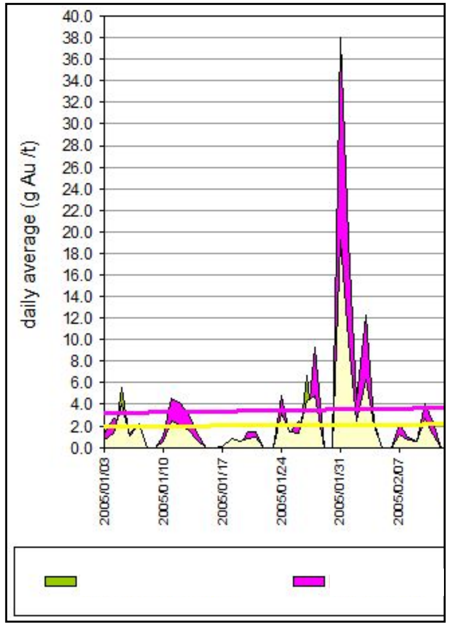
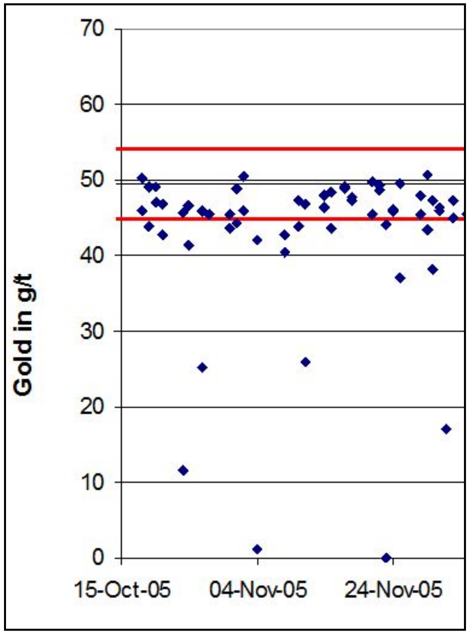
Quality Assurance and Quality Control





Presented: James Dendle

Date: 29/11/2011

Location: Park Plaza

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Content:

Definitions and Principles – why implement QAQC?

Types of QAQC:

- Drilling
- Survey (downhole, collars)
- Geological logging (structural data collection)
- Density analysis
- Sample preparation
- Laboratory analysis
- Database and sample management

What QAQC data to we deal with?

SRK QAQC analysis

- What is required?
- How is the analysis done?

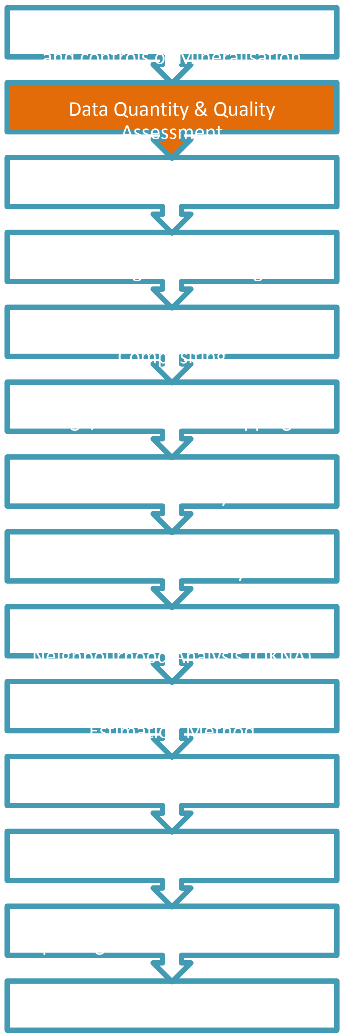
Auditing labs and preparation facilities – what to look for

Summary

QAQC covers all data capture from drillhole collars to sample analysis to database management

Definitions and Principles – why implement QAQC?

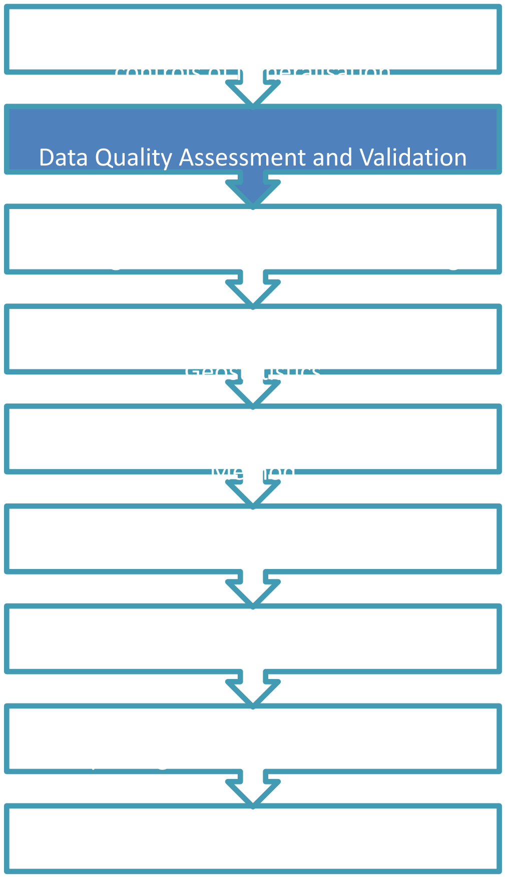
- Typically over looked - QAQC should be a **continual process** and not something that is done because SRK requires QAQC to support Mineral Resource estimates.



