lab. Only at grades greater than 1.7 g/t 4E (LGO ore), are the errors at the GC-Lab less than 10 %. For sub-sampling random errors for RC sampling are only < 10 % at grades > 2.5 g/t 4E, that is ore category MGO.

Table 6-12 Random errors quantified for different analytical methods, at the GCDPs

		Random Error ± % RSD			
		3E	3E	4E	
4E		RC Sampling		Expl Sampling	
grade g/t		GC Lab, Analytical	Sub-Sampling	EXP Lab, Analytical	Ore
From	To	Spark, ICP	Spark, ICP	ICP-OES	Type
0	0.4	44.3	57.4	11.0	Waste ↑
0.4	0.99	16.9	22.4	4.5	
1	1.69	10.5	14.3	3.0	VLGO ↑↓
1.7	1.99	9.1	12.6	2.7	LGO ↓↑
2	2.49	7.6	10.6	2.3	
2.5	2.94	6.7	9.4	2.1	MGO ↑↓
2.95	3.99	5.3	7.7	1.8	
4	5.49	4.2	6.3	1.5	HGO↓
5.5	higer	4.0	6.0	1.5	

Table 6-13 present a summary for the random errors quantified at the grade control decision points (GCDPs) for the individual elements at the GC-lab. The calculated Pt random errors for the pulp replicates (GC Lab, Analytical) for RC sampling are listed in columns 4 (Pt % RSD). Only at grades, above 3 g/t Pt is the analytical random error < ± 10 %.

Table 6-13 Method precision (random error) for the individual PGE elements, analysed at the GC-Lab using RC sampling and Spark analysis

Ore	grade g/t		Pt	Pd	Rh	Au	4E (as 3E)
Type	From	To	%RSD	%RSD	%RSD	%RSD	%RSD
Waste ↑	0	0.4	83.6	46.4	140.4	n.d	44.3
	0.4	**0.99**	31.6	18.0	51.5	n.d	16.9
VLGO ↑↓	1	**1.69**	19.5	11.4	30.9	n.d	10.5
LGO ↓↑	1.7	1.99	16.9	10.0	26.5	n.d	9.1
	2	**2.49**	14.0	8.4	21.5	n.d	7.6
MGO ↑↓	2.5	2.94	12.3	7.4	18.5	n.d	6.7
	2.95	**3.99**	9.6	6.0	14.0	n.d	5.3
HGO↓	4	5.49	7.6	4.9	10.6	n.d	4.2
	5.5	higer	7.2	4.7	9.8	n.d	4.0

6.6.2 RANDOM ERROR EFFECT ON THE MINING BLOCK

The mine uses a grid size of 10 m x 10 m for RC drilling, where samples are taken at every 2.5 m depth. Thus each sample represents a 10 m x 10 m x 2.5 m volume of ore (lot), with an average density of 3.1 g/cm^3; thus the sample represents 775 tonnes of ore (mass = density x volume). The 4E grades for each sampling grid are fed into a software package that composite (average) 2 samples to represent a 5 m composite. The software uses the variogram variables obtained from the long term resource model (exploration data) to assign 4E grade for a (6.5 m x 6.5 m x15 m) mining block. These variogram variables are used in a kriging process, which uses thirty (30) samples closest in distance to the center of the block. These 30 samples are averaged into a single grade for the mining block; each sample contributing to the average is weighted according its distance from the center of the block. Thus samples closest to the center would have a higher weighting (contributing more) in the averaging process. Due to the properties of the central limit theorem, each block variance is thus reduced by a factor of square root of 60 (7.75 x). Table 6-7, presents the reduction in random error, due to the effect of averaging 30 samples analysed in duplicate, to assign grade to a mining block. From the pulp replicate and field duplicate data (section 6.1.1 and 6.2), it was noted that the uncertainty due to random error is highly dependent on grade. At the analytical detection limit, the random error is expected to be ± 100 % (2 x ± % RSD).

Although this factor reduces the random error significantly, the large errors within the individual samples (n = 1), at 1 g/t 4E will be large and thus still present a risk of mis-classification of the ore at this grade (waste vs. VLGO).

The Spark-ICP method has the benefit of a 24-hour turn-around time (TAT) at volumes as large as 10,000 samples / month. The only other analytical technique that can compete with this required TAT for grade control, is the gravimetric lead fire assay technique.

Table 6-14 Effect of thirty samples analysed in duplicate (n = 30 x 2), show a significant reduction in random error for the RC sampling block

Method Precision at GC-Lab, Random error as ±%RSD = Intercept / grade + slope				
Ore	4E grade g/t		4E (as 3E)	4E (as 3E)
Type	From	To	%RSD, n=1	%RSD, n=30
Waste ↑	**0.00**	0.99	16.9	3.1
VLGO ↑↓	**1.00**	1.69	10.5	1.9
LGO ↓↑	**1.70**	2.49	7.6	1.4
MGO ↑↓	**2.50**	3.99	5.3	1.0
HGO↓	**4.00**	higher	4.2	0.8

Random error for GC-Lab using RC sampling:

- *For (n = 1), is less than 10 % at grades > 1.7 g/t 4E*
- *For (n = 30), is less than 10 % for all grades*

7. SYSTEMATIC ERROR

7.1 INTRODUCTION 3-WAY TWIN HOLE DATA – Data set 1

See section 4.1 for detailed description of the 3-way twin hole program. None of the streams (figure 4.4) can be considered to give the "true" result for the hole/depth set but in order to compare the techniques and laboratories with each other a "most" likely reference result (referred to as BE, best estimate of true value) for the particular hole/depth set was calculated as the average of BQ stream-B:B, BQ stream-B:D, NQ stream-A:A, A:C, B:B, B:D; all 6 streams were analysed at EXP-Lab. These streams were selected as the "diamond drilling" (DD) sampling technique and "Pb Fire assay, ICP-OES finish" analytical techniques are regarded superior over RC drilling sampling and Spark analytical techniques.

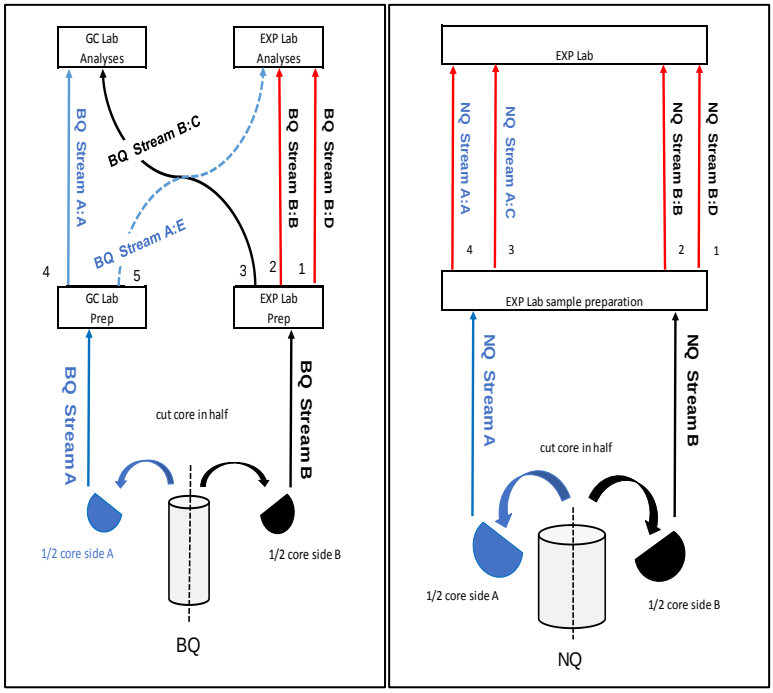


Figure 7-1 Twin hole program streams used to calculated the "true" value, highlighted in red

It was possible to quantify the average differences between sampling techniques, sample preparation and Analytical techniques using the difference between BE and the stream result for particular streams under investigation. These differences were expressed in terms of an absolute value e.g. g/t for PGMs and as a % difference. This was done in order to give perspective to extremely high % differences at very low grades which may be insignificant in absolute terms.

It should be noted that no "true" value for the hole/depth set is known, thus differences reported were "systematic errors" with respect to:

- Sampling techniques (RC vs. BQ vs. NQ)
- Analytical techniques

  GC-Lab (Pb fire assay, Spark-ICP finish)

  vs.

  EXP-Lab (Pb fire assay with co-collector, ICP-OES finish)
- Sample preparation

  GC-Lab automated sample preparation

  vs.

  EXP-Lab manual sample preparation

After sorting the data set according to the BE grade, the differences (from BE) were expressed as % difference as well as in absolute terms (g/t 4E).
A running mean of 11 consecutive records, was calculated. For each record, a group average was calculated using the % difference (or g/t difference) for results 1-11 as record 1. Next, the group average for results 2-12 was calculated as record 2. Next the group average for results 3-13 was calculated as record 3, etc.

The overall average differences (from BE) for all relevant combinations were calculated in order to estimate the contribution of sampling, sample preparation as well as Analytical to the observed Systematic errors.

Different combinations of the different streams (see figure 4-4) were compared in order to identify and quantify the contributing factors. The magnitude of the differences were only indicative and were thus regarded as estimates. The “sign” (directions) of the differences observed were consistent and regarded as conclusive.

7.2 OVERALL SYSTEMATIC ERROR BETWEEN GRADE CONTROL AND EXPLORATION

The total sampling error includes errors associated with the action of taking a sample, sample preparation and analytical.

The sampling protocol for grade control (GC) samples were:

- RC sampling
- Automated robotic sample preparation and
- Analytical Pb fire assay with Spark-finish at the GC-Lab

The sampling protocol for exploration (EXP) samples were:

- BQ Diamond drilling
- Manual sample preparation and
- Analytical Pb fire assay (Ag and Pd co-collector), with ICP-OES finish at the EXP-Lab

7.2.1 AVERAGE SYSTEMATIC ERROR

In order to calculate the systematic error between the grade control and exploration sampling, stream A:A from the RC protocol was compared with streams B:B and B:D from the BQ protocol. These streams were highlighted in red in figure 7-2.

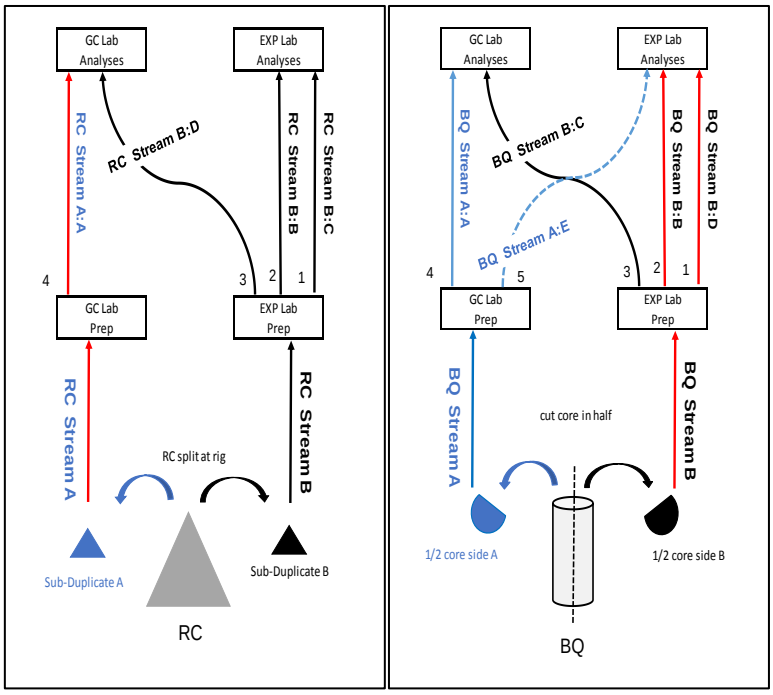


Figure 7-2 RC and BQ sampling streams used to calculated the average systematic error sampling between grade control and exploration highlighted in red

The total average sampling difference (sampling, sample prep as well as analytical) between grade control and exploration sampling are estimated as an average -11 % systematic error for 4E, with grade control sampling reporting lower than exploration sampling.

The average systematic error between grade control and exploration sampling is presented in an uncertainty table, table 7-1.

Table 7-1 Systematic error between grade control and exploration sampling protocols, highlighted in red.

4E g/t Uncertainty Table			Systematic Error							
as % Error	4E g/t		SAMPLING		Action of taking a Sample		Sample Prep		Analytical	
Ore classification:	From:	To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0	0.99	-11%							
Very low grade ore (VLGO)	1	1.69								
Low grade ore (LGO)	1.7	2.49								
Medium grade ore (MGO)	2.5	4								
High grade ore (HGO)	4	above								
High grade ore (HGO)	5.5	above								
High grade ore (HGO)	10	above								

7.2.2 SYSTEMATIC ERROR AT GCDPs

The differences between grade control (GC) and exploration (EXP) sampling protocols were found to change in magnitude and "sign" across the 4E grade range.

Grade control sampling over-reporting at grades below 1.7 g/t 4E and under-reporting at grades above 2.5 g/t 4E.

The average differences of grade control (GC) vs. exploration (EXP) are summarised below:

- At 1 g/t 4E GC is + 0.16 g/t (~ + 50 %) higher than EXP
- At 1.7 g/t 4E GC is + 0 g/t (~ + 1 %) higher than EXP
- At 2.5 g/t 4E GC is (- 0.25 g/t) ~ - 10 % lower than EXP
- At 4 g/t 4E GC is (- 0.33 g/t) ~ - 8 % lower than EXP
- At > 5.5 g/t 4E GC is (-1 g/t) ~ - 18 % lower than EXP

The average systematic errors between grade control and exploration sampling, at the GCDPs, are presented in an uncertainty table, table 7-2.

Table 7-2 Systematic errors grade control vs. exploration at the GCDPs in % Diff, highlighted in red

4 g/t Uncertainty table			Systematic error							
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep		Analytical	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99	-11%	+ 50 %						
Very low grade ore (VLGO)	1.0	1.69		+ 1 %						
Low grade (LGO)	1.7	2.49		- 10 %						
Medium grade (MGO)	2.5	3.99		- 8 %						
High grade (HGO)	4.0	above		- 18 %						
High grade (HGO)	5.5	above		- 18 %						
High grade (HGO)	10.0	above								

The line graphs below present the 4E grade differences across the ore grade range for the grade control; RC stream AA (blue) and exploration; the BQ stream B:B (red), B:D (orange), as g/t difference (figure 7-3) and as % difference (figure 7-4).

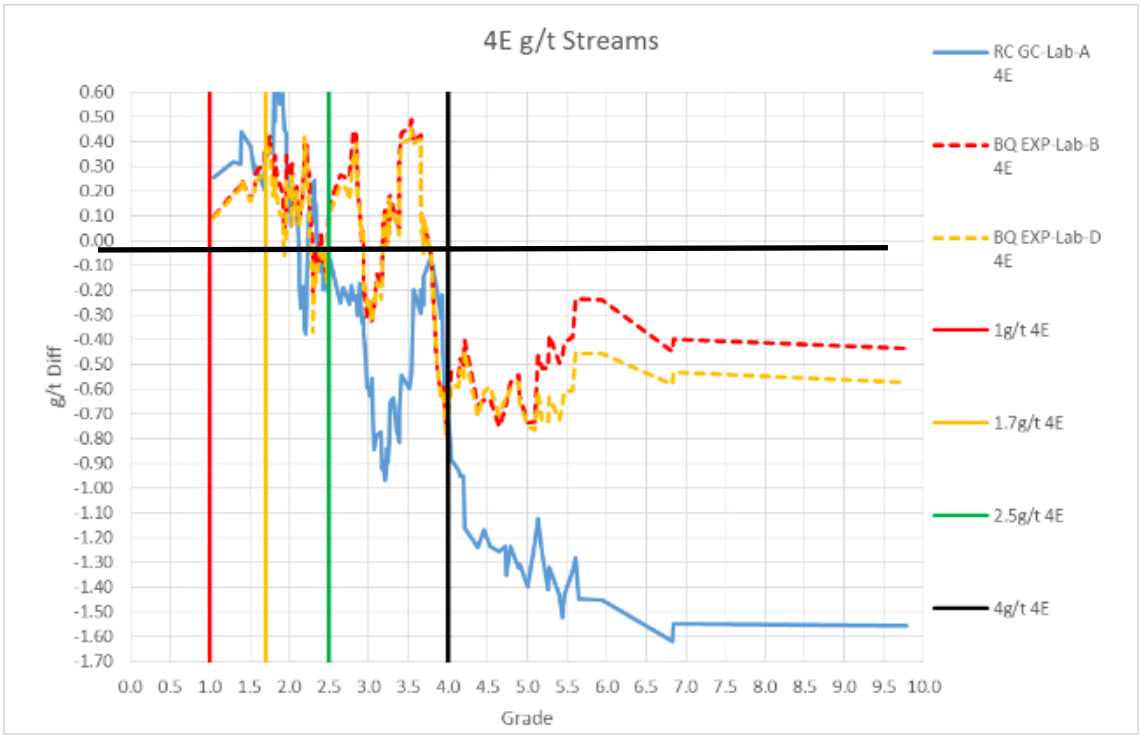


Figure 7-3 Streams used to demonstrate the systematic error between grade control and exploration sampling, in g/t 4E

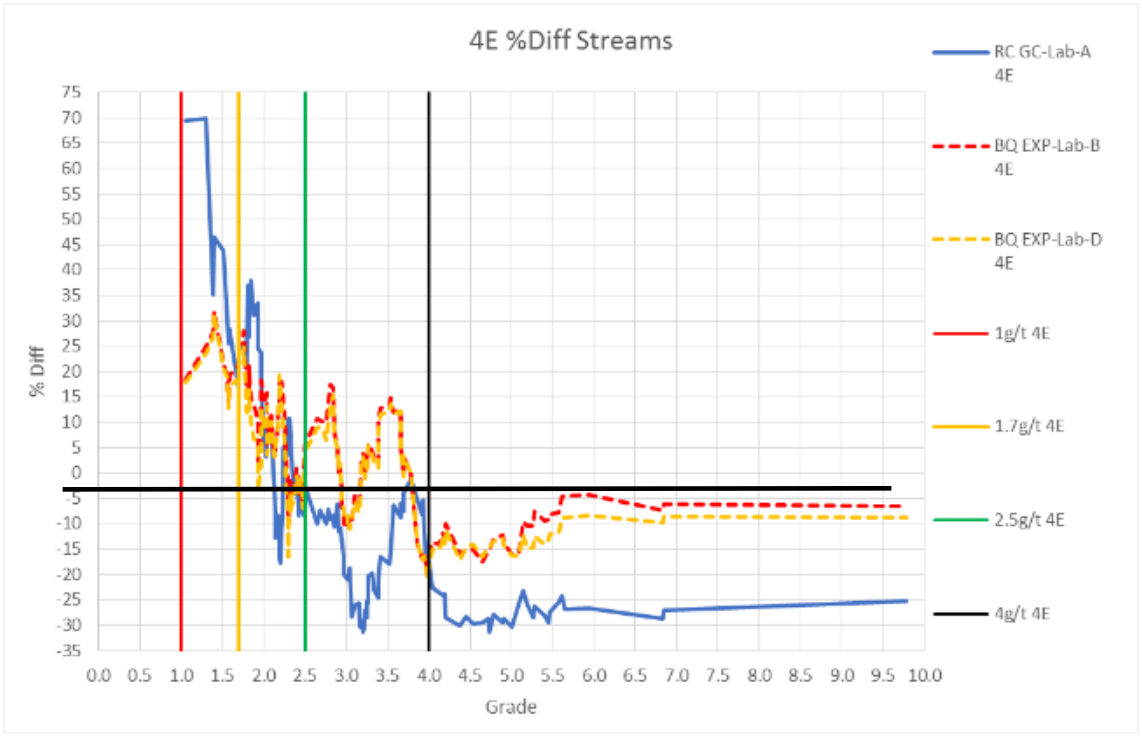


Figure 7-4 Streams used to demonstrate systematic error between grade control and exploration sampling, in % Diff

The systematic errors between grade control and exploration sampling, at the GCDPs are presented in bar charts in figure 7-5, expressed in g/t and % differences.