- **Poor Quality Data=Poor MRE**
- **QAQC is a fundamental preliminary stage**
- Is the Data Quality fit for purpose?
- Survey/topographic data Quality?
- Sampling Methodology appropriate and unbiased?
- Drilling recovery?
- Quality Assurance/Quality Control (QAQC) procedures and results appropriate?
- Sample preparation appropriate?
- Sample Analysis by reputable/accredited laboratory?
- Analysis Precision/accuracy/repeatability?
- Independent Verification?
- Sample Security?
- Has data been collected following Industry standards and best practices with Quality Assurance in place, i.e. documented protocols

QAQC is an often underestimated/overlooked step that is CRITICAL all other project components

Data Quality: Examples of Common Issues



- Several phases of drilling and sampling using different techniques with different Quality
- Lack of Quality Control information
- Core has been lost/disposed or bad condition so no re-sampling or re-logging can be done
- Coarse Rejects and pulps not retained
- Missing Core logs (multiple reasons)
- Assays missing, incomplete or suspicious
- Missing Collar and survey information
- Co-ordinate system problems: Soviet/Local/UTM
- Core Recovery not recorded or too low
- Inappropriate orebody intersection angles and lack of orientated core
- Compatibility of mixed and old and new data
- Limited SG/Density Data
- Lack of Twin drilling of different drilling methods

CP must ensure QAQC Protocols are in place and adequate
CP must decide if the data meets JORC/CRIRSCO Data Quality Standards

Data Quality: Quality Assurance/Quality Control (QAQC)

- Ensuring good design, protocols and procedures prior to data collection to ensure "correctness" of sampling
  - A sample is correct when each particle is given equal opportunity of being accepted
  - Sampling "correctness" is hard (if not impossible) to verify experimentally
- Planning and defining activities
- Eliminating of known or predictable causes of poor quality data

Data Quality: Quality Assurance/Quality Control (QAQC)

- Monitoring of quality of data collected including:
  - Drilling/sample recoveries
  - Correct splitting of samples
  - Weighing/measurement calibration checks
  - Sample preparation hygiene/contamination (**blanks**)
  - Analytical **ACCURACY** (Standards/CRM's/External lab checks)
  - **PRECISION** associated with sampling stage (duplicates: ¼ core, pulps, coarse rejects)

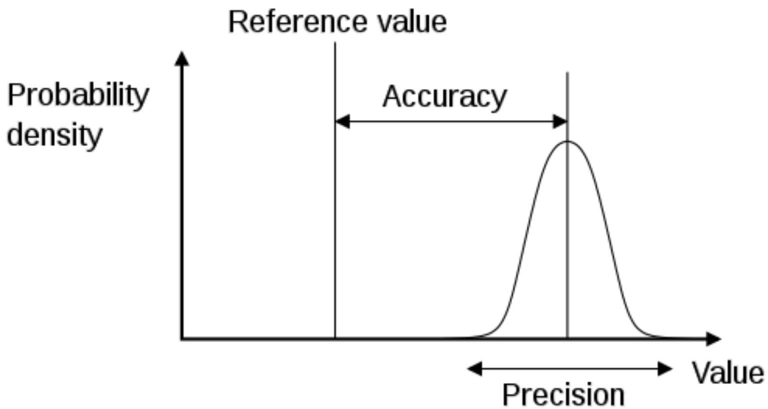
SRK has not assigned Mineral Resource classification some project based on poor QAQC

"Poor Data in, Poor Estimates Out……put politely"

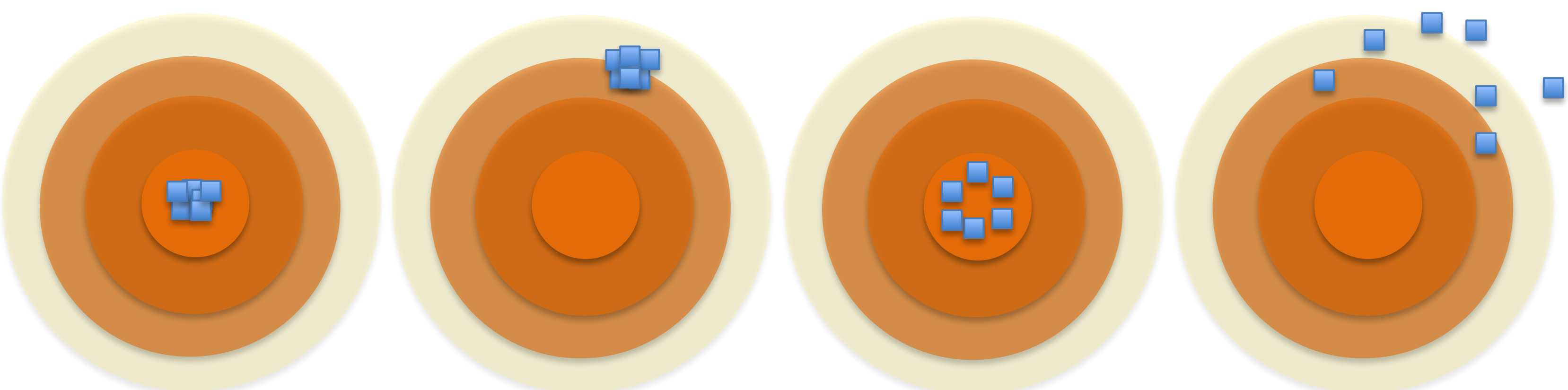
Definitions and Principles – why implement QAQC?