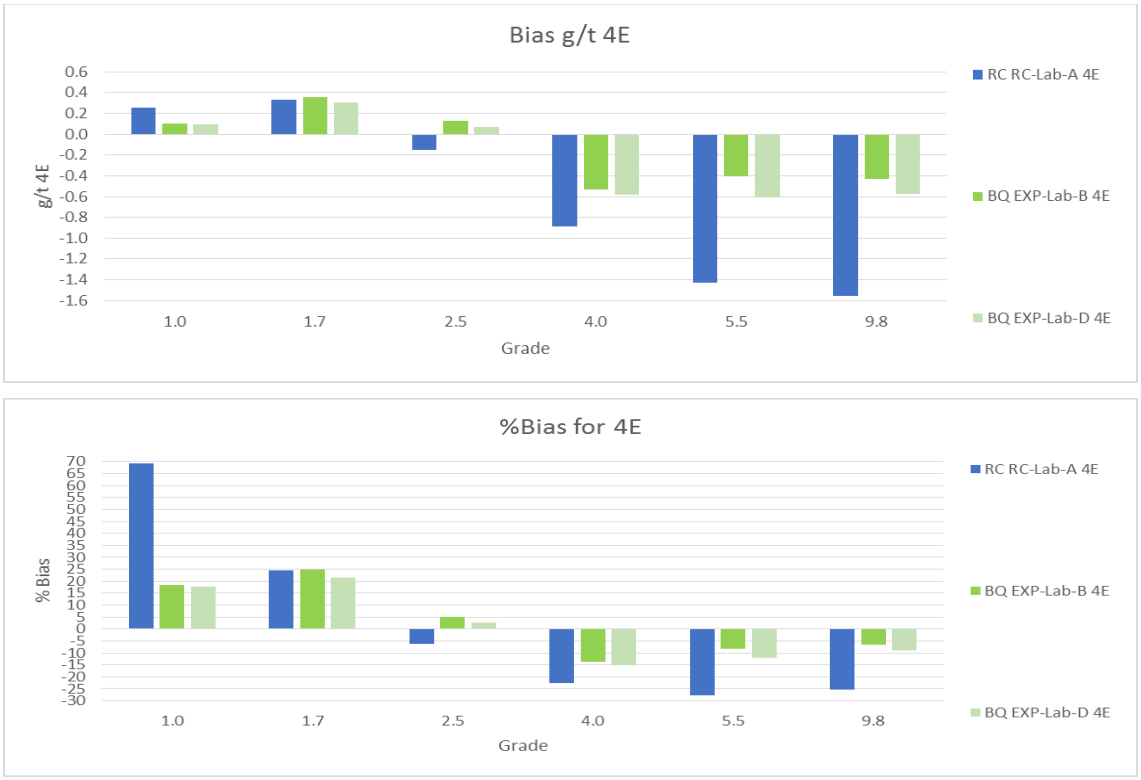


Figure 7-5 Systematic error between grade control and exploration sampling quantified at GCDPs, in g/t 4E and % Diff 4E

The average systematic errors between grade control and exploration sampling, at the GCDPs, were calculated in table 7-3.

Table 7-3 Systematic error between grade control and exploration at the GCDPs, in g/t 4E and % Diff

GC vs EXP	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	
4E g/t	**RC RC-Lab-A 4E**	BQ EXP-Lab-B 4E	BQ EXP-Lab-D 4E	**BQ EXP-Lab-4E Ave**	Diff (g/t)
1.0	**0.26**	0.10	0.10	**0.10**	0.16
1.7	**0.33**	0.36	0.30	**0.33**	0.00
2.5	**-0.15**	0.13	0.07	**0.10**	-0.25
4.0	**-0.88**	-0.53	-0.58	**-0.55**	-0.33
5.5	**-1.43**	-0.41	-0.61	**-0.51**	-0.92
9.8	**-1.55**	-0.43	-0.57	**-0.50**	-1.05
GC vs EXP	%Diff	%Diff	%Diff	%Diff	
4E g/t	**RC RC-Lab-A 4E**	BQ EXP-Lab-B 4E	BQ EXP-Lab-D 4E	**BQ EXP-Lab-4E Ave**	%Diff
1.0	**69**	18	18	**18**	51
1.7	**24**	25	21	**23**	1
2.5	**-6**	5	3	**4**	-10
4.0	**-23**	-14	-15	**-14**	-8
5.5	**-28**	-8	-12	**-10**	-18
9.8	**-25**	-7	-9	**-8**	-18

7.3 SAMPLING SYSTEMATIC ERROR – between RC and BQ

The sampling error referred to in this section, only relates to the “action of taking a sample”. This error excludes sample preparation and analytical errors because the samples were prepared and analysed at the same laboratory.

RC sampling were compared with BQ diamond drilling sampling; both used :

- the same lab (EXP-Lab)
- manual sample preparation and
- analytical Pb fire assay (Ag and Pd co-collector), with ICP-OES finish

7.3.1 AVERAGE SYSTEMATIC ERROR – between RC and BQ

In order to calculate the systematic error between reverse circulation and BQ diamond drilling sampling techniques, Stream B:B&B:C for RC were compared with stream B:B&B:D for BQ. These streams were highlighted in red in figure 7-6.

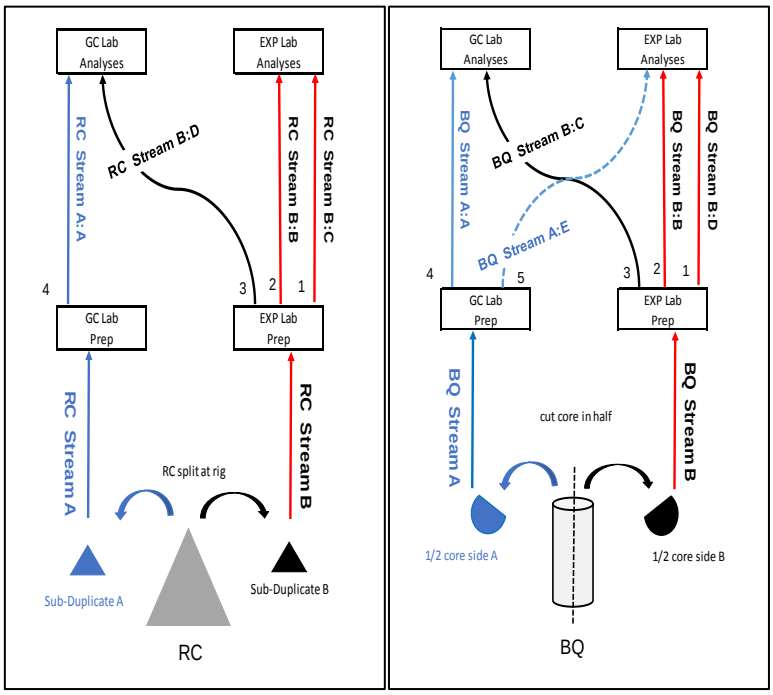


Figure 7-6 RC and BQ sampling, streams used to calculated the total average sampling (the action of taking the sample) systematic error between grade control and exploration sampling highlighted in red

The total average sampling difference between RC and BQ sampling is estimated as an average - 4% systematic error for 4E, with reverse circulation sampling reporting lower than BQ diamond drilling sampling.

The average systematic error between reverse circulation and BQ diamond drilling sampling is presented in an uncertainty table, table 7-4.

Table 7-4 Systematic error between RC and BQ sampling

4 g/t Uncertainty table			Systematic error							
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep		Analytical	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99								
Very low grade ore (VLGO)	1.0	1.69		+ 50 %						
Low grade (LGO)	1.7	2.49		+ 1 %						
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %					
High grade (HGO)	4.0	above		- 8 %						
High grade (HGO)	5.5	above		- 18 %						
High grade (HGO)	10.0	above		- 18 %						

7.3.2 SYSTEMATIC ERROR AT GCDPs – between RC and BQ

The differences between reverse circulation (RC) and BQ diamond drilling (BQ) sampling were found to change in magnitude and "sign", in an inconsistent way across the 4E grade range.

The sampling systematic errors were not consistent across the 4E grade range of the ore.

The average differences of RC Sampling vs. BQ sampling are summarised below:

- At 1g/t 4E RC is + 0.04 g/t (~ + 5 %) higher than BQ
- At 1.7g/t 4E RC is + 0.12 g/t (~ + 12 %) higher than BQ
- At 2.5 g/t 4E RC is (- 0.20 g/t) ~ - 8 % lower than BQ
- At 4 g/t 4E RC is (- 0.04 g/t) ~ + 1 % lower than BQ
- At > 5.5 g/t 4E RC is (- 0.6 g/t) ~ - 11 % lower than BQ

The average systematic errors between reverse circulation and BQ diamond drilling sampling, at the GCDPs are presented in an uncertainty table, table 7-5.

Table 7-5 Systematic errors RC vs. BQ sampling at the GCDPs, in %Diff

4 g/t Uncertainty table			Systematic error							
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep		Analytical	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99								
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %				
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %				
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %				
High grade (HGO)	4.0	above		- 8 %		+ 1 %				
High grade (HGO)	5.5	above		- 18 %		- 11 %				
High grade (HGO)	10.0	above		- 18 %		- 11 %				

The line graphs below present the 4E grade differences across the ore grade range for the RC sampling; stream AA (solid lines) and BQ sampling; BQ stream B:B (red), B:D (orange), as g/t difference (figure 7-7) and as % difference (figure 7-8).

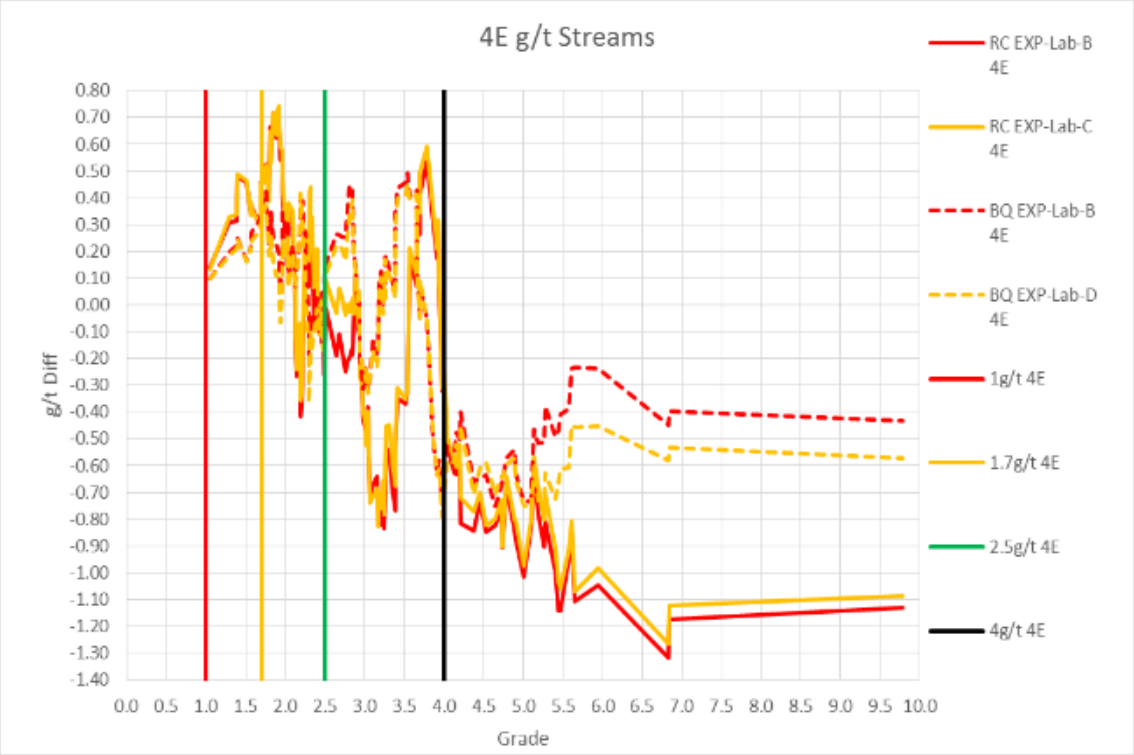


Figure 7-7 Streams used to demonstrate the systematic errors in RC vs. BQ sampling, in g/t 4E

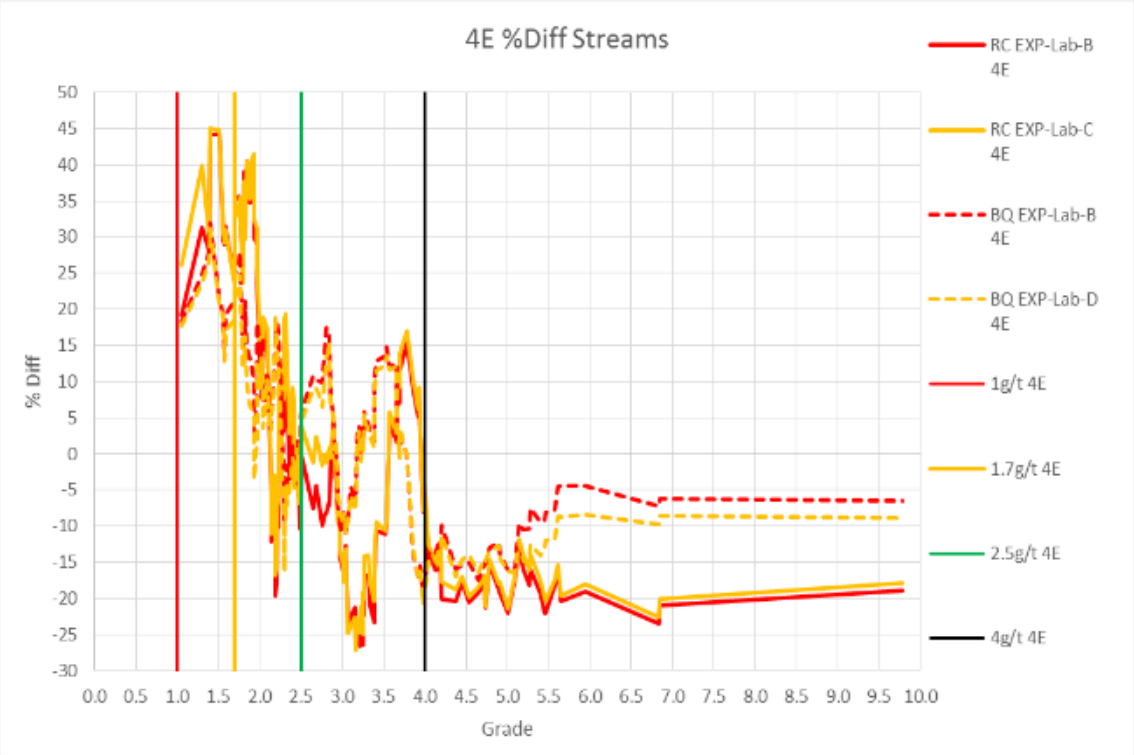


Figure 7-8 Streams used to demonstrate the systematic errors in RC vs. BQ sampling, in % Diff

The systematic errors between RC and BQ sampling, at the GCDPs are presented in bar charts in Figure 7-9, expressed in g/t and % differences.

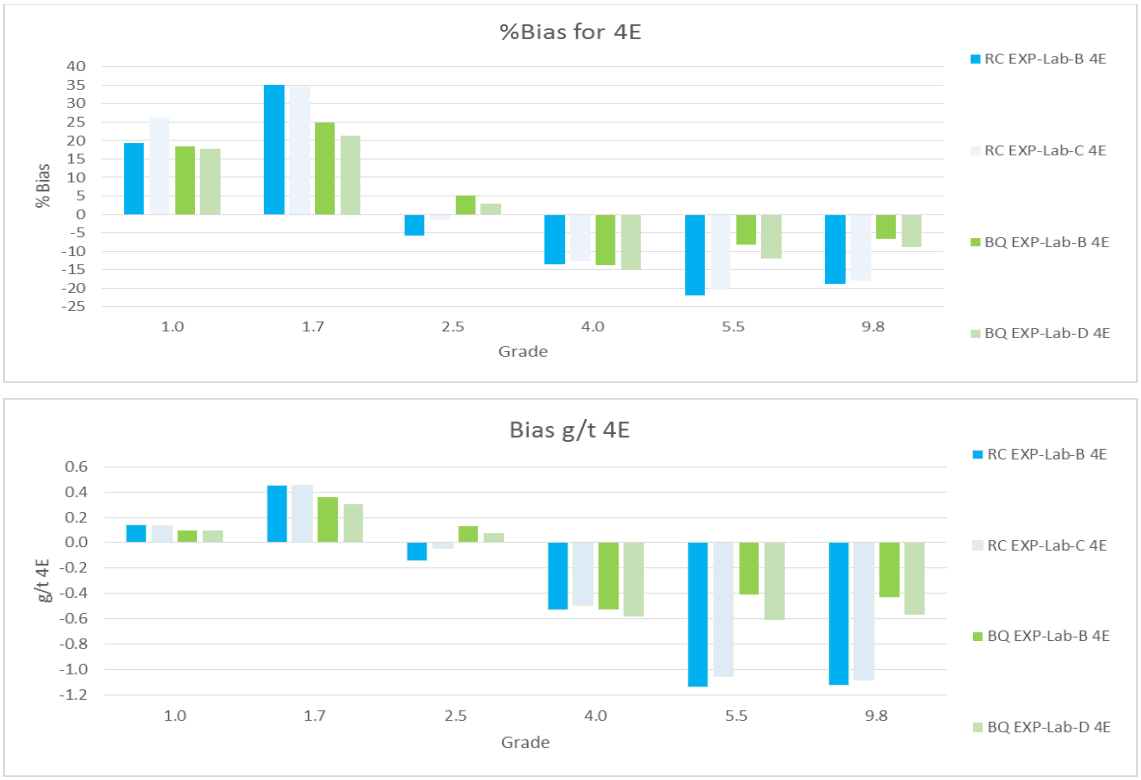


Figure 7-9 Systematic errors RC vs. BQ sampling at quantified at the GCDPs, in g/t 4E and %Diff 4E

The average systematic errors between RC and BQ sampling, at the GCDPs, were calculated in table 7-6.