Precision: the ability of a measurement to be consistently reproduced

Accuracy: the degree of closeness of measurements of a quantity to that quantity's actual (true) value



Estimation Precision:
Number and type of samples
Regularity / Continuity of mineralisation



Precise & Accurate | **Precise & Inaccurate** | **Imprecise & Accurate** | **Imprecise & Inaccurate**

Precision:

Drilling

Things to look out for

Sample recovery:

- Is a representative sample being recovered?
- Does the sample accurately represent the downhole position?

Spatial location:

- Is the collar correctly located?
- Is the down hole survey reliable?

Geometry

- Is core orientation being accurately captured?

Method:

Has an appropriate drilling method been used?

Does the quality of the drilling vary between exploration programs, rigs or location?

Underlies all other stages

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Drilling

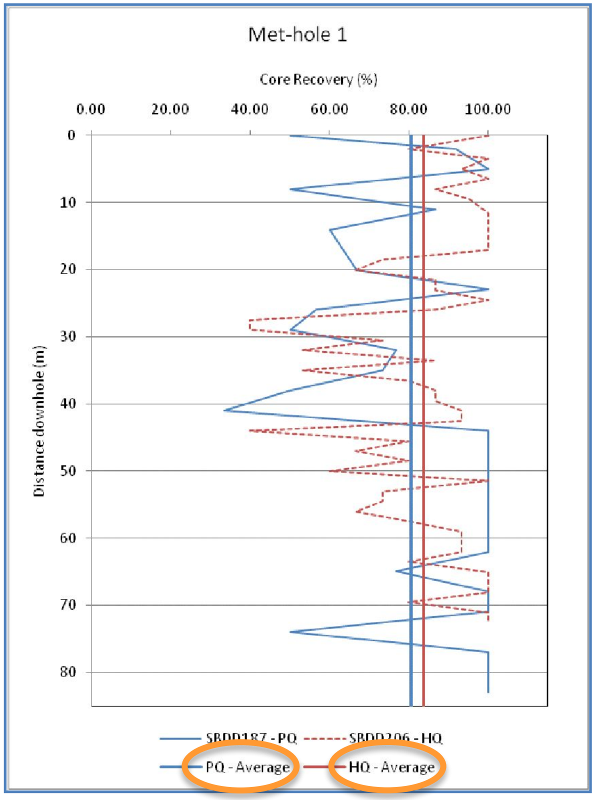
Sample Recovery

Important to understand the drilling method and the physical properties of the material

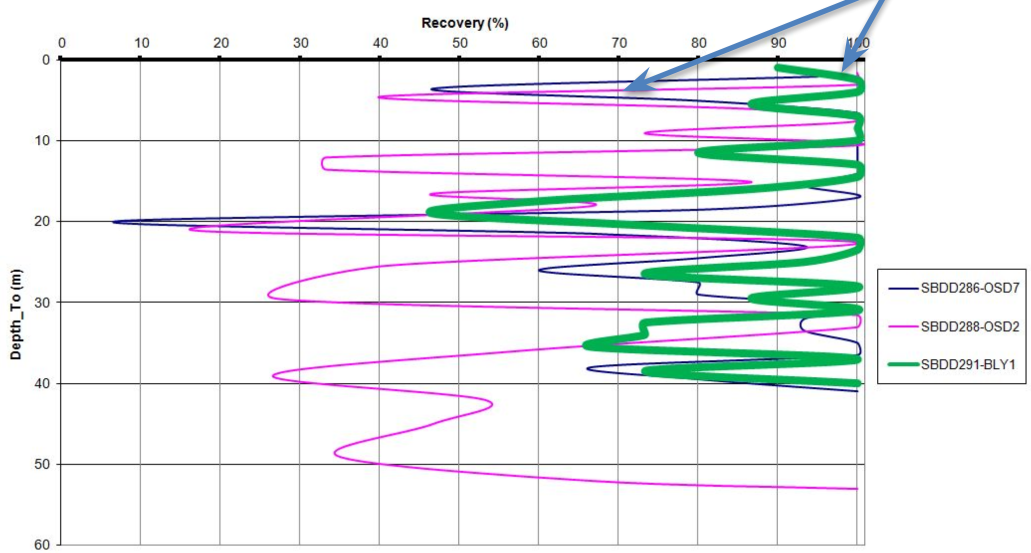
Drilling

Sample Recovery

RIG	SHIFT	Average of RECOVERY(%)	Sum of LENGTH
BLY1	DAY	86	377
	NIGHT	82	411
BLY1 Total		84	788
OSD2	DAY	74	222
	NIGHT	67	165
OSD2 Total		71	387
OSD4	DAY	90	274
	NIGHT	79	321
OSD4 Total		84	595
OSD7	DAY	70	119
	NIGHT	78	94
OSD7 Total		73	212
Grand Total		80	1981



Difference between drilling contractors!



Sample recovery varies between shifts and individual drillers

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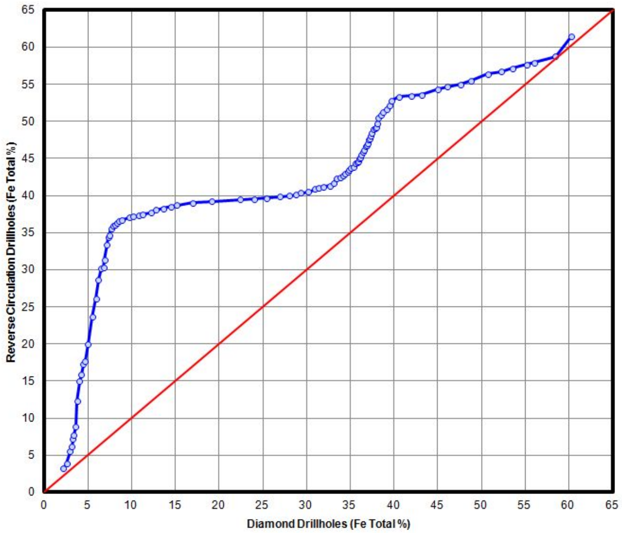
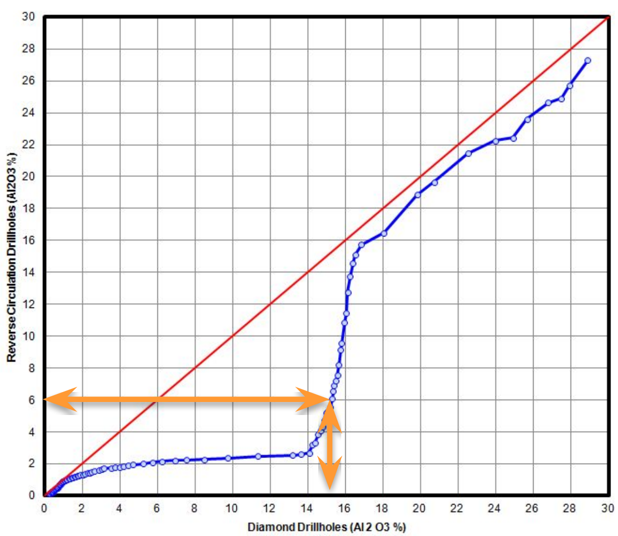
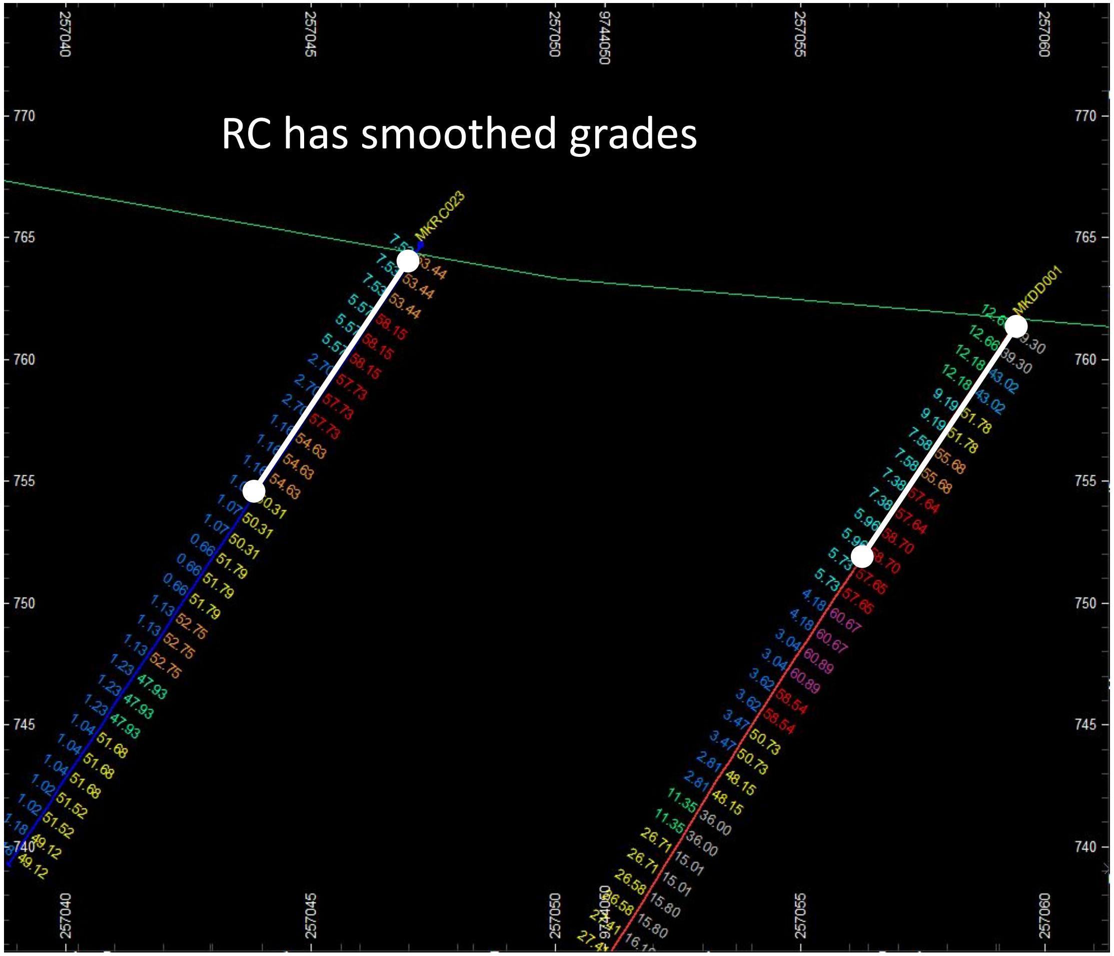
Drilling