Table 7-6 Systematic errors RC vs. BQ sampling at the GCDPs, in g/t 4E and %Diff

RC vs BQ	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	
4E g/t	RC EXP-Lab-B 4E	RC EXP-Lab-C 4E	RC EXP-Lab-4E Ave	BQ EXP-Lab-B 4E	BQ EXP-Lab-D 4E	BQ EXP-Lab-4E Ave	Diff (g/t)
1.0	0.14	0.13	0.14	0.10	0.10	0.10	0.04
1.7	0.46	0.45	0.45	0.36	0.30	0.33	0.12
2.5	-0.15	-0.04	-0.09	0.13	0.07	0.10	-0.20
4.0	-0.53	-0.50	-0.52	-0.53	-0.58	-0.55	0.04
5.5	-1.14	-1.06	-1.10	-0.41	-0.61	-0.51	-0.59
9.8	-1.13	-1.09	-1.11	-0.43	-0.57	-0.50	-0.61
RC vs BQ	%Diff	%Diff	%Diff	%Diff	%Diff	%Diff	
4E g/t	RC EXP-Lab-B 4E	RC EXP-Lab-C 4E	RC EXP-Lab-4E Ave	BQ EXP-Lab-B 4E	BQ EXP-Lab-D 4E	BQ EXP-Lab-4E Ave	%Diff
1.0	19	26	23	18	18	18	5
1.7	35	35	35	25	21	23	12
2.5	-6	-2	-4	5	3	4	-8
4.0	-14	-13	-13	-14	-15	-14	1
5.5	-22	-20	-21	-8	-12	-10	-11
9.8	-19	-18	-18	-7	-9	-8	-11

7.4 SAMPLE PREPARATION SYSTEMATIC ERRORS

The sample preparation systematic errors are quantified in this section. This error excludes the sampling technique and analytical errors because the two streams were sampled using the same sampling and analytical technique as well as being analysed at the same laboratory. The only difference between the two streams was the sample preparation facility i.e GC-Lab vs. EXP Lab sample preparation. The “A” sample was crushed and milled at the GC-Lab. The “B” sample was crushed and milled at the EXP-Lab.

7.4.1 WITHIN BQ SAMPLING – sample preparation errors

Automated (at the GC-Lab) vs. manual (at the EXP-Lab) sample preparation was compared; both used the same:

- sampling technique and
- analysing lab, EXP-Lab
- Analytical technique - Pb Fire Assay (Ag and Pd co-collector), with ICP-OES finish

Streams used for comparison were:

- ½ core “B” produced BQ Stream B:B and B:D
- ½ core “A” produced BQ Stream A:E

7.4.1.1 AVERAGE SYSTEMATC ERROR – sample preparation, BQ sampling

The relevant streams compared are highlighted in red in figure 7-10.

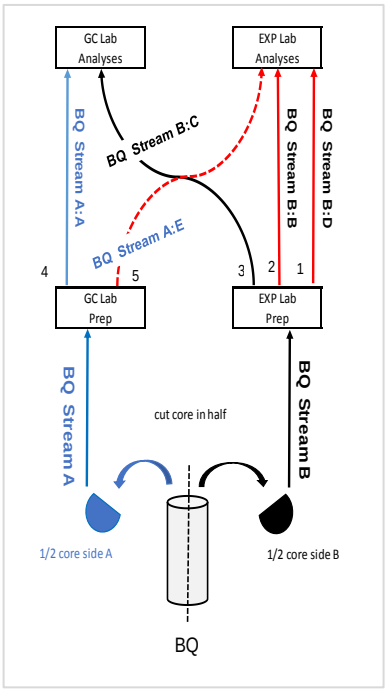


Figure 7-10 BQ sampling streams used to calculated the average sample preparation systematic error highlighted in red

The average sample preparation error (within BQ sampling) is estimated as - 3.5 %

The average systematic error between GC-Lab and EXP-Lab sample preparation, for BQ sampling is presented in an uncertainty table, table 7-7.

Table 7-7 GC-Lab sample preparation systematic errors in % Diff

4 g/t Uncertainty table			Systematic error									
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep within RC		Sample prep within BQ		Analytical	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99										
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %						
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %						
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %			- 3.5%			
High grade (HGO)	4.0	above		- 8 %		+ 1 %						
High grade (HGO)	5.5	above		- 18 %		- 11 %						
High grade (HGO)	10.0	above		- 18 %		- 11 %						

7.4.1.2 SYSTEMATIC ERROR AT GCDPs – sample preparation, BQ sampling

The differences between GC-Lab and EXP-Lab sample preparation within BQ sampling were mostly "-", except at grades ≤ 1 g/t 4E. Samples prepared at the GC-Lab reported consistently lower (except for samples with grades ≤ 1 g/t).

The average differences of GC-Lab prep and EXP-Lab prep using BQ sampling are summarised below:

- At 1 g/t 4E RC-Lab prep is + 0.07 g/t (~ + 42 %) higher than EXP-Lab prep
- At 1.7 g/t 4E RC-Lab prep is - 0.03 g/t (~ - 3 %) lower than EXP-Lab prep
- At 2.5 g/t 4E RC-Lab prep is - 0.12 g/t (~ - 5 %) lower than EXP-Lab prep
- At 4 g/t 4E RC-Lab prep is - 0.27 g/t (~ - 7 %) lower than EXP-Lab prep
- At 5.5 g/t 4E RC-Lab prep is - 0.29 g/t (~ - 6 %) lower EXP-Lab prep
- At 9.8 g/t 4E RC-Lab prep is - 0.09 g/t (~ - 2 %) lower EXP-Lab prep

The average systematic errors between GC-Lab and EXP-Lab prep, for BQ sampling at the GCDPs are presented in an uncertainty table, table 7-8.

Table 7-8 Systematic errors for GC-Lab preparation vs. EXP-Lab preparation at the GCDPs

4 g/t Uncertainty table			Systematic error									
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep within RC		Sample prep within BQ		Analytical	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99										
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %				+ 42 %		
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %				- 3 %		
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %			- 3.5%	- 5 %		
High grade (HGO)	4.0	above		- 8 %		+ 1 %				- 7 %		
High grade (HGO)	5.5	above		- 18 %		- 11 %				- 6 %		
High grade (HGO)	10.0	above		- 18 %		- 11 %				- 2 %		

The line graphs below present the 4E grade differences for the BQ sampling;

- stream A:E (green solid line) – prepared at GC-Lab
- stream B:B (red, dotted), stream B:D (orange,dotted) – prep'ed at EXP-Lab

as g/t difference (figure 7-11) and as % difference (figure 7-12).

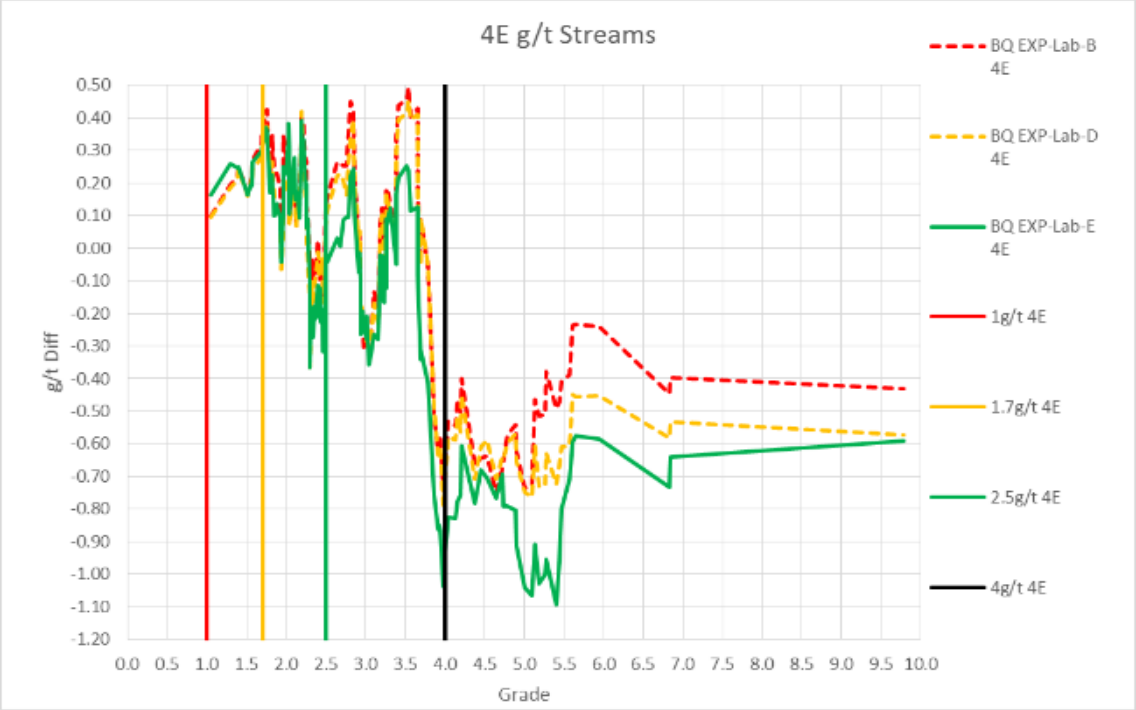


Figure 7-11 BQ streams used to demonstrate systematic errors between GC-Lab preparation vs. EXP-Lab preparation, in g/t 4E

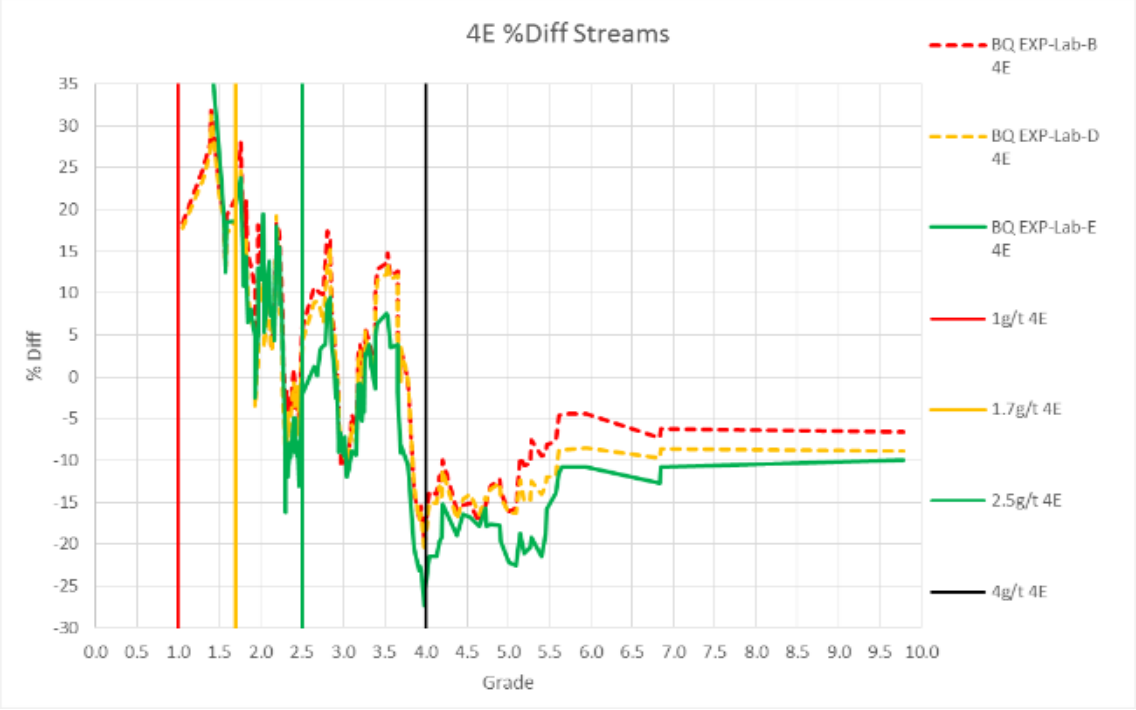


Figure 7-12 BQ streams used to demonstrate systematic errors between GC-Lab preparation vs. EXP-Lab preparation, in % Diff

The systematic errors between GC-Lab prep and EXP-Lab prep for BQ sampling, at the GCDPs are presented in bar charts in figure 7-13, expressed in g/t and % differences.



Figure 7-13 Systematic errors GC-Lab vs. EXP-Lab sample preparation quantified at the GCDPs, in g/t 4E and % Diff 4E

The average systematic errors between GC-Lab and EXP prep for BQ sampling, at the GCDPs, were calculated in table 7-9.

Table 7-9 Systematic errors for GC-Lab preparation vs. EXP-Lab preparation at the GCDPs

GC Lab Prep	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	
4E g/t	BQ EXP-Lab-E 4E	BQ EXP-Lab-B 4E	BQ EXP-Lab-D 4E	BQ EXP-Lab-4E Ave	Diff (g/t)
1.0	0.16	0.10	0.10	0.10	0.07
1.7	0.30	0.36	0.30	0.33	-0.03
2.5	-0.02	0.13	0.07	0.10	-0.12
4.0	-0.83	-0.53	-0.58	-0.55	-0.27
5.5	-0.80	-0.41	-0.61	-0.51	-0.29
9.8	-0.59	-0.43	-0.57	-0.50	-0.09
GC Lab Prep	%Diff	%Diff	%Diff	%Diff	
4E g/t	BQ EXP-Lab-E 4E	BQ EXP-Lab-B 4E	BQ EXP-Lab-D 4E	BQ EXP-Lab-4E Ave	%Diff
1.0	61	18	18	18	42
1.7	20	25	21	23	-3
2.5	-1	5	3	4	-5
4.0	-22	-14	-15	-14	-7
5.5	-16	-8	-12	-10	-6
9.8	-10	-7	-9	-8	-2

7.4.2 WITHIN RC SAMPLING – sample preparation errors

Automated (at the GC-Lab) vs. manual (at the EXP-Lab) sample preparation was compared; both used the same:

- sampling technique and
- analysing lab, GC-Lab
- analytical technique - Pb Fire Assay, with Spark-ICP finish

Streams used for comparison were:

- Sample “B” produced RC Stream B:D
- Sample “A” produced RC Stream A:A

7.4.2.1 AVERAGE SYSTEMATIC ERROR - sample preparation, RC sampling

The relevant streams compared are highlighted in red in figure 7-14.

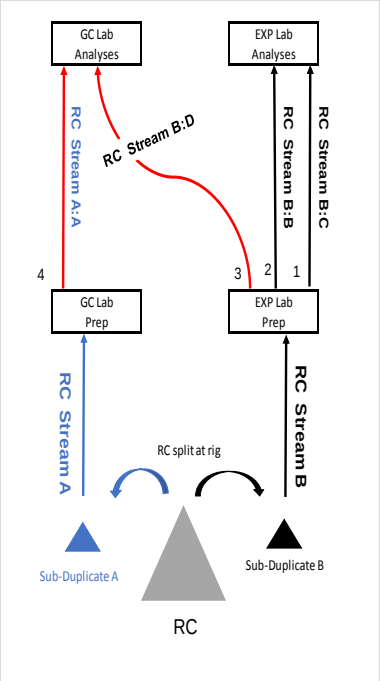


Figure 7-14 RC sampling, streams used to calculate the average sample preparation systematic error at the GC-Lab highlighted in red

The average sample preparation error (within RC sampling) is estimated as - 8%

The average systematic errors between GC-Lab and EXP-Lab prep, for RC sampling are presented in an uncertainty table, table 7-10.

Table 7-10 RC Sample preparation systematic errors at the GC-Lab in % Diff

4 g/t Uncertainty table			Systematic error									
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep within RC		Sample prep within BQ		Analytical	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99										
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %				+ 42 %		
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %				- 3 %		
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %	- 8 %		- 3.5%	- 5 %		
High grade (HGO)	4.0	above		- 8 %		+ 1 %				- 7 %		
High grade (HGO)	5.5	above		- 18 %		- 11 %				- 6 %		
High grade (HGO)	10.0	above		- 18 %		- 11 %				- 2 %		

7.4.2.2 SYSTEMATC ERROR AT GCDPs – sample prep, RC sampling

The differences between GC-Lab and EXP-Lab sample preparation within RC sampling were mostly "-", except at grades ≤1 g/t 4E. Samples prepared at the GC-Lab reported consistently lower (except for samples with grades ≤ 1 g/t).

The average differences of GC-Lab prep and EXP-Lab prep using RC sampling are summarised below:

- At 1 g/t 4E RC-Lab prep is + 0.07 g/t (~ + 18 %) higher than EXP-Lab prep
- At 1.7 g/t 4E RC-Lab prep is - 0.18 g/t (~ - 15 %) lower than EXP-Lab prep
- At 2.5 g/t 4E RC-Lab prep is - 0.21 g/t (~ - 9 %) lower than EXP-Lab prep
- At 4 g/t 4E RC-Lab prep is - 0.36 g/t (~ - 9 %) lower than EXP-Lab prep
- At 5.5 g/t 4E RC-Lab prep is - 0.24 g/t (~ - 5 %) lower EXP-Lab prep
- At 9.8 g/t 4E RC-Lab prep is - 0.41 g/t (~ - 7 %) lower EXP-Lab prep

The average systematic errors between GC-Lab and EXP-Lab prep, for RC sampling at the GCDPs are presented in an uncertainty table, table 7-11.

Table 7-11 Systematic errors for GC-Lab preparation vs. EXP-Lab preparation at the GCDPs

4 g/t Uncertainty table			Systematic error									
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep within RC		Sample prep within BQ		Analytical	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99										
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %		+ 18 %		+ 42 %		
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %		- 15 %		- 3 %		
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %	- 8 %	- 9 %	- 3.5%	- 5 %		
High grade (HGO)	4.0	above		- 8 %		+ 1 %		- 9 %		- 7 %		
High grade (HGO)	5.5	above		- 18 %		- 11 %		- 5 %		- 6 %		
High grade (HGO)	10.0	above		- 18 %		- 11 %		- 7 %		- 2 %		

The line graphs below present the 4E grade differences across the ore grade range for the RC sampling; stream AA (dark blue lines) prepared at GC-Lab and B:D (light blue lines) prepared at EXP-Lab, as g/t difference (figure 7-15) and as % difference (figure 7-16).