Sample Recovery – loss of fines & Clays







Statistical Analysis of drilling types can highlight potential issues

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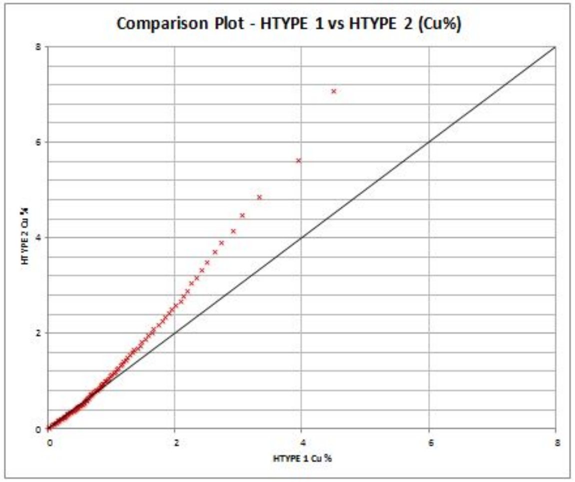
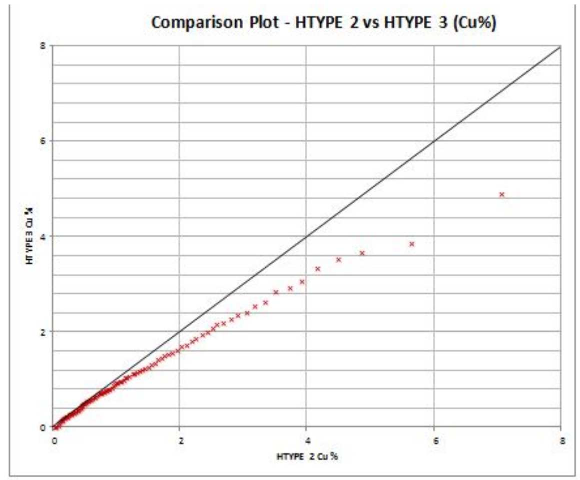
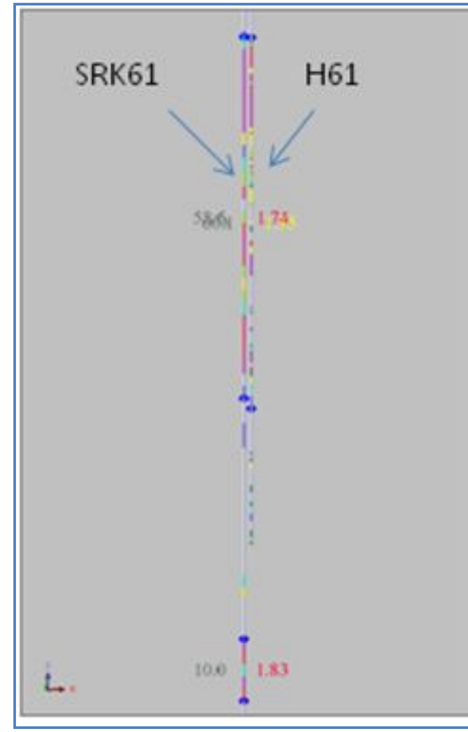
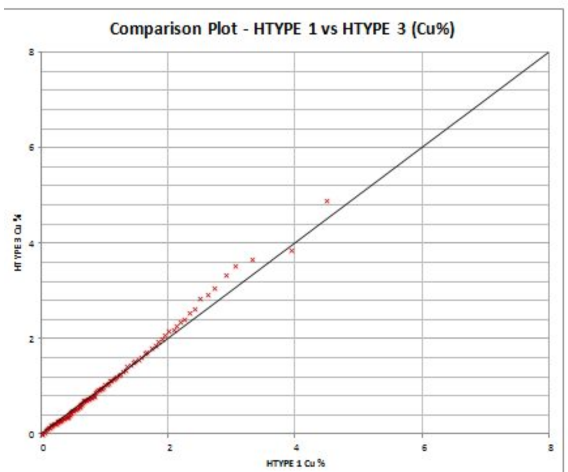
Drilling

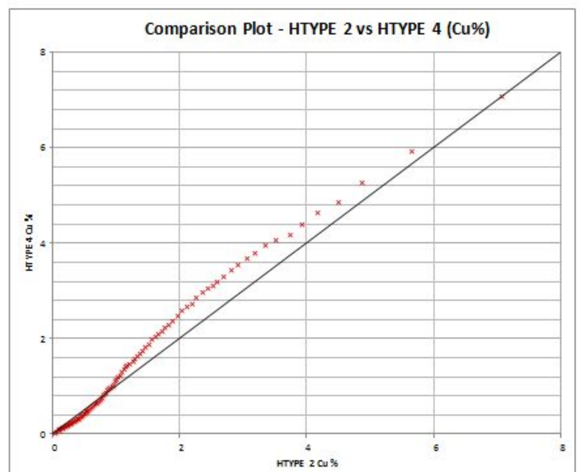
Multiple drilling methods – statistical comparison







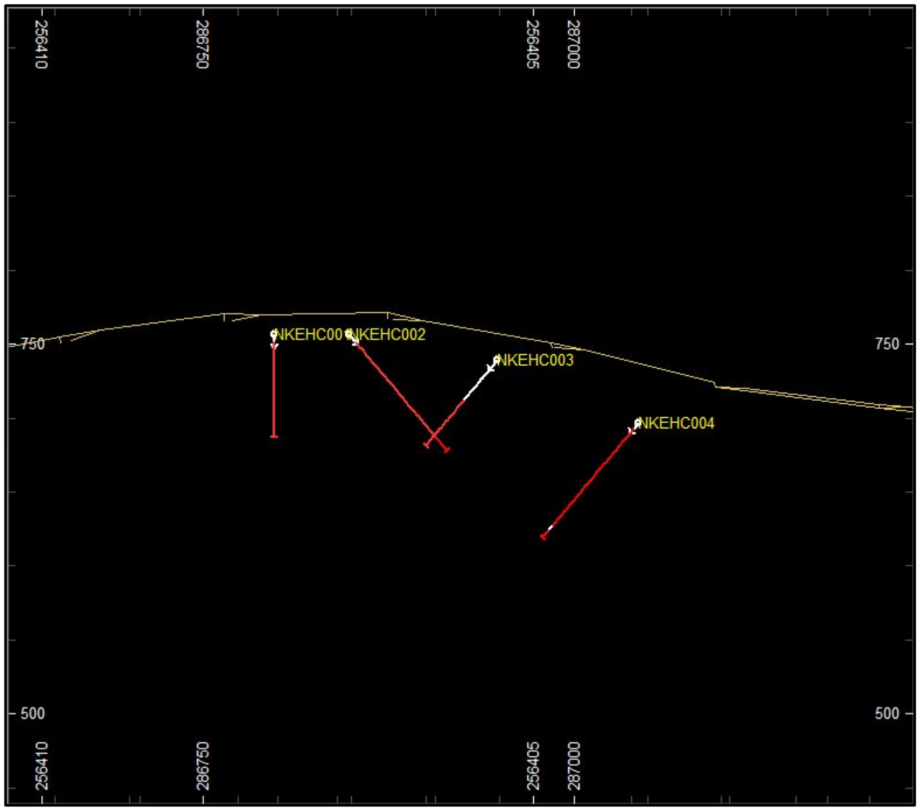




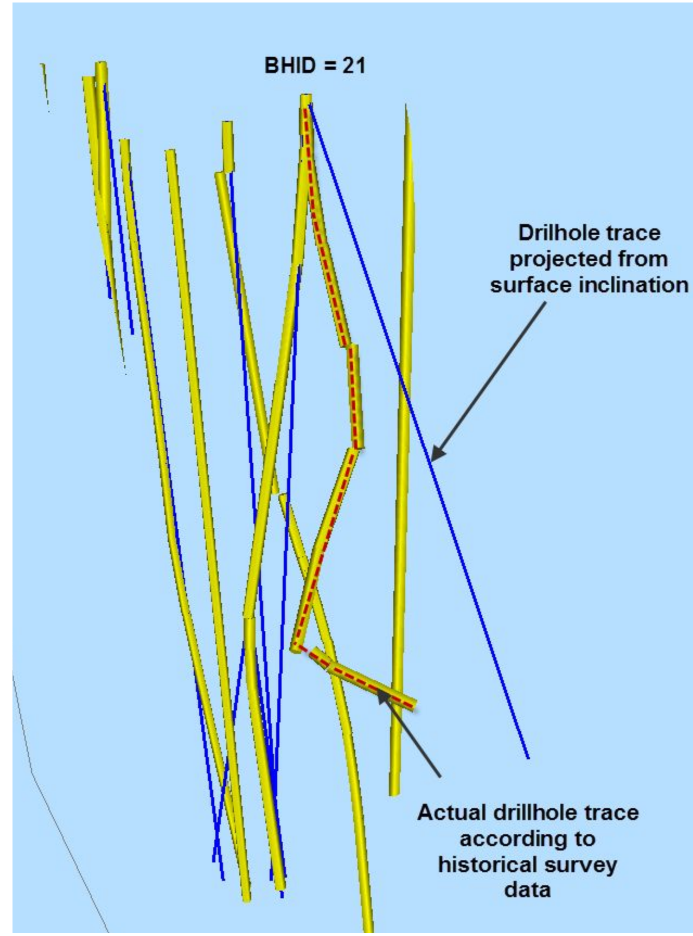
Certain drilling methods may be relatively biased

Drilling
Survey

Textbook example where collars do not match the topography (one or other is wrong); happens on 80 to 90% (if not more).