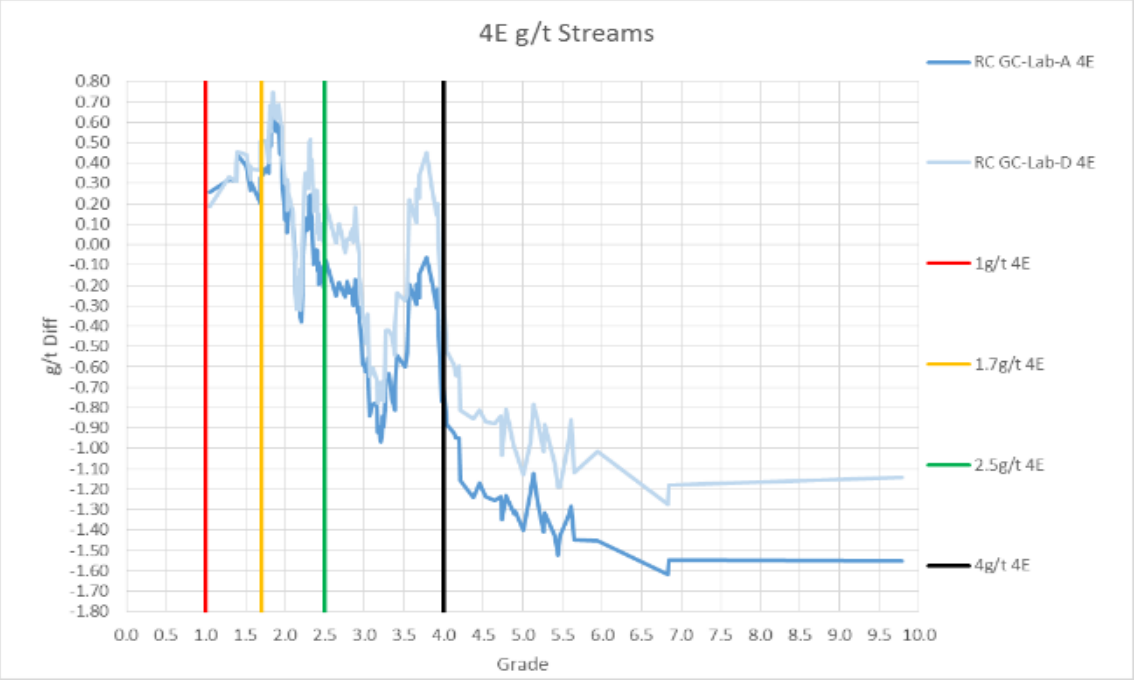


Figure 7-15 RC streams used to demonstrate systematic errors between GC-Lab preparation vs. EXP-Lab preparation, in g/t 4E

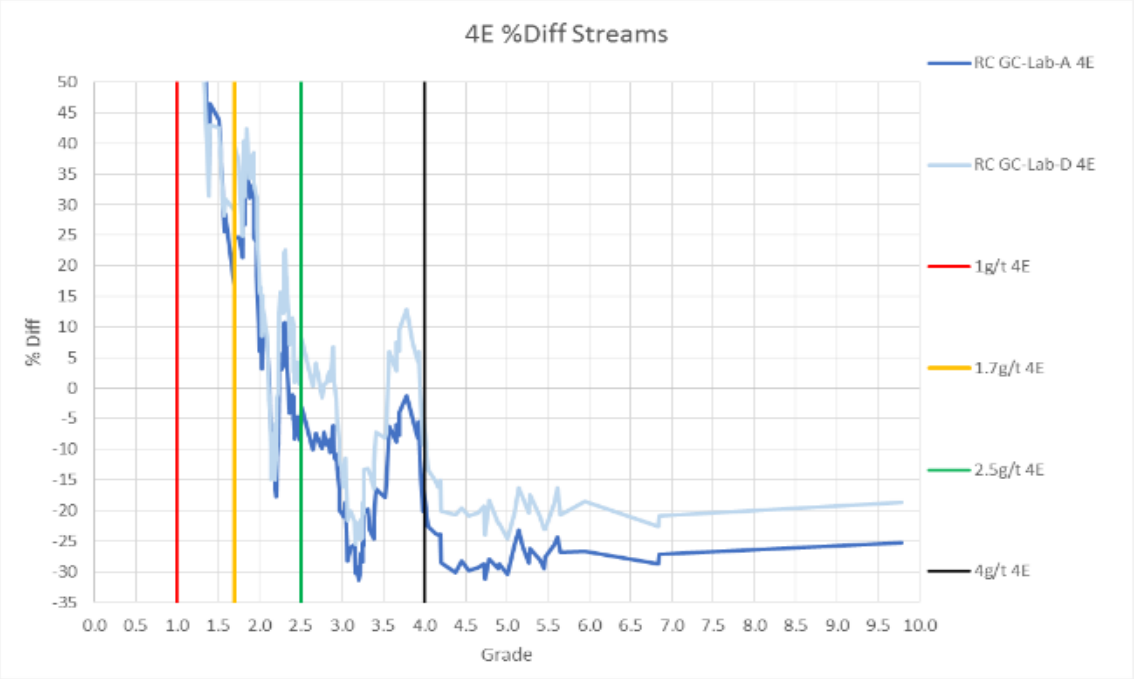


Figure 7-16 RC streams used to demonstrate systematic errors between GC-Lab preparation vs. EXP-Lab preparation, in % Diff

The systematic errors between GC-Lab and EXP-Lab prep for RC sampling, at the GCDPs are presented in bar charts in figure 7-17, expressed in g/t and % differences.

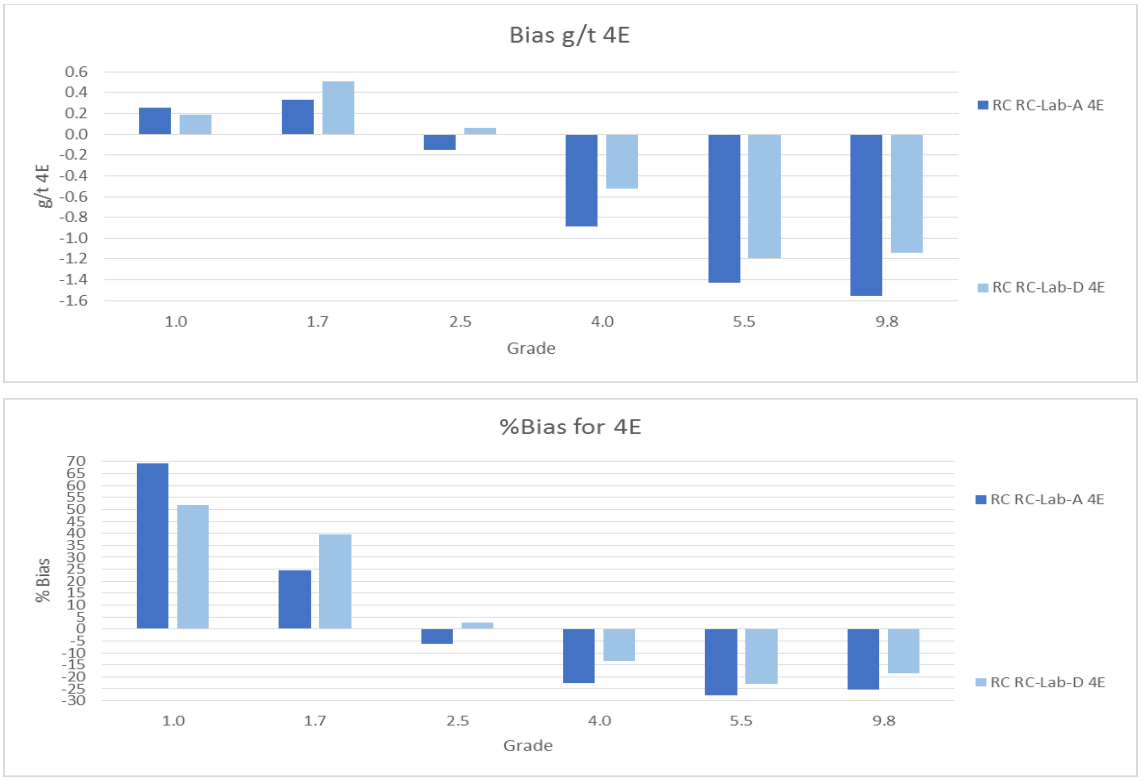


Figure 7-17 Preparation systematic errors GC-Lab vs. EXP-Lab quantified at the at GCDPs, in g/t 4E and % Diff 4E

The average systematic errors between GC-Lab and EXP-Lab prep for RC sampling, at the GCDPs, were calculated in table 7-12.

Table 7-12 Systematic errors for GC-Lab preparation vs. EXP-Lab preparation at the GCDPs

GC Lab Prep	Diff 4E g/t	Diff 4E g/t	
4E g/t	RC RC-Lab-A 4E	RC RC-Lab-D 4E	Diff (g/t)
1.0	0.26	0.19	0.07
1.7	0.33	0.51	-0.18
2.5	-0.15	0.06	-0.21
4.0	-0.88	-0.53	-0.36
5.5	-1.43	-1.19	-0.24
9.8	-1.55	-1.14	-0.41
GC Lab Prep	%Diff	%Diff	
4E g/t	RC RC-Lab-A 4E	**RC RC-Lab-D 4E**	%Diff
1.0	69	52	17.53
1.7	24	40	-15.11
2.5	-6	3	-8.79
4.0	-23	-13	-9.31
5.5	-28	-23	-4.57
9.8	-25	-19	-6.63

7.4.3 DIFFERENCE IN THE SAMPLE PREPARATION ERRORS

The average sample preparation systematic error for the respective sampling protocols was calculated:

- *Sample preparation at GC-Lab vs. at EXP-Lab = - 8 % , see section 7.4.2*
  Both sets of samples originated from RC sampling, Spark-ICP analytical method
- *Sample preparation at GC-Lab vs. EXP-Lab = - 3.5 % , see section 7.4.1*
  Both sets of samples originated from BQ sampling, ICP-OES analytical method

This error is larger when:

- *the sampling technique used is RC sampling*
- *the analysing lab is GC-Lab*

The difference between the two tests above were the physical properties of the sample as a result of the Sampling technique used to take the sample. Specifically:

- *For RC sampling, the sample consists of sample cuttings with lots of fines*
- *For BQ sampling, the sample is a solid core with minimal fines*

The particle size of the RC samples has more fines, PGMs are ~ 95 % liberated in the - 25 µm fraction [(27)], thus any losses in fines during sample preparation will generate a systematic error. The % errors (7.4.2 (sample preparation using RC sampling) & 7.4.1 (sample preparation using BQ sampling)) were converted to variances, subtracted from each other and then again converted to a % RSD. The resultant error is due to the physical property of the RC sample clippings and estimated at "-" 7.2 % (for RC sampling, GC Lab). Table 7-13 tabulate the calculation for subtracting sample preparation variances.

Table 7-13 Calculation for subtracting the sample preparation variances (for RC sampling – for BQ sampling)

Grade 4e g/t	%RSD	StdDev		Var	StdDev	%RSD
	8	0.2352		0.055319		
2.94	3.5	0.1029	-	0.010588		
				0.044731	0.211496	7.2

Test work is under way at the GC-Lab to determine if the crushing step in the sample preparation procedure can be removed; so as to introduce the sample directly into the milling circuit. Thus eliminating procedural steps that may introduce sample loss.

7.5 ANALYTICAL SYSTEMATIC ERROR

The analytical systematic errors were measured using 5 different data sets namely:

- 3-way Twin hole dataset (7.5.1, within RC sampling & 7.5.2 within BQ sampling)
- 4-way Exploration check data (7.5.3)
- “Blind” CRMs (7.5.4)
- 2-way RC check data (7.5.3)

This error is the easiest to measure and is, in many cases, the focus of most resources.

7.5.1 WITHIN RC SAMPLING

The analytical error measured here, includes sample preparation error but excludes sampling errors. The same sampling technique (RC) was used to generate the samples. Any systematic errors between sub-sample “A” and “B” was assumed to be “null”.

7.5.1.1 AVERAGE SYSTEMATIC ERROR – within RC sampling

Figure 7-18 present the streams used to quantify the analytical systematic error between the GC-Lab and the EXP-Lab:

- Streams A:A (prepared and analysed at the GC-Lab)
- Streams B:B and B:C (prepared and analysed at the EXP-Lab)
- Using the same RC sampling technique

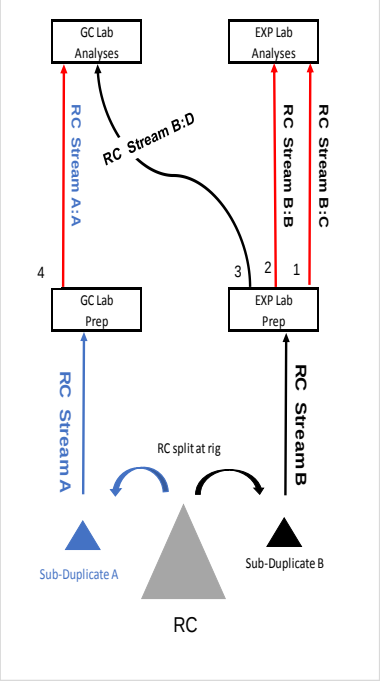


Figure 7-18 RC sampling, streams used to calculate the average analytical and sample preparation systematic error between the GC-Lab and the EXP-Lab highlighted in red

The average analytical (and sample preparation) systematic error, contribution to the 4E difference between grade control and exploration is estimated as - 7%, with the GC-Lab reporting lower than the EXP-Lab.

The average systematic error between GC-Lab and EXP-Lab, using RC sampling is presented in an uncertainty table, table 7-14.

Table 7-14 Analytical (and sample preparation) systematic error using RC sampling

4 g/t Uncertainty table			Systematic error											
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep within RC		Sample prep within BQ		Analytical within RC		Analytical within BQ	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99												
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %		+ 18 %		+ 42 %				
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %		- 15 %		- 3 %				
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %	- 8 %	- 9 %	- 3.5%	- 5 %	- 7 %			
High grade (HGO)	4.0	above		- 8 %		+ 1 %		- 9 %		- 7 %				
High grade (HGO)	5.5	above		- 18 %		- 11 %		- 5 %		- 6 %				
High grade (HGO)	10.0	above		- 18 %		- 11 %		- 7 %		- 2 %				

7.5.1.2 SYSTEMATIC ERROR AT GCDPs – within RC sampling

The differences between GC-Lab and EXP-Lab within RC sampling were mostly "-", except at grades ≤1 g/t 4E. Samples prepared and analysed at the GC-Lab reported consistently lower (except for samples with grades ≤ 1 g/t).

The average differences between the RC-Lab and EXP-Lab using RC sampling are summarised below:

- At 1 g/t 4E RC-Lab is + 0.12 g/t (~ + 47 %) higher than EXP-Lab
- At 1.7 g/t 4E RC-Lab is - 0.13 g/t (~ - 10 %) lower than EXP-Lab
- At 2.5 g/t 4E RC-Lab is - 0.06 g/t (~ - 2 %) lower than EXP-Lab
- At 4 g/t 4E RC-Lab is - 0.37 g/t (~ - 10 %) lower than EXP-Lab
- At 5.5 g/t 4E RC-Lab is - 0.33 g/t (~ - 6 %) lower EXP-Lab
- At 9.8 g/t 4E RC-Lab is - 0.45 g/t (~ - 7 %) lower EXP-Lab

The average systematic errors between GC-Lab and EXP-Lab at the GCDPs, using RC sampling are presented in an uncertainty table, table 7-15.

Table 7-15 Analytical (and sample preparation) systematic error using RC sampling at the GCDPs

4 g/t Uncertainty table			Systematic error											
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep within RC		Sample prep within BQ		Analytical within RC		Analytical within BQ	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99												
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %		+ 18 %		+ 42 %		+ 47 %		
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %		- 15 %		- 3 %		- 10 %		
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %	- 8 %	- 9 %	- 3.5%	- 5 %	- 7 %	- 2 %		
High grade (HGO)	4.0	above		- 8 %		+ 1 %		- 9 %		- 7 %		- 10 %		
High grade (HGO)	5.5	above		- 18 %		- 11 %		- 5 %		- 6 %		- 6 %		
High grade (HGO)	10.0	above		- 18 %		- 11 %		- 7 %		- 2 %		- 7 %		

The line graphs below present the 4E grade differences across the ore grade range for RC sampling; stream AA (blue) analysed at GC-Lab, and B:B (red),B:C (orange) analysed at EXP-Lab, as g/t difference (figure 7-19) and as % difference (figure 7-20).

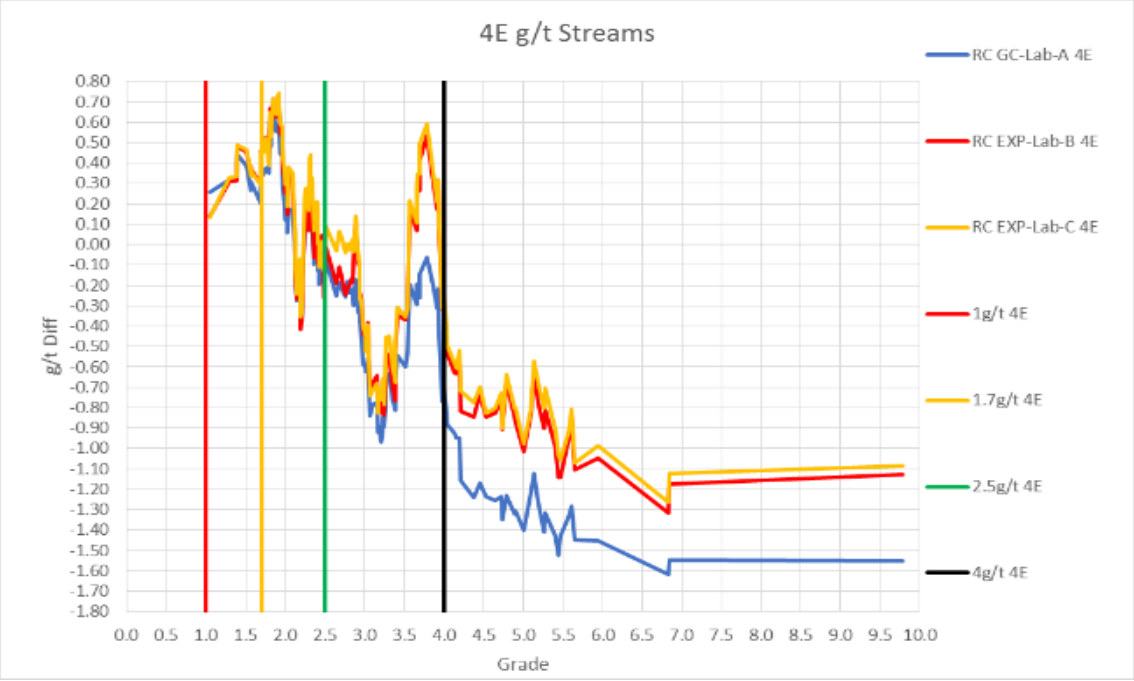


Figure 7-19 RC streams used to demonstrate analytical systematic errors GC-Lab vs. EXP-Lab (g/t 4E)

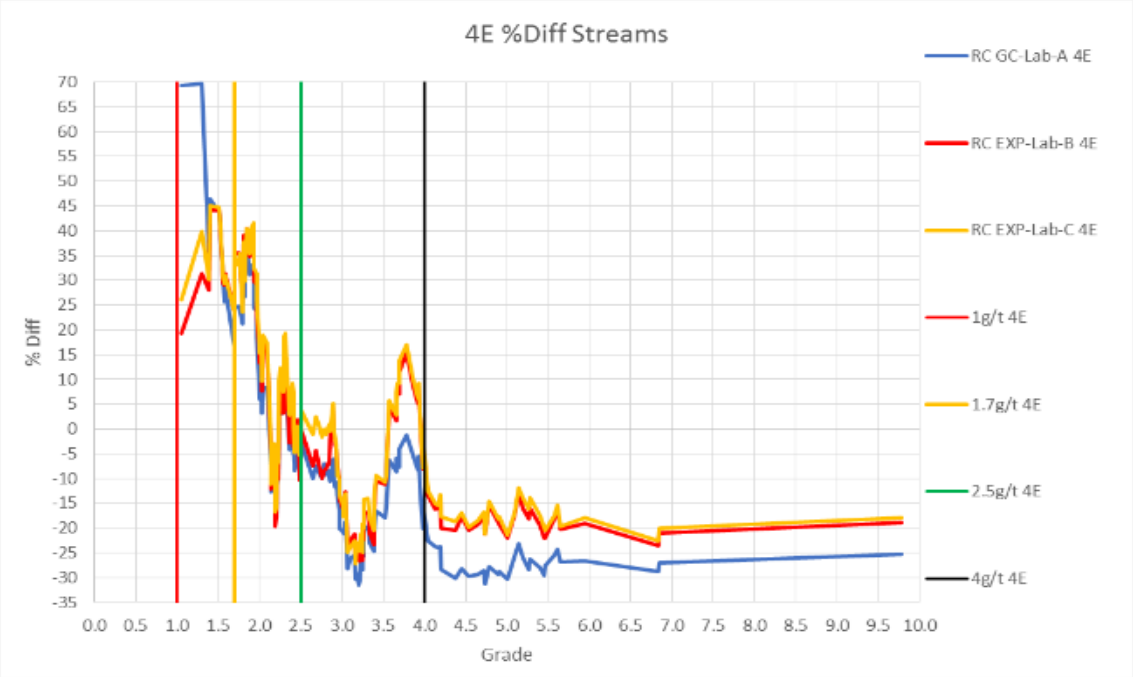


Figure 7-20 RC streams used to demonstrate analytical systematic errors GC-Lab vs. EXP-Lab (% Diff 4E)

The analytical systematic errors between GC-Lab and EXP-Lab using RC sampling, at the GCDPs, are presented in bar charts in figure 7-21, expressed in g/t and % differences.

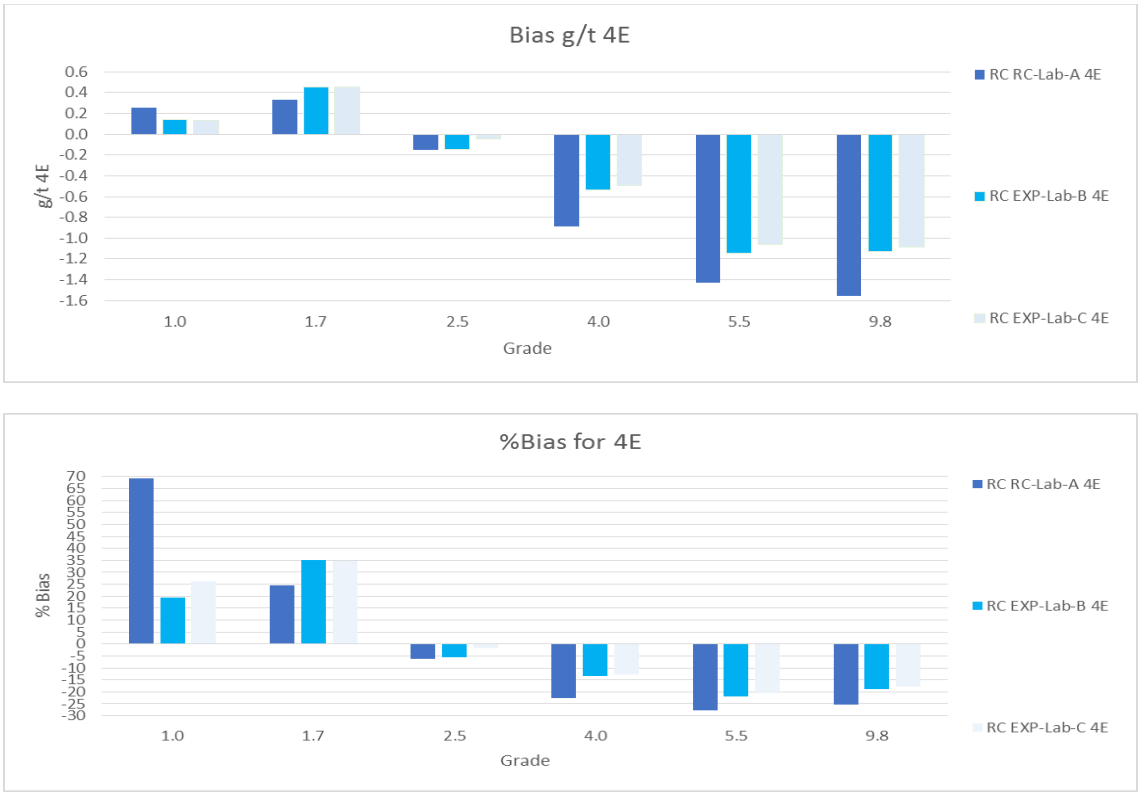


Figure 7-21 Analytical systematic errors between GC-Lab and EXP-Lab quantified at the GCDPs, in g/t 4E and % Diff 4E

The average analytical systematic errors between GC-Lab and EXP-Lab using RC sampling, at the GCDPs, were calculated in table 7-16.

Table 7-16 Analytical systematic errors between GC-Lab and EXP-Lab at the GCDPs

GC Lab Ana	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	
4E g/t	RC RC-Lab-A 4E	RC EXP-Lab-B 4E	RC EXP-Lab-C 4E	RC EXP-Lab-4E Ave	Diff (g/t)
1.0	0.26	0.14	0.13	0.14	0.12
1.7	0.33	0.46	0.45	0.45	-0.13
2.5	-0.15	-0.15	-0.04	-0.09	-0.06
4.0	-0.88	-0.53	-0.50	-0.52	-0.37
5.5	-1.43	-1.14	-1.06	-1.10	-0.33
9.8	-1.55	-1.13	-1.09	-1.11	-0.45
GC Lab Ana	%Diff	%Diff	%Diff	%Diff	
4E g/t	RC RC-Lab-A 4E	RC EXP-Lab-B 4E	RC EXP-Lab-C 4E	RC EXP-Lab-4E Ave	%Diff
1.0	69	19	26	23	47
1.7	24	35	35	35	-10
2.5	-6	-6	-2	-4	-2
4.0	-23	-14	-13	-13	-10
5.5	-28	-22	-20	-21	-6
9.8	-25	-19	-18	-18	-7

7.5.2 WITHIN BQ SAMPLING

The analytical error measured here, included sample preparation error but excludes sampling errors. The same sampling technique, (BQ) was used to generate the samples. Any systematic errors between cores was assumed to be “null”.

7.5.1.1 AVERAGE SYSTEMATIC ERROR – within BQ sampling

Figure 7-22 present the streams used to quantify the analytical systematic error between the GC-Lab and the EXP-Lab:

The streams used in the comparison between the GC-Lab and the EXP-Lab were:

- Streams A:A (prepared and analysed at the GC-Lab)
- Streams B:B and B:D (prepared and analysed at the EXP-Lab)

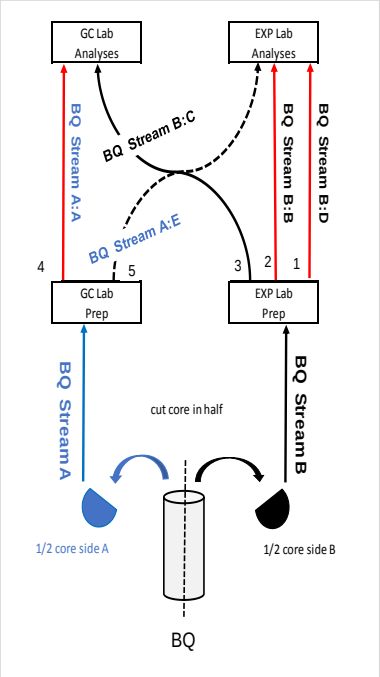


Figure 7-22 BQ sampling, streams used to calculate the average analytical and sample preparation systematic error between the GC-Lab and the EXP-Lab highlighted in red

The average analytical (and sample preparation) systematic error, contribution to the 4E difference between grade control and exploration is estimated as - 6%. The GC-Lab reporting lower than the EXP-Lab.

The average systematic errors between GC-Lab and EXP-Lab, using BQ sampling are presented in an uncertainty table, table 7-17.

Table 7-17 Analytical (and sample preparation) systematic error using BQ sampling

4 g/t Uncertainty table			Systematic error											
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep within RC		Sample prep within BQ		Analytical within RC		Analytical within BQ	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99												
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %		+ 18 %		+ 42 %		+ 47 %		
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %		- 15 %		- 3 %		- 10 %		
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %	- 8 %	- 9 %	- 3.5%	- 5 %	- 7 %	- 2 %	- 6 %	
High grade (HGO)	4.0	above		- 8 %		+ 1 %		- 9 %		- 7 %		- 10 %		
High grade (HGO)	5.5	above		- 18 %		- 11 %		- 5 %		- 6 %		- 6 %		
High grade (HGO)	10.0	above		- 18 %		- 11 %		- 7 %		- 2 %		- 7 %		

7.5.1.2 SYSTEMATIC ERROR AT GCDPs – within BQ sampling

The differences between GC-Lab and EXP-Lab within BQ sampling were mostly "-", except at grades ≤1 g/t 4E. Samples prepared and analysed at the GC-Lab reported consistently lower (except for samples with grades ≤ 1 g/t).

The average differences between the RC-Lab and EXP-Lab using BQ samples are summarised below:

- At 1 g/t 4E RC-Lab is + 0.18 g/t (~ + 58 %) higher than EXP-Lab
- At 1.7 g/t 4E RC-Lab is (- 0.05 g/t) ~ - 2 % lower than EXP-Lab
- At 2.5 g/t 4E RC-Lab is (- 0.23 g/t) ~ - 10 % lower than EXP-Lab
- At 4 g/t 4E RC-Lab is (- 0.34 g/t) ~ - 9 % lower than EXP-Lab
- At 5.5 g/t 4E RC-Lab is (- 0.40 g/t) ~ - 8 % lower EXP-Lab
- At 9.8 g/t 4E RC-Lab is (- 0.42 g/t) ~ - 7 % lower EXP-Lab

The average systematic errors between GC-Lab and EXP-Lab at the GCDPs, using RC sampling are presented in an uncertainty table, table 7-18.

Table 7-18 Systematic error using BQ sampling between GC-Lab and EXP-lab at the GCDPs

4 g/t Uncertainty table			Systematic error											
as % Error	4E (g/t)		Sampling		Action of taking a sample		Sample prep within RC		Sample prep within BQ		Analytical within RC		Analytical within BQ	
Ore classification:	Grade From:	Grade To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs
Waste	0.0	0.99												
Very low grade ore (VLGO)	1.0	1.69		+ 50 %		+ 5 %		+ 18 %		+ 42 %		+ 47 %		+ 58 %
Low grade (LGO)	1.7	2.49		+ 1 %		+ 12 %		- 15 %		- 3 %		- 10 %		- 2 %
Medium grade (MGO)	2.5	3.99	- 11 %	- 10 %	- 4 %	- 8 %	- 8 %	- 9 %	- 3.5%	- 5 %	- 7 %	- 2 %	- 6 %	- 10 %
High grade (HGO)	4.0	above		- 8 %		+ 1 %		- 9 %		- 7 %		- 10 %		- 9 %
High grade (HGO)	5.5	above		- 18 %		- 11 %		- 5 %		- 6 %		- 6 %		- 8 %
High grade (HGO)	10.0	above		- 18 %		- 11 %		- 7 %		- 2 %		- 7 %		- 7 %

The line graphs below present the 4E grade differences across the ore grade range for the BQ sampling; stream AA (blue) analysed at GC-Lab, and B:B (red),B:D (orange) analysed at EXP-Lab, as g/t difference (figure 7-23) and as % difference (figure 7-24).

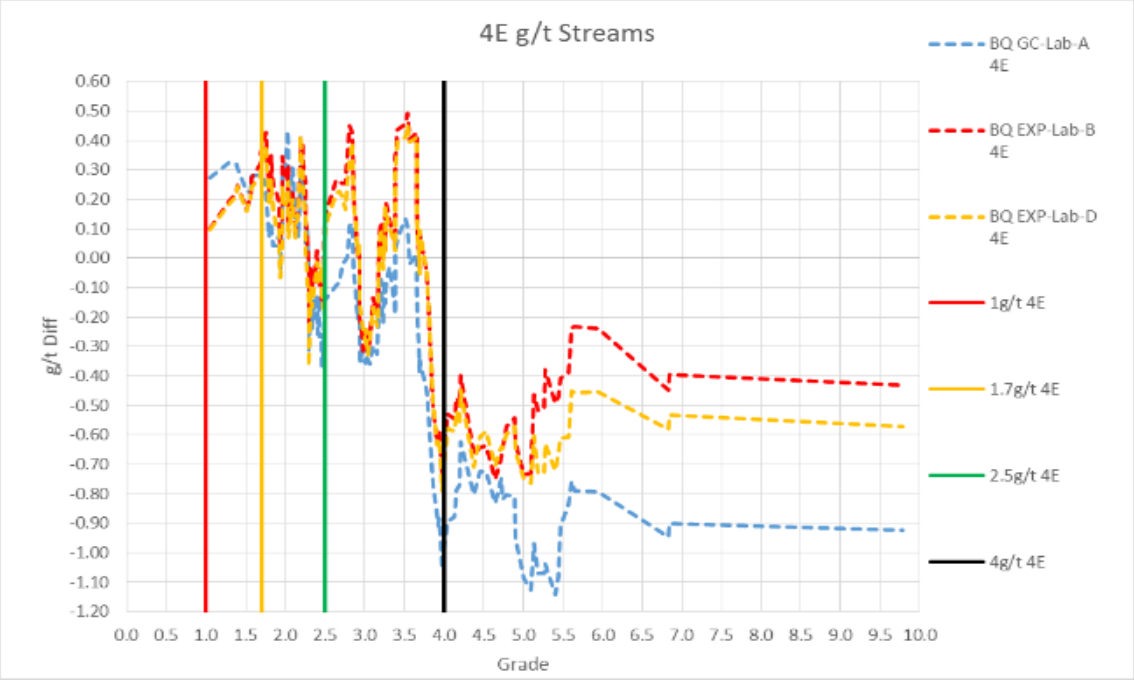


Figure 7-23 BQ streams used to demonstrate analytical systematic errors GC-Lab vs. EXP-Lab (g/t 4E)

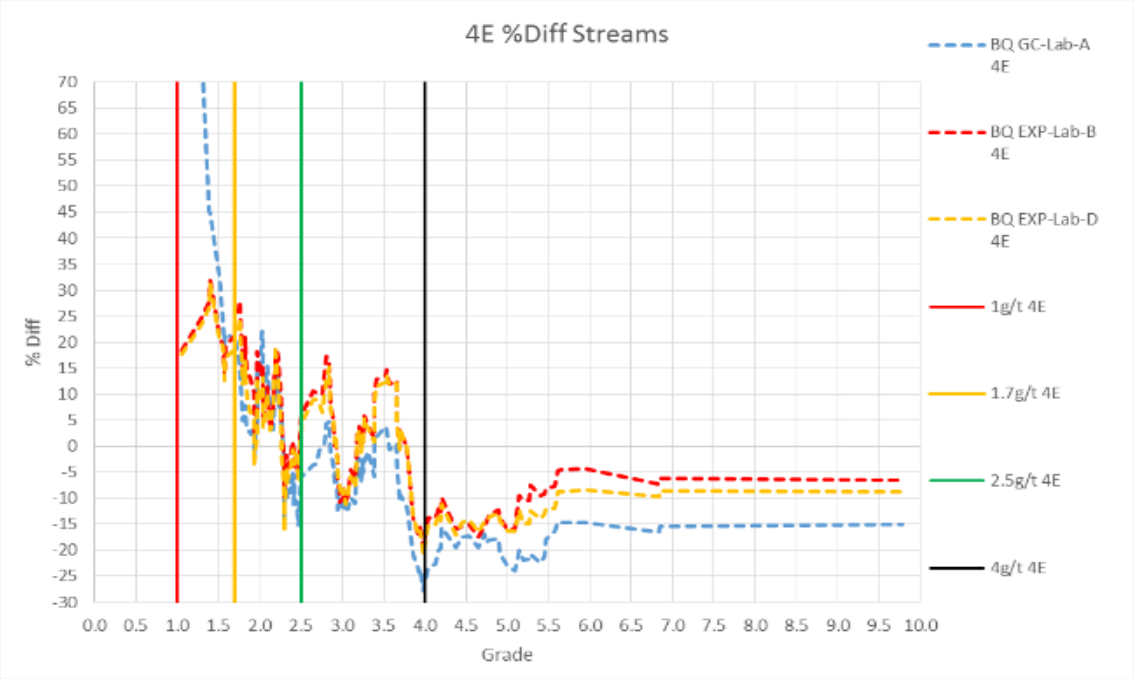


Figure 7-24 BQ streams used to demonstrate analytical systematic errors GC-Lab vs. EXP-Lab (% Diff 4E)

The analytical systematic errors between GC-Lab and EXP-Lab using BQ sampling, at the GCDPs are presented in bar charts in figure 7-25, expressed in g/t and % differences.



Figure 7-25 Analytical systematic errors GC-Lab vs. EXP-Lab quantified at the GCDPs for BQ sampling, in /t 4E and % Diff 4E

The average analytical systematic errors between GC-Lab and EXP-Lab using BQ sampling, at the GCDPs, were calculated in table 7-19.

Table 7-19 Analytical systematic errors, GC-Lab vs. EXP-Lab at the GCDPs using BQ sampling

GC Lab Ana	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	Diff 4E g/t	
4E g/t	BQ RC-Lab-A 4E	BQ EXP-Lab-B 4E	BQ EXP-Lab-D 4E	RC EXP-Lab-4E Ave	Diff (g/t)
1.0	0.27	0.10	0.10	0.10	0.18
1.7	0.28	0.36	0.30	0.33	-0.05
2.5	-0.13	0.13	0.07	0.10	-0.23
4.0	-0.90	-0.53	-0.58	-0.55	-0.34
5.5	-0.91	-0.41	-0.61	-0.51	-0.40
9.8	-0.92	-0.43	-0.57	-0.50	-0.42
GC Lab Ana	%Diff	%Diff	%Diff	%Diff	
4E g/t	BQ RC-Lab-A 4E	BQ EXP-Lab-B 4E	BQ EXP-Lab-D 4E	Diff (g/t)	%Diff
1.0	76	18	18	18	58
1.7	21	25	21	23	-2
2.5	-6	5	3	4	-10
4.0	-23	-14	-15	-14	-9
5.5	-18	-8	-12	-10	-8
9.8	-15	-7	-9	-8	-7

7.5.3 EXPLORATION CHECK DATA - Data set 3

In this section, the analytical error is measured between three laboratories, analysing a split of the same pulp sample (after the sample particle size were reduced to 80 % less than 75 micrometres). This error excludes sample preparation and sampling errors. The error is generated from the analytical laboratory's techniques used to analyse the samples.

Routine exploration samples are taken using diamond drilling with BQ diameter every 1.25 m. These samples are milled to 80 % less than 75 micrometres. Typically 5 % of all samples are randomly selected and split into four analytical samples. Set 1 is sent to EXP-Lab for routine analyses. Set 2 & 3 are sent respectively to GC-Lab and Check-Lab for check analyses. Set 4 is kept back for 2 weeks and then submitted to EXP-Lab for long-term reproducibility. This 4-way comparison can be used to quantify analytical systematic errors between the laboratories, over the grade range of the samples. This is not possible with "blind" certified reference materials (CRMs) because these only give a snap shot of the Systematic error at the grade of the CRMs used. Although the 4-way check data's median is probably the best estimate of the "true" value, it is not a CRM consensus value. Thus the systematic error is the error "between" laboratories. The systematic error found using the check data, can be verified using the results of the inserted "blind" CRMs (7.5.4).