In this case historical survey could not be resolved – hole was projected from surface inclination instead.



Things to check:

- Scales must be calibrated and monitored.
- Water bath must be clean and free of debris.
- Paraffin wax must be a the correct temperature (where required for porous material).
- Is the correct formula being used?

Laboratory QAQC

The aim of a good QAQC program:

- Practices and procedures used in the sampling program should be **appropriate** for the objective of the program.

- QAQC programs should be tailored to reflect the requirements of the mineralisation and sample type required.

- Methods must be **documented** and **justified**.

- Emphasis should be placed on **full** and **open disclosure.**

- Best practice guides must be followed and accredited labs used.

- The QP/CP must document sampling, assaying and QAQC.

- Out of **159** NI 43-101 compliant reports filed over 30 days in 2009:
  - **24** cases of early exploration phase where no QAQC was used
  - **25** cases (projects with resources and reserves) with no reference to QAQC

Sampling, Assaying, Rice and Risk

•50,000 grains in 1 kg of rice.

• 1g/t Au (0.0001%) is equivalent to 1 a grain of rice in 1 kg. Or 1 minute of every 2 years!

•Getting a representative sample and ensure that there is no contamination is not easy!

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What are QAQC samples? What's the point?

- **Field Duplicates**: duplication of core samples (quartered core), RC chips etc, inserted onsite – prior to an sample crushing, etc. **Sampling error.**

- **Preparation Duplicates**: submission two samples which are a split of a sub-sample. **Preparation error.**

- **Analytical Duplicates/Repeats:** double analysis of a single sample. **Analytical precision.**

- **Field/hard Blanks**: blank rock or chip samples inserted early, prior to any crushing. Test of contamination in the sample preparation and analytical process.

- **Certified/Standard Reference Materials:** homogenous, well characterised material with known grades that have been analysed by a large number of accredited labs globally. These samples are associated with a certified mean confidence limits and standard deviation.

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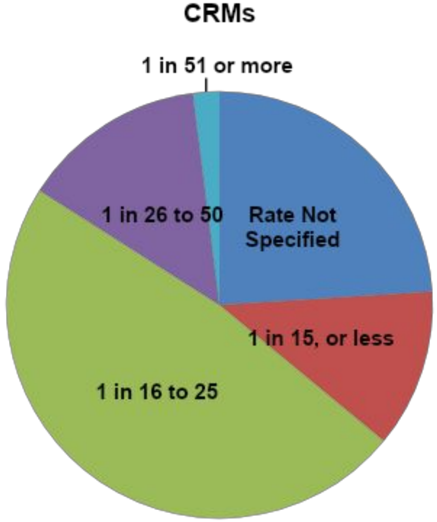
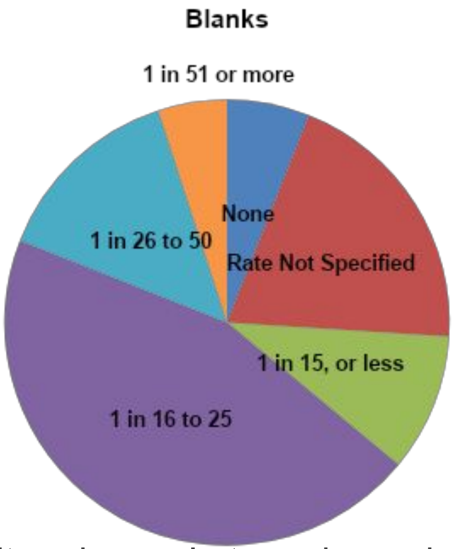
How many QAQC Samples do I use?





Based on analysis presented at PDAC by ASL: data is derived from a review of 160 NI43-101 Reports

The reality:

- There is **<u>no</u> <u>definitive</u> <u>answer</u>** – the QAQC insertion rate is deposit and sample type dependent
    - Field blanks – 1:20
    - Field duplicates – 1:20
    - Standards - 1:20
    - Results in an insertion rate of 3/20 = 15%
- This may need to be increased to 20% to 30% for certain types of mineralisation, such a nugget/coarse gold where a higher rate of field duplicates, blanks and blind duplicates may be required

There is no set rules regarding insertions rates!

How many QAQC Samples do I use?

Frequency of Inserting QAQC Material in Assay Batches

- The number of quality control samples and the frequency of their insertion in analytical batches should be sufficient for systematic monitoring of assay quality.

- Recommended quality control materials **vary from 5% to 20%** of the total analyses depending on **mineralization type**, **location of the mining project**, and **stage of the project evaluation**.

- A brief overview of the different recommendations on frequency of insertion of QAQC materials is given below (Abzalov, 2008):
  - *Garrett (1969)* -**10%** of geochemical samples should be controlled by collection of duplicate samples.
  - *Taylor (1987)* - **5%** to **10%** of samples analysed by a laboratory should be reference materials.
  - *Leaver et al. (1997)* - analyse 1 in-house reference material with every 20 assayed samples, & >1 CRM
  - *Vallée et al. (1992)* >**10%** of the determinations in exploration or mining projects should be QAQC samples (standards, blanks, and duplicates).
  - *Long (1998)* **>5% of pulps** (crushed and pulverized sample material); **5%** of field and/or coarse rejects should have a second pulp prepared and analyzed by the primary laboratory; and every sample batch - **1% to 5% of CRM**.
  - *Sketchley (1998)* - **10% to 15% of QAQC samples**. In particular, every batch of 20 samples should **include at least one standard, one blank, and one duplicate** sample.