Data processing:

All four results (for the same pulp samples) are matched according to its unique sample identification. For each analyte / sample the median of the 3 laboratories is calculated. The EXP-Lab re-submit (Split 4) is not included in the median; this is done so as not to give EXP-Lab the advantage of contributing twice to the median. A new analyte 4E is calculated for each laboratory by adding Pt + Pd + Au + Rh. In the case of GC-Lab, the median Au is used to make up the 4E. For Check-Lab the median Rh results is added to make up the 4E calculation, this is because the Check-Lab does not analyse for Rh.

For each sample the laboratory % systematic error (or rather % difference from the median) was calculated using the formula:

$$\textit{Lab \% difference} = \frac{(Lab\ result - median)}{median}\ x\ 100$$

As well as the g/t systematic error (or rather g/t difference from the median) was calculated using the formula:

$$\textit{Lab g/t difference} = \frac{(Lab\ result - median)}{median}$$

The complete data set is then sorted by the 4E median grade.

For each laboratory / analyte, a group average is calculated using for example 11 results; records 1-11, next the group average for records 2-12, etc. This is done for the Lab %difference as well as the Lab g/t difference. These group averages are then plotted against the median of the particular element, with 4E g/t on the x-axis.

Table 4-2 in section 4.3 presents the parameters used for the 4-way check program for exploration samples.

4E g/t comparisons, such as the 4-way check data comparisons are very useful to understand any systematic errors that originate at the laboratories. These systematic errors cannot be reduced by analysing more samples (unlike random error). These systematic errors will introduce differences between the grade control model and the long term resource model.

Converting 4E information into individual element information:

The laboratory calibrates and analyses for the individual platinum group metals. Therefore, the systematic errors need to be quantified at individual element level (that is Pt, Pd, Au and Rh). In order to visually represent the systematic error between laboratories, four different graphs were constructed using the same data for each element namely:

- 2 graphs in terms of (on y-axis) % difference
    - graph – top left and right respectively
        - Left graph's x-axis in terms of 4E g/t
        - Right graph's x-axis in terms of "analyte" g/t e.g. Pt g/t
- 2 graphs in terms of (on the y-axis) g/t difference
    - graph – bottom left and right respectively
        - Left graph's x-axis in terms of 4E g/t
        - Right graph's x-axis in terms of "analyte" g/t e.g. Pt g/t

The format of these graphs were constructed in this particular way for specific reasons:

- The end-user of the data view the data in 4E g/t terms (needing to understand errors at the different GCDPs), top and bottom *left* graphs are relevant, *with 4E g/t* as the x-axis
- The laboratories view the data in terms of "element" g/t terms (needing to understand errors on an individual element level, top and bottom *right* graphs are relevant, with *element in absolute terms* (e.g. Pt g/t) as the x-axis

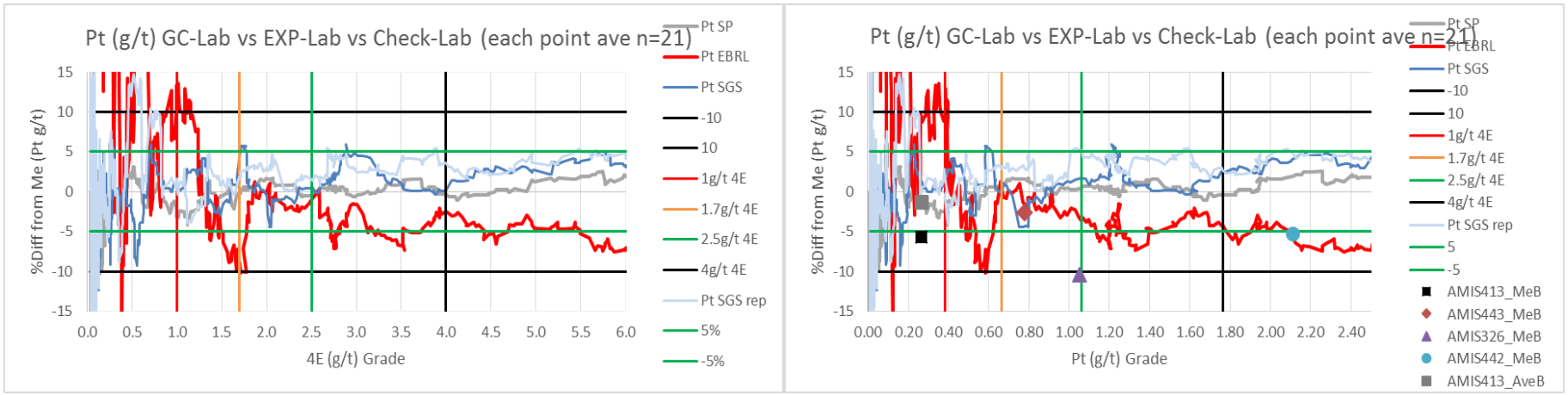


Figure 7-26 Pt systematic error profile (% diff) on the y-axis and 4E g/t on the x-axis (left graph), Pt g/t on the x-axis (right graph)

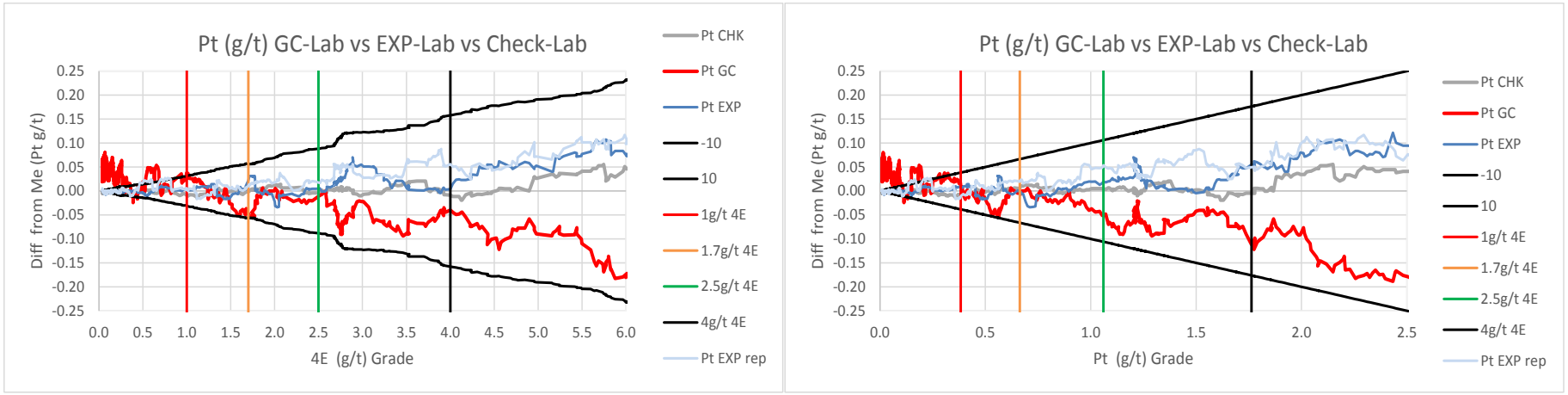


Figure 7-27 Pt systematic error profile (g/t diff) on the y-axis and 4E g/t on the x-axis (left graph), Pt g/t on the x-axis (right graph)

Percent differences at very low grades could be extremely high. It is therefore useful to present these differences in “actual” concentration (that is g/t) as well as in % terms.

- To quantify differences at very low grades (grades < 10x DL of the method), it is useful to rather refer to bottom left and right graphs in absolute terms, g/t on the y-axis
- To quantify differences at higher grades (grades > 10xDL of the method), it is useful to refer to top left and right graphs in percentages, % difference on the y-axis

See section 7.5.4.1 and 2 for Pd and Rh graphs (figure 7-30 & 7-31 and 7-32 & 7-33)

Figure 7-28 (4E g/t) and figure 7-29 (%Diff 4E) are similar graphs constructed using 4E as analyte. It is clear from these graphs that the analytical systematic error between laboratories differ significantly over the grade range of the ore.

- *At grades <0.5 g/t 4E the GC Lab report 0.2 - 0.1 g/t 4E high*
  (the % systematic error is much >> 10 %, noise range of the method)
- *At grades >0.75 g/t 4E the GC Lab report within 10 % of the Check and EXP Lab*
- *All three laboratories compare best (within ± 5 %) at grades between 1.25 - 2.5 g/t 4E*
- *At grades >2.5 g/t 4E; the EXP-Lab report < Check-Lab report < GC-Lab (within 5 %)*
- *At grade >5.5 g/t the GC-Lab report results with a systematic error >- 5 % & < -10 %*
- *The difference between the GC-Lab and the EXP-Lab at grades >5.5 g/t 4E is ~10 %*

Below are the graphs for the laboratory differences from the median (sorted by 4E g/t grade).

The black horizontal lines represent ± 10 % error and the green horizontal line represent ± 5 % error in the graphs below.

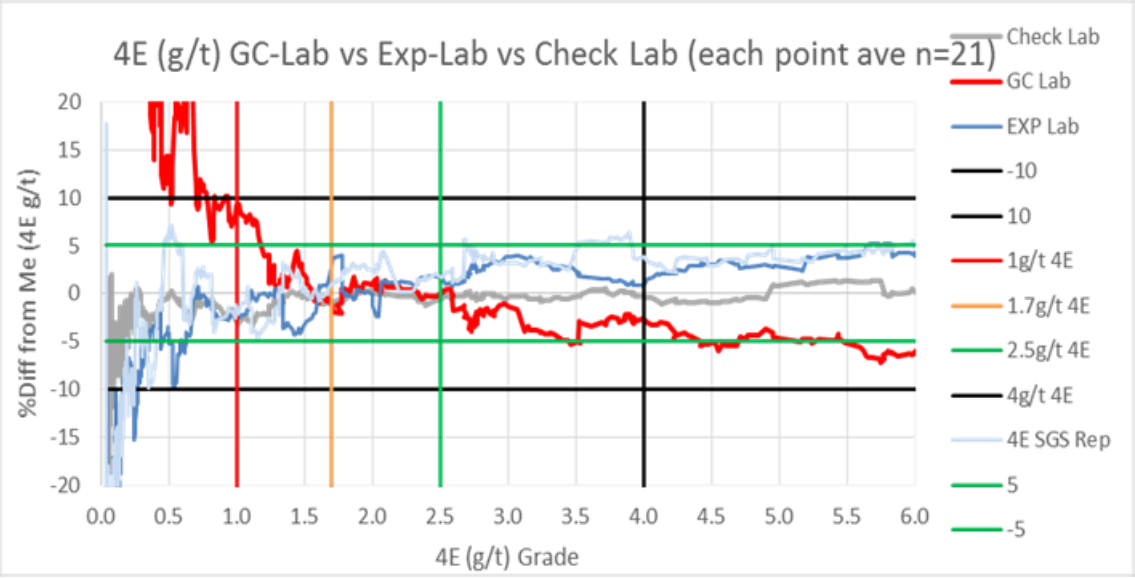


Figure 7-28 Analytical systematic error profile using 4-way check data (data set-3), % diff 4E on the y-axis and 4E g/t grade on the x-axis

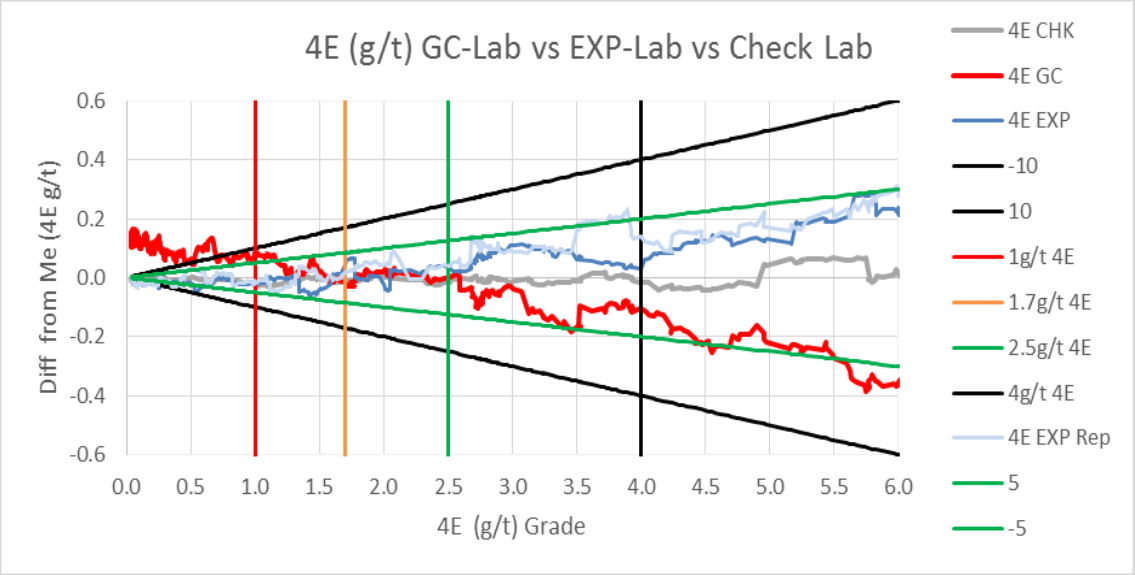


Figure 7-29 Analytical systematic error profile using 4-way check data (data set-3), 4E g/t difference on the y-axis and 4E g/t grade on the x-axis

7.5.4 ”BLIND” CRMs – Data set 8

The systematic error within a laboratory can be determined using the results from “blind” CRMs. It is important to check the findings of the 4-way check program with the finding of the “blind” CRM inserts.

In this study, the results from the 4-way pulp check comparison were superimposed on the “blind” CRM systematic errors in order to determine if the differences identified (with the 4-way check program) are confirmed with the systematic errors identified with the “blind” standards (*see section 7.5.4.1 and 7.5.4.2, graphs on right side of the page*).

For the time period under investigation, 5 “blind” CRMs were inserted between the routine samples submitted to the GC-Lab. The median systematic errors obtained for these CRMs were superimposed on the % difference graphs. Four of the “blind” CRMs used plotted fairly close to the 4-way % difference of the GC-Lab, verifying that the 4-way data set is a good estimator for laboratory systematic errors. Systematic errors for AMIS 326 plotted well below the 4-way difference line (red line on the graphs) for the GC-Lab. It is possible that the CRM consensus value (CV) assigned to the AMIS 326 certificate could be incorrect or the systematic error at the GC-Lab is underestimated at this grade using the 4-way check program. *It is recommended that the certification of AMIS 326 be investigated*. This can be done by comparing the performances of other laboratories using this CRM or investigating the certification methodology of the CRM.

Table 7-20, present the performance of the GC-Lab on the inserted “blind” CRMs. Biases for AMIS326 are highlighted because the quantified biases were not in line with the findings of the 4-way check data.

Table 7-20 GC-Lab accuracy performance using inserted “blind” CRMs

GC-Lab				
Std	4E grade	Pt grade	Me Bias	n
AMIS413	0.6	0.3	-5.7	2484
AMIS443	1.9	0.8	-2.6	2302
AMIS326	**2.5**	**1.1**	**-10.5**	**412**
AMIS442	5.0	2.1	-5.2	3012
GC-Lab				
Std	4E grade	Pd grade	Me Bias	n
AMIS413	0.7	0.3	-0.3	2484
AMIS443	2.0	1.0	-1.0	2302
AMIS326	**2.6**	**1.3**	**-6.3**	**412**
AMIS442	5.4	2.7	-3.8	3012
GC-Lab				
Std	4E grade	Rh grade	Me Bias	n
AMIS413	0.8	0.03	4.0	2484
AMIS443	2.3	0.07	2.9	2302
AMIS326	**2.7**	**0.08**	**-4.9**	**412**
AMIS442	6.3	0.19	-4.2	3012

Table 7-21, superimposes the results of the “blind” CRM inserts with the results from the 4-way pulp check assay program in table format.

Table 7-21 GC-Lab “blind” CRMs performances as well as % error calculated using the 4-way check data at the GCDPs

4E grade (g/t		Pt	Pd	
From	To	% error		"blind" CRM
0	0.49	noise	noise	
0.5	0.99	noise	-2.5	
0.6		-5.7	-0.3	AMIS413
1	1.69	-10 to +10	-2.5	
1.7	2.49	-2.5		
1.9		-2.6	-1	AMIS443
2.5	3.99	-5.0	-5	
2.5		-10.5	-6.3	AMIS326
4	5.49	-5.0	-5	
5.4		-5	-3.8	AMIS442
5.5	5.99	-5.2	-5	
6	high	-7.5	-5	

In general, the GC-Lab performs best (within ± 5 %) in the grade range between 1.7 and 2.5 g/t 4E. This is at the grade control waste vs. ore cut-off at 1.7 g/t 4E. The GC-Lab was designed to produce optimal accuracy in this 4E grade range.

In order to communicate %errors to the laboratory, the errors need to be translated into specific individual element errors.

Findings for Pt analysed at the GC-Lab:

- For 4E grades < 1g/t, the GC-Lab Pt grades are in the noise range of the technique
- For 4E grades between 1 - 1.7g/t, the GC-Lab Pt grades are within ± 10 % error
- For 4E grades between 1.7 - 2.5 g/t, the GC-Lab Pt grades within ± 5 % error
- For 4E grades between 2.5 - 5 g/t, the GC-Lab Pt grades are - 5 % low
- For 4E grades > 5 g/t, the GC-Lab Pt grades are > - 5 % low

Findings for Pd analysed at the GC-Lab:

- For 4E grades < 0.5 g/t, the GC-Lab Pd grades are in the noise range of the technique
- For 4E grades between 0.5 to 2.5 g/t, the GC-Lab Pd grades are within ± 5 % error
- For 4E grades between 2.5 g/t and higher, the GC-Lab Pd grades are - 5 % low

7.5.4.1 LABORATORY SYSTEMATIC ERROR FOR PALLADIUM – using the 4-way check data

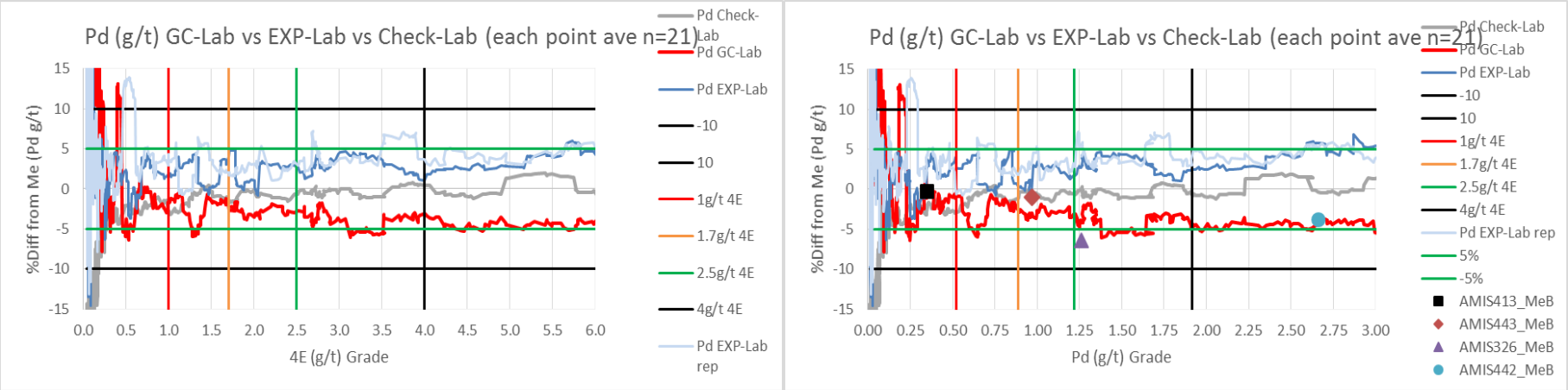


Figure 7-30 Pd systematic error profile (% diff) on the y-axis and 4E g/t on the x-axis (left graph), Pd g/t on the x-axis (right graph)

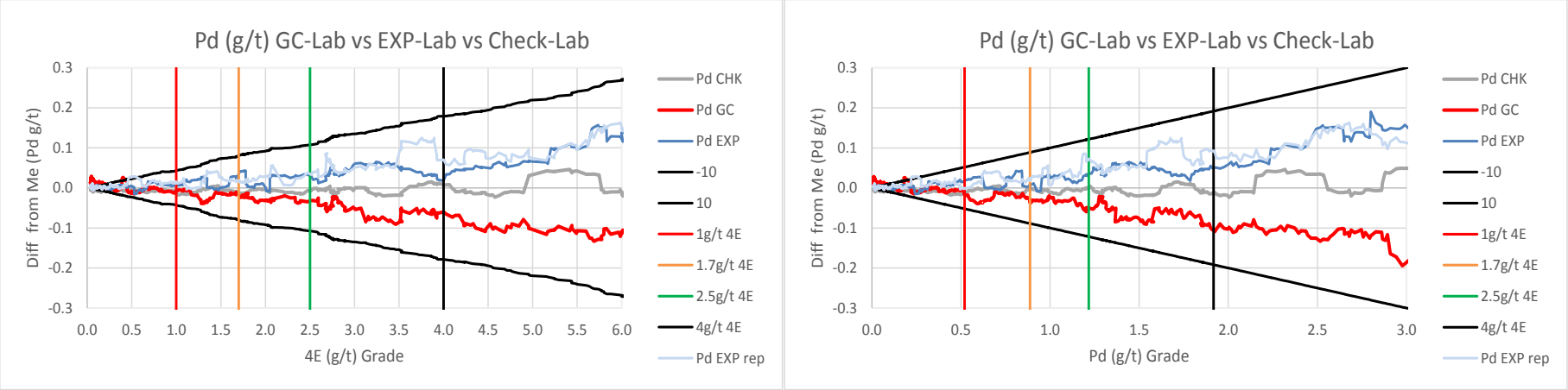


Figure 7-31 Pd systematic error profile (g/t diff) on the y-axis and 4E g/t on the x-axis (left graph), Pd g/t on the x-axis (right graph)

7.5.4.2 LABORATORY SYSTEMATIC ERROR FOR RHODIUM – using the 3-way check data

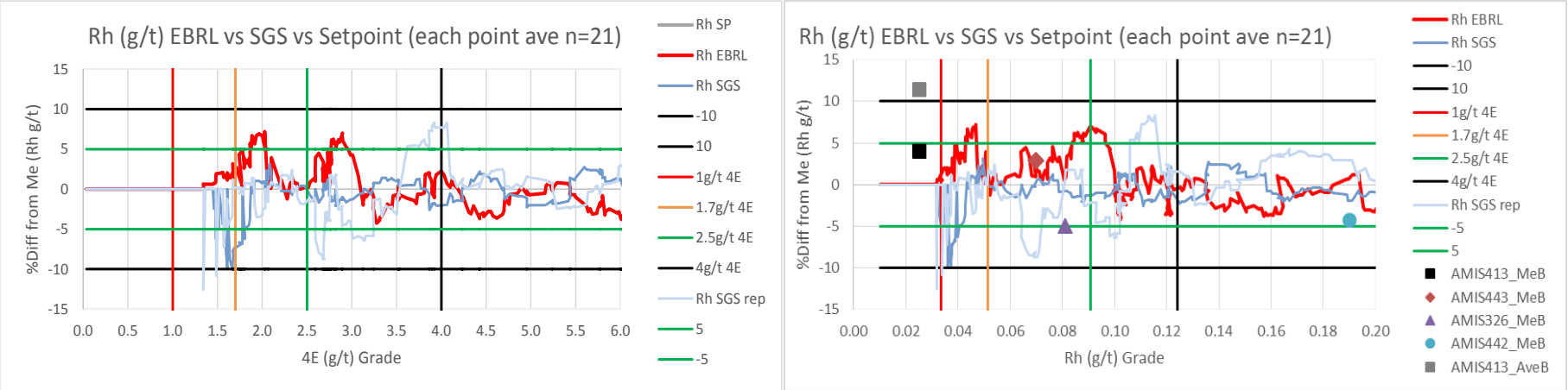


Figure 7-32 Rh systematic error profile (% diff) on the y-axis and 4E g/t on the x-axis (left graph), Rh g/t on the x-axis (right graph)

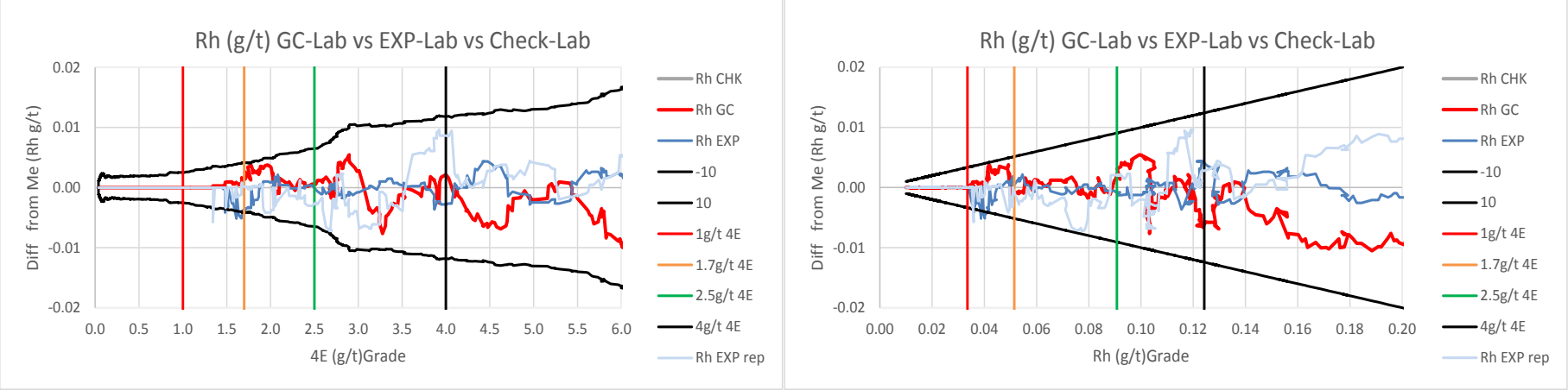


Figure 7-33 Rh systematic error profile (g/t diff) on the y-axis and 4E g/t on the x-axis (left graph), Rh g/t on the x-axis (right graph)

7.5.5 GRADE CONTROL CHECK DATA - Data set 4

The Analytical error is measured between two laboratories analysing a split of the same pulp sample (after the sample particle size of each sample was reduced to 80 % less than 75 micrometres). This error excludes sample preparation and sampling errors. The error is generated from the analytical laboratory / technique used to analyse the sample.

The 4th data set used to quantify analytical systematic error in this study, is the 2-way grade control check program data (data set 4). The GC-Lab submits some samples (n = 75) from its routine RC samples as check samples to the Check-Lab on a monthly basis. The results reported by the GC-Lab are compared with the result reported by the Check-Lab for these samples, in order to quantify the systematic error between the 2 laboratories.

Due to the volume of information, only platinum and SG are discussed in this report.

Findings for platinum: (see figure 7-34, 7-35)

The laboratory only selects samples with a maximum grade of 3 g/t Pt as check samples. Thus the systematic errors at higher grades cannot be quantified using this data set.

Extremely good comparison (within ± 2.5 % error) between GC-Lab and Check-Lab at grades between 1 g/t and 1.7 g/t 4E for Platinum. This is different from the 4-way check lab data set which indicate a ± 10 % error at this grade.

The only difference between the 2 data sets are the selection criteria:

- For the 4-way data set, samples are taken on a purely random basis
- For the 2 way data set, the laboratory selects samples at a selected grade; this may introduce a selection error

Findings for SG: An interesting observation was made with SG (see figure 7-36, 7- 37)

For the 2 way data set a + 2% Systematic error is observed between the GC-Lab and the Check-Lab. For the 4-way data set, *no Systematic error* was observed between the 3 laboratories. For the 4-way data set, samples are prepared at the Check-Lab and introduced as a pulp into the GC-Lab. For the 2 way data set, samples are prepared at the GC-Lab.

Thus the sample preparation systematic error identified in section 7.4 at the GC-Lab for RC type samples, are confirmed in this 2-way check data set.

7.5.5.1 PLATINUM - 2 Lab systematic error comparisons (GC-Lab vs. Check-Lab):

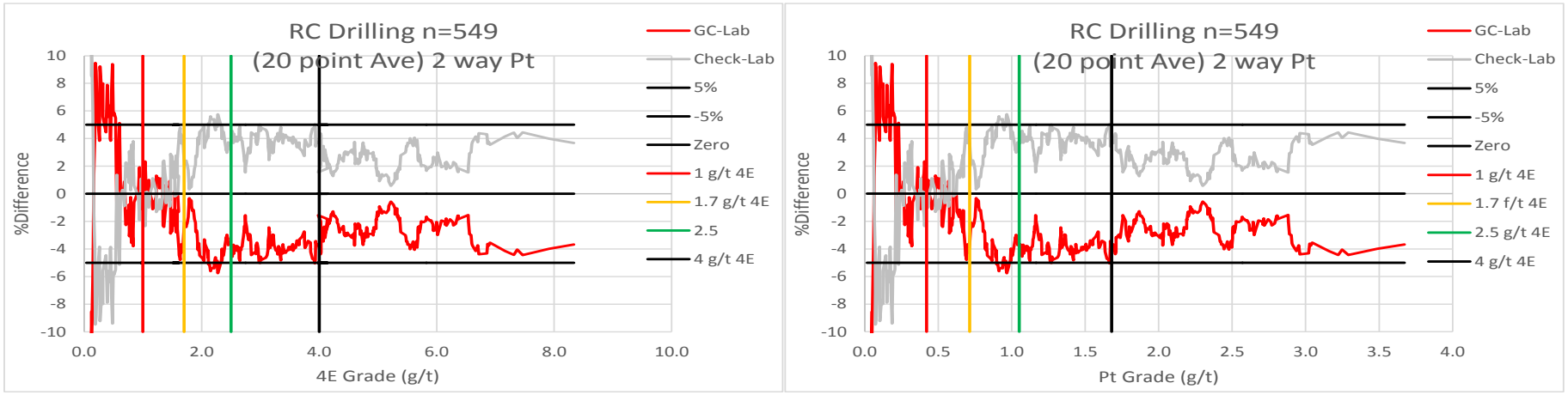


Figure 7-34 Pt systematic error profile (% diff) on the y-axis and 4E g/t on the x-axis (left graph), Pt g/t on the x-axis (right graph)

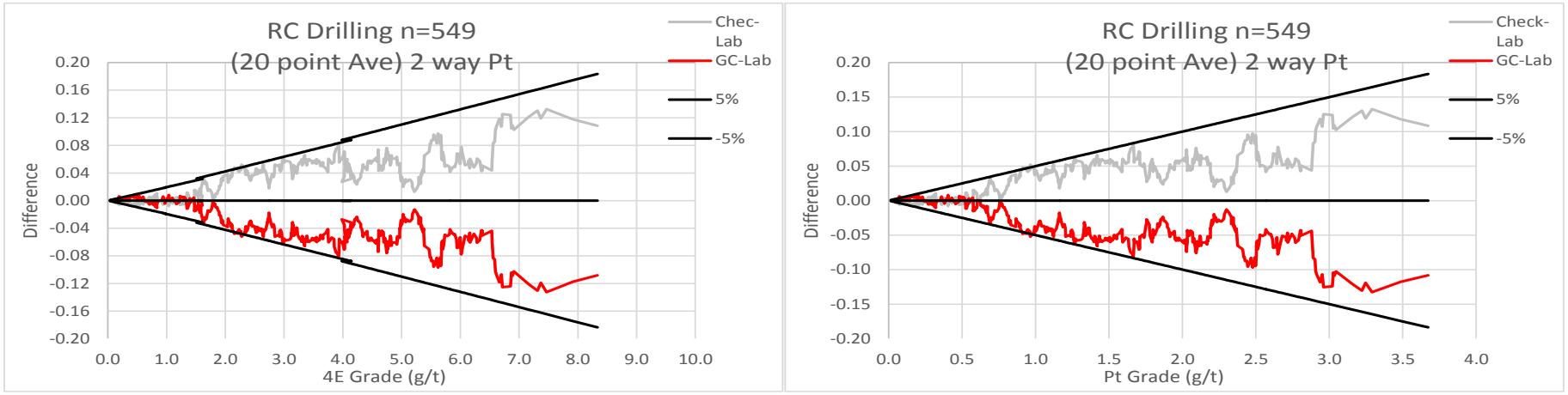


Figure 7-35 Pt systematic error profile (g/t diff) on the y-axis and 4E g/t on the x-axis (left graph), Pt g/t on the x-axis (right graph)

7.5.5.2 SG - Comparisons (GC-Lab vs. Check-Lab):

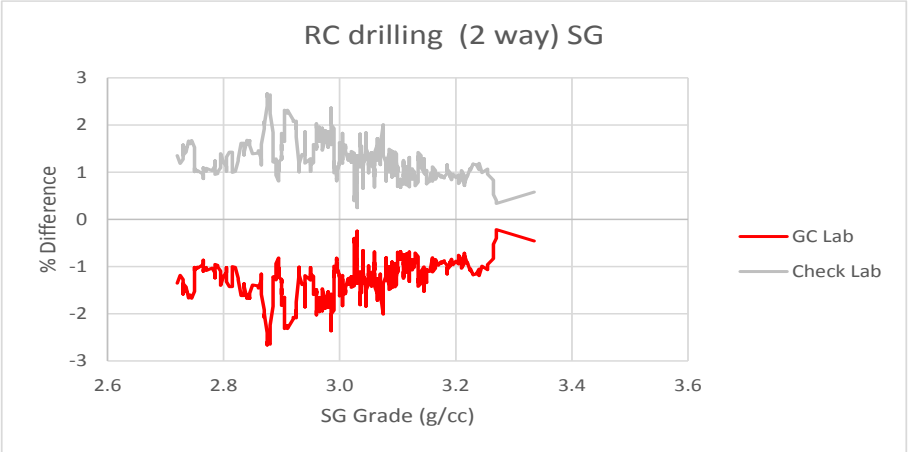


Figure 7-36 SG systematic error profile (% diff) on the y-axis and SG grade on the x-axis for RC sampling using 2- way check data

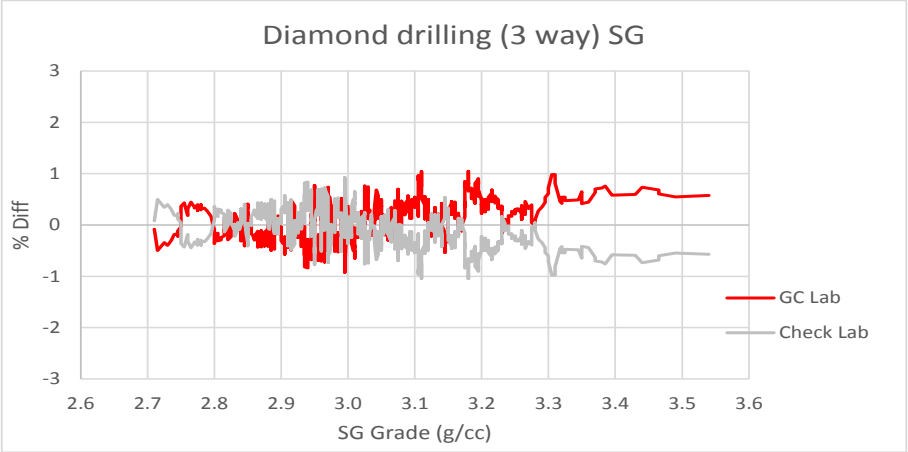


Figure 7-37 SG systematic error profile (% diff) on the y-axis and SG grade on the x-axis for BQ sampling using 3-way check data

7.5.6 SUMMARY OF ANALYTICAL SYSTEMATIC ERROR

The analytical systematic errors at the GC-Lab is *not consistent across the ore grade range;*

- "+" at grades < 1 g/t 4E
- within ± 1% between grades 1 to 1.7g/t 4E
- "-" error at grades > 1.7 g/t 4E

The average analytical systematic errors between GC-Lab and EXP-Lab at the GCDPs, are presented in an uncertainty table, table 7-22.

Table 7-22 Analytical systematic errors at the GC-Lab and the EXP-Lab highlighted in red, with the pay limit cut off highlighted in green

4E g/t Uncertainty Table			Systematic Error														
as % Error	4E g/t		SAMPLING		Action of taking a Sample		Prep within RC		Prep within BQ		Analytical within RC		Analytical within BQ		Analytical only		
Ore classification:	From:	To:	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	EXP check data	Blind CRMs (Pt, Pd)	RC check data
Waste	0	0.99													> + 10%	-6%, -0.3%	+large
Very low grade ore (VLGO)	1	1.69		50%		+ 5%		+ 18%		+ 42%		+ 47%		+ 58%	+10 to 0%		+ 5%
Low grade ore (LGO)	1.7	2.49		+1%		+		- 15%		- 3%		- 10%		- 2%	± 1%	-2.6%, -1%	< ± 2 %
Medium grade ore (MGO)	2.5	4	-11%	-10%	-4%	- 8%	-8.0%	- 9%	-3.5%	- 5%	-7%	-2%	-6%	- 10%	-2.5%	- 11 %,-6%	- 4%
High grade ore (HGO)	4	above		-8%		+1%		- 9%		- 7%		- 10%		- 9%	- 5%	-5%,-3.8%	- 10%
High grade ore (HGO)	5.5	above		-18%		-11%		- 5%		- 6%		- 6%		- 8	- 7%		- 8%
High grade ore (HGO)	10	above		-18%		-11%		- 7%		- 2%		- 7%		- 7%			- 5%

7.6 SUMMARY OF SYSTEMATIC ERROR

7.6.1 FINDINGS

The differences between grade control (GC) and exploration (EXP) sampling protocols were found to change in magnitude and “sign” across the 4E ore grade range. Grade control sampling over report at grades below 1.7 g/t 4E and under-report at grades above 2.5 g/t 4E when compared with ore grades obtained with exploration sampling. The differences between the two sampling techniques are the smallest at ore grades between 1.7 and 2.5 g/t 4E.