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When should QAQC samples be inserted?

How **not** to do it:..................................we need to obscure the sequence from the lab!

Sample 124: Regular sample
Sample 125: 25th sample duplicate,
Sample 126: 26th sample blank,
Sample 127: 27th sample CRM,
Sample 128: Regular sample
…..
Sample 150: 50th sample duplicate,
Sample 151: 51st sample blank,
Sample 152: 52nd sample CRM,
…..etc.,

- Sample numbers/codes should **not** highlight the presence of QAQC samples. Do not do the following:

*Coding QAQC samples with a suffix **"B" for blinds**, **"D" for duplicate**, **"S1" for standard/CRM 1**, **"S2" for standard/CRM 2**, etc.*

- QAQC sample insertion should be as random as possible. There are cases where some samples may be paired to help identify specific problems.

- Difficult to get right!

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Laboratory QAQC

Standards

- Test of both analytical **accuracy** and **precision**
- Critical to select standards that **reflect the grade range and distribution.**
- **Matrix-matched** samples are desirable but not always available.
- Standards can be purchased from a many difference suppliers:
  - Rocklabs
  - OREAS
  - AMIS
  - MineralStats Inc
  - Geostats PTY LTD
  - Nrcan (Canada natural resources)

Product Code	Nickel Statistics (ppm)				Copper Statistics (ppm)			
	Mean	Stdev	Count	95% CI	Mean	Stdev	Count	95% CI
GBM903-11	43030	1609	43	+/- 501	4100	221	30	+/- 84
GBM903-13	24337	845	67	+/- 208	28953	805	91	+/- 169
GBM903-16	97	10	19	+/- 5	213328	7836	43	+/- 2440
GBM304-11	65	18	24	+/- 8	104011	3070	45	+/- 933
GBM304-13	21	10	32	+/- 4	97125	3310	77	+/- 756
GBM304-16	16	11	14	+/- 6	22721	915	48	+/- 268
GBM904-11	17	20	16	+/- 11	8808	403	33	+/- 145
GBM305-12	42	8	17	+/- 4	119	42	43	+/- 13
GBM305-16	6503	304	41	+/- 97	381	62	44	+/- 19
GBM905-11	38	8	16	+/- 4	31758	1017	47	+/- 302
GBM905-12	62	11	20	+/- 5	21853	743	46	+/- 223
GBM905-14	531	36	24	+/- 15	173667	5097	43	+/- 1587
GBM306-12	9483	336	27	+/- 135	14804	347	47	+/- 103
GBM306-14	34435	1124	63	+/- 285	16709	594	87	+/- 127
GBM306-16	157	14	20	+/- 7	13409	355	45	+/- 108
GBM906-11	nr	nr	nr	nr	369	30	49	+/- 9
GBM906-13	nr	nr	nr	nr	21862	781	50	+/- 224

GEOSTATS PTY LTD
Mining Industry Consultants
Reference Material Manufacture and Sales

Certified Ore Grade Base Metal Reference Material Product Code

GBM304-13

Certified Control Values

Ore Grade Base Metal Analyses

Element	Grade	Standard Deviation	No of Analyses	Confidence Interval
Nickel (ppm)	21	10	32	+/- 4
Copper (ppm)	97125	3310	77	+/- 756
Zinc (ppm)	59274	2603	86	+/- 561
Lead (ppm)	235648	7889	71	+/- 1881
Cobalt (ppm)	nr	nr	nr	nr
Silver (ppm)	nr	nr	nr	nr
Sulphur (%)	nr	nr	nr	nr

CRM Details

Control Statistic Details
Control statsitics were produced from results accumulated in the :
October-2005 Geostats Pty Ltd Laboratory Round Robin Program.
71 laboratories (at least) tested this material for base metal content

Source Material
Prior to homogenisation and testing, this material was sourced from Lead / Zinc Middlings Material (Sulphide)

Geostats Pty Ltd A.C.N. 072 971 272 THE Common Seal OF

Colour Designation
Medium dark gray

Usage
This product is for use in the mining industry as reference materials for monitoring and testing the accuracy of laboratory assaying.

Preparation and Packaging
All standards are dried in an oven for a minimum of 12 hours at 110C. The dry material is then pulverised to better than 75 micron (nominal mean of 45 micron) using an Air Classifier. Thematerial is then homogenised and stored in a sealed, stable container ready for final packaging.

Materials are statistically sampled from stores, then packaged into either heat sealed, air tight, plastic pulp packets or screw top sealed plastic containers ready for distribution. All packaging has been chosen to ensure minimal contamination from outside sources during shipment, use and storage.

Assay Testwork
All standards are tested thoroughly in the Geostats bi-annual laboratory survey. This involves assaying by a minimum of 50 reputable laboratories selected from across the world using a variety of methods (including AR, 3AD, 4AD and ICP, AAS and XRF). Results are compiled into a comprehensive report detailing statistics for each standard. Assay distributions are checked and processed statistically, producing monitoring statistics for these standards. Materials