The average differences between grade control (GC) vs. exploration (EXP) at the GCDPs are summarised below:

- At 1g/t 4E GC is + 0.2 g/t higher than EXP (~ + 50 %)
- At 1.7g/t 4E GC is ~ -1 % higher than EXP (+ 0.1 g/t 4E)
- At 2.5 g/t 4E GC is ~ - 10 % lower than EXP (- 0.2 g/t 4E)
- At 4 g/t 4E GC is ~ - 8 % lower than EXP (- 0.4 g/t 4E)
- At > 5.5 g/t 4E GC is ~ - 18 % lower than EXP (- 1 g/t)

The total average sampling (sampling, sample prep as well as analytical) difference between grade control (RC / GC-Lab) and exploration (BQ / EXP-Lab) sampling protocols were estimated to be -11 % 4E. At grades >5.5 g/t 4E the differences are a much as -18 % 4E.

The average differences between grade control and exploration sampling were disseminated into its contributing parts, mainly using the 3-way twin hole program data set.

The average, contributions to the 4E difference between GC and EXP are estimated as:

- RC sampling technique contributing - 4 %
- Resultant robotic sample preparation (GC-Lab) - 7.2 %
    - measured using RC sampling - 8 %
    - measured using BQ sampling - 3.5 %
- Analytical technique (GC-LAB) – 6 %
    - At 1.7 to 2.5 g/t 4E ore grade, the analytical systematic errors between the GC-Lab and the EXP-Lab are the smallest (within < ± 2 %)
    - At grade > 4 g/t 4E ore grade, the analytical systematic errors between the GC-Lab and the EXP-Lab are the largest (~"- " 10%)

7.6.2 SYSTEMATIC ERROR EFFECT ON THE MINING BLOCK

Systematic errors have a direct effect on the uncertainty of the grade assigned to the mining block. These errors cannot be reduced by averaging more samples. The average systematic errors between the exploration and grade control sampling were quantified into its individual components as well as across the grade range of the ore.

For grade control purposes, the systematic error are the smallest (within ± 2 %) between grades 1.7 to 2.5 g/t 4E. This grade range, is the critical grade for grade control because a decision to stock pile or to process the ore is made at this grade (Paylimit = 2.5 g/t 4E).

For reconciliation purposes, the systematic errors quantified are with the "warning zone" of acceptance, when compared to the business objectives (defined in table 1-1) for the reconciliation of the long term resource model vs. grade control models.

8. CONCLUSIONS AND RECOMENDATION

8.1 CONCLUSION

It has become necessary to clearly understand the weakest link in the sampling chain (that is, the action of taking the sample, sample preparation and analytical). The highest contributing components in the uncertainty of a sampling measurement, need to be quantified so as to identify opportunities where quality can be improved. The components in sampling can be considered as an interlinked chain of events, each contributing to the overall quality.

The measuring system for grade control at the mine consists of seven sampling chain components:

I. Reverse circulation *primary sampling*
II. *Sub-sampling* using gravity fall through a rota-port cone and rotating splitter
III. Automated *sample preparation* at the grade control laboratory (GC-Lab)
IV. *Analyses* at the GC-Lab using a Spark-OES analytical method
V. Importing assays into the d*atabase*
VI. C*alculation of the 4E grade*
VII. *4E grade assignment* to the mining block

The first four components in the sampling chain were investigated using eight data sets. Five out of the eight data sets available, were focused on analytical errors. These errors are easier to quantify, than errors related to taking a sample. It is for this reason, that analytical errors traditionally, receive more focus. Management must be applauded for investing in projects such as the heterogeneity test work[(5)] and the twin hole project, introduced at the mine[(20,8,)]. These sets of test work, reveal uncertainties in sampling components that do not receive much focus, due to the cost involved in quantifying these.

The differences between grade control (GC) and exploration (EXP) sampling protocols were found to change in magnitude and “sign” across the 4E ore grade range. Grade control sampling over-report at grades below 1.7 g/t 4E and under-report at grades above 2.5 g/t 4E when compared with ore grades obtained with exploration sampling. The differences between the two sampling techniques are the smallest at ore grades between 1.7 and 2.5 g/t 4E.

Table 8-2 is a summary of all the *random errors* (highlighted in red) quantified in this study. Sampling (the action of taking a sample) random errors were at least twice the random errors quantified at the laboratories. The overall random error is reduced by a factor of 7.75, due to the effect of averaging 30 samples (analysed in duplicate) to assign grade to a mining block. Although this factor reduces the random error sufficiently, the large errors within the individual

samples (n = 1), at 1 g/t 4E are large and thus still present a risk of incorrect classification of the ore at this grade (Waste vs. VLGO).

All sampling components investigated presented s*ystematic errors* (see table 8-1; large errors were highlighted in red, with small errors highlighted in green). The largest systematic error being the error for RC samples that occur during the sample preparation step at the GC-Lab. This error is related to the physical properties (e.g. the amount of fines present) of the sample. The average sampling (the action of taking a sample) and analytical systematic errors were similar, "-" 5 % and "-" 6 %, respectively. Systematic errors are additive and cannot be reduced by averaging more assays (unlike random error). These errors have their origin in the "design" of the sampling protocol; sampling and analytical techniques/procedures and fall under the quality assurance component of a QAQC program.

For grade control purposes, the systematic errors are the smallest (within ± 2 %) between grades 1.7 to 2.5 g/t 4E. This grade range, is the critical grade for grade control because a decision to stock pile or to process the ore is made at this grade (Paylimit = 2.5 g/t 4E).

The systematic errors quantified are with the "warning zone" of acceptance, when compared to the business objectives (defined in table 1-1) for the reconciliation of the long term resource model with grade control models. Resources invested into the resolution of systematic errors are well spent.

This study showed that the errors obtained with RC drilling and Spark analytical technique are very large at grades less than 1.7 g/t 4E. Thus the grade control sampling technique used cannot distinguish between waste and VLGO ore.

8.2 RECOMMENDATIONS

All grade control sampling components in the sampling chain pose an opportunity for improvement.

Increasing the sample mass after sub-sampling at the RC rig:

The sample cups are designed to collect the maximum sample mass required by the GC-Lab. This sample mass is not a representative sample of the bulk RC drill hole; Harley (2017)[9]. Alternatively, decreasing the drilling depth per sample (e.g. 2.5 m to 1.25 m) will have the effect of improving the representativeness of the sub-samples.

Re-design of the sampling cups:

Improving the geometry of the sample cups to comply with best practice theory of sampling e.g. the lips of the sample cups should be 45 degree edging and the edges of the cups should not be bent.

Protect the integrity of the sample:

If a coarse fraction of the sample is taken out of the sample intended for the laboratory, the sample will have been compromised. The fragment should be taken from the bulk reject or 3rd sample cup.

Optimize RC drilling speed:

Mohanlal (2017)[20], presented test work on site by the drilling contractor has indicated that reduced drilling speed, increases the size of the cutting fragments of the sample (figure 8-1). This, in turn, reduces the amount of fines produced in the final sample. Systematic errors increase with loss of fines. Reducing the drilling speed would not have a negative effect on RC sampling production. It will also have a positive effect on the wear and tear of the sampling equipment e.g. drill bits.



Figure 8-1 Effect of drilling rotation speed on sample fineness, demonstrating slower drilling speed produce sample chips with coarser factions

Particle size analysis:

Regular particle size analyses will provide a quality control on the particle size of the samples, thus monitoring effective drilling speed.

Speed of the rota-port cone splitter:

The speed of the cone splitter should be reduced, in order to reduce the centrifugal force of the rotation while still maintaining the minimum required sample cuts, as suggested in ToS.

Placement of the cone splitter under the falling stream:

The rota-port cone splitter should be perfectly centered under the falling stream.

Primary sample (RC drill hole) to sub-sample mass ratio:

The required ratio of primary sample to sub-sample mass needs to be calculated and monitored.

Field sub-sampling duplicates:

The Random error between field sub-sampling duplicates needs to be monitored on a regular basis, thus monitoring sub-sampling efficiency.

Sample aliquot increase:

The heterogeneity test work done at the mine, recommended that the sample aliquot (Barr, et al. 2016)[(5)] needed to be increased to the maximum ratio of sample aliquot to flux. The effect on the reduction in random errors at the GC-Lab needs to be quantified.

Sample preparation at GC-Lab:

The study revealed that the sample loss at the GC-Lab for RC sampling is significantly more than the sample loss for BQ sampling. This is indicating that the physical property of the sample (e.g. number of fines) introduced into the sample preparation stage of the process may be the cause of this error. Test work needs to be done to determine if eliminating the drying and or crushing components of the sample preparation procedure will result in a reduction in this error.

Manual sample preparation:

The introduction of a “pulp” sample into the GC-Lab, produce results with significantly smaller systematic errors. The feasibility of introducing a manual sample preparation step should be investigated.

Analytical technique comparison:

The mine requires a 24-hour turnaround time for large volumes of samples. The only analytical technique that can compare with the Spark-ICP technique (with regard to this requirement), is the gravimetric analysis of 4E g/t. A comparison of these 2 techniques is required to ensure that the Spark-ICP technique is still the best option available for grade control.

Modification of grade control decision points:

Grade control sampling (RC drilling and Spark analytical technique) cannot distinguish between grades < 1.7g/t 4E. It is thus recommended that the waste and VLGO grade groups be combined as waste.

Further investigation in the systematic errors:

The type of systematic error found for each sampling component needs to be investigated for its proportionality or dependence on analytic concentration and sample size. Such information can then be used to identify the underlying root cause for these errors.

Measuring these errors is the first step towards reduction or elimination of error.

Table 8-1 Summary of all systematic sampling errors quantified in this study

4E g/t Uncertainty Table			Systematic & Random error			Systematic Error														
as % Error	4E g/t		All	Analytical		SAMPLING		Action of taking a Sample		Prep within RC		Prep within BQ		Analytical within RC		Analytical within BQ		Analytical only		
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	Ave	at GCDPs	EXP check data	Blind CRMs (Pt, Pd)	RC check data
Waste	0	0.99		27%	12.5%													> + 10%	-6%, -0.3%	+large
Very low grade ore (VLGO)	1	1.69					+ 50%		+ 5%		+ 18%		+ 42%		+ 47%		+ 58%	+10 to 0%		+ 5%
Low grade ore (LGO)	1.7	2.49					+ 1%		+ 12%		- 15%		- 3%		- 10%		- 2%	± 1%	-2.6%, -1%	< ± 2 %
Medium grade ore (MGO)	2.5	4	30%	17%	7.6%	-11%	- 10%	-4%	- 8%	-8%	- 9%	- 3.5%	- 5%	-7%	- 2%	- 6%	- 10%	-2.5%	- 11 %,-6%	- 4%
High grade ore (HGO)	4	above					- 8%		+ 1%		- 9%		- 7%		- 10%		- 9%	- 5%	-5%,-3.8%	- 10%
High grade ore (HGO)	5.5	above					- 18%		- 11%		- 5%		- 6%		- 6%		- 8	- 7%		- 8%
High grade ore (HGO)	10	above					- 18%		- 11%		- 7%		- 2%		- 7%		- 7%			- 5%

Table 8-2 Summary of all sampling random errors quantified in this study for single analysis (n = 1)

4E g/t Uncertainty Table			Systematic & Random error			Random error					
as % Error	4E g/t		All	Analytical		Sampling		Analytical	Sampling	Sub-Sampling	Analytical
Ore classification:	From:	To:	Overall error	Between pulps (at GC lab)	Between pulps (all Labs)	Between 1/2 NQ core	Within sampling technique	Between pulps	Intrinsic Heterogeneity	Field dups (at GC Lab) for 3E	Between reps (at GC Lab) for 3E
Waste	0	0.99	30%	27%	12.5%	± 14%	± 10%	± 6%	± 6.1	± 22.4%	± 16.9%
Very low grade ore (VLGO)	1	1.69								± 14.3%	± 10.5%
Low grade ore (LGO)	1.7	2.49								± 10.6%	± 7.6%
Medium grade ore (MGO)	2.5	4		17%	7.6%					± 7.7%	± 5.3%
High grade ore (HGO)	4	above								< ± 7 %	< ± 5%

9. REFERENCES

1. Amira P754 (2004), pp37.
2. *Annual Report*. (2015). Anglo Platinum available at: http: // www. angloamericanplatinum. com /
3. AOCS *Evaluation and design of Test Methods*, (2017). Determination of Precision of Analytical Methods. AOCS Procedure M 1-92. Available at: https: // www.aocs.org /Documents/ TechnicalPDF /m1_92.pdf /
4. Atlas Copco. *An introduction to reverse circulation drilling*. Talking Technically. Available at: https:// www.scribd.com/document/179709238/an-introduction-to-reverse-circulation-drilling-pdf /
5. Barr, J. Woollam, M. Roux, J. and, et al. (2016). *Optimization of Mogalakwena RC Ore Control Sampling*. Johannesburg: Anglo American Platinum internal report, JMB505.
6. Carrasco, P. and Jara, E. (2003). *The economic impact of correct sampling and analysis practices in the copper mining industry*. Esbjerg, southwest Denmark: First World Conference on Sampling and Blending.
7. Gerlach, R. and Martin, L. and Nocerino, J. (2003). *Guidance for obtaining representative Laboratory Analytical subsamples from particulate Laboratory samples*, United States Environmental Protection Agency. Washington, DC: Office of Research and Development Publications.
8. Gy, P. (1995). Introduction to the theory of sampling I*. Heterogeneity of a population of uncorrelated units*. Cannes, France: Trends in Analytical Chemistry. Vol 14 (2).
9. Harley, M. (2017). *RC-DD Twin hole study*. Johannesburg: Anglo American Platinum internal presentation.
10. Holmes, R. (2010). *Sampling mineral commodities-the good, the bad and the ugly*. Johannesburg: The Journal of the Southern African Institute of Mining and Metallurgy, Vol 110.
11. Langa, Z. (2014a). Mineral Resource Management Geoscience, *Management of RC drilling and Sampling in Open pit operation*. South Africa: Anglo American Platinum internal group standard.
12. Langa, Z. (2014b). *Mineral Resource Management In-pit Grade Control Sampling, Quality Assurance and Quality Control Procedures*. South Africa: Anglo American Platinum internal group standard.
13. Mashabela, S. and Bosch, D. (2016). *Mine Twinning Exercise*. Johannesburg: Anglo American Platinum internal report.
14. Minnitt, R. (2007). Sampling: *The impact on cost and decision making*. Johannesburg: Journal of the Southern African Institute of Mining and Metallurgy. Vol107 (7). pp.451.

15. Minnitt, R. (2017). *Poor sampling, grade distribution, and financial outcomes*. Johannesburg: Journal of the Southern African Institute of Mining and Metallurgy. Vol117 (2).
16. Minnitt, R. and Bonsu, A. (2010). *A comparison between the duplicate series analysis method and the heterogeneity test as methods for calculating the sampling constants, K and alpha*. Johannesburg: Journal of the Southern African Institute of Mining and Metallurgy. Vol 110 (6). pp. 251-268.
17. Minnitt, R. and Pitard, F. (2015). Sampling in the Minerals Industry. *Introduction to Sampling Theory and Sampling Practices*. Johannesburg: University of the Witwatersrand.
18. Minnitt, R., Rice, P. and Spangenbergs, C. (2007a). Part 1: *Understanding the components of the fundamental sampling error: a key to good sampling practice*. Johannesburg: Journal of the Southern African Institute of Mining and Metallurgy. Vol 107 (8). pp. 505.
19. Minnitt, R., Rice, P. and Spangenbergs, C. (2007b). Part 2: *Experimental calibration of sampling parameters K and alpha for Gy's formula by sampling tree method*. Johannesburg: Journal of the Southern African Institute of Mining and Metallurgy. Vol 107 (8). pp. 513.
20. Mohanlal, K. (2017). *Twin Drilling Project*. Johannesburg: Anglo Platinum internal project minutes.
21. Pitard, F. (1989a). Pierre Gy's Heterogeneity Sampling Theory and Sampling Practices. *Heterogeneity.* Boca Raton, FL: CRC Press. Vol1.
22. Pitard, F. (1989b). Pierre Gy's Sampling Theory and Sampling Practices*. Sampling Correctness and Sampling Practices.* Boca Raton, FL: CRC Press. Vol2.
23. Pitard, F. (1993). Pierre Gy's Sampling Theory and Sampling Practice. *Heterogeneity Sampling correctness and Statistical Process Control.* 2cd Edition. Boca Raton, FL: CRC Press.
24. Pitard, P. (2008). *Blasthole sampling for grade control-The many problems and solutions.* Melbourne: Sampling Conference. Journal of the Australasian Institute of Mining and Metallurgy Conference.
25. Schouwstra, R. De Vaux, D. and Muzondo,T., et al. (2013). *A Geometallurgical Approach at Anglo American Platinum's Mine Operation.* Brisbane, QLD: The second AUSIMM international Geometallurgy conference, pp 85-92.
26. South African Mineral Resource Committee working group. (2009). *Samrec code*. Available at: http: // www.samcode.co.za/ .
27. Spangenberg, I. and Minnitt, R. (2014). *An overview of sampling best practice in African mining.* The Journal of the Southern African Institute of Mining and Metallurgy, Vol 114.

28. Stanley, C. (2006). *The special application of the Thomson-Howarth error analysis to geochemical variable exhibiting a nugget effect.* London: Geochemistry Exploration, Environment, Analyst. Vol 6, pp 357-368.
29. Stanley, C. and Lawie, D. (2007a). *Average Relative Error in Geochemical Determinations: Clarification, Calculation and a Plea for Consistency.* Canadian Institute of Mining, Metallurgy and Petroleum. Canada: Exploration and Mining Geology, Vol16 (3-4), pp. 267-275.
30. Stanley, C. and Lawie, D. (2007b). *Thompson-Howarth error analysis: unsystematic errored alternatives to the large-sample method for assessing non-normally distributed measurement error in geochemical samples.* Geochemistry Exploration, Environment, Analyst. Vol.8. pp173-182.
31. Thompson, M. and Howarth, R. (1973). *The rapid estimation and control of precision by duplicate determination*, Part 2. Analyst, Vol 98 pp. 153-160.
32. Thompson, M. and Howarth, R. (1976a). *Duplicate Analysis in Geochemical Practices, Part 1. Theoretical approach and estimation of analytical reproducibility.* Analyst, Vol 101 pp. 690-698.
33. Thompson, M. and Howarth, R. (1976b). *Duplicate Analysis in Geochemical Practices, Part 2. Examination of proposed method and examples of its use.* Analyst, Vol 101 pp. 699-709.
34. Thompson, M. and Howarth, R. (1977). *A new approach to the estimation of Analytical precision.* Imperial College, Geochemistry Research group. The Netherlands: Elsevier Scientific Publishing Company.
35. U.S. Environmental Protection Agency (2006). *Guidance on Planning using the Data Quality Objectives Process.* EPA QA/G-4. Washington DC: Available at: https: // www.epa.gov / quality /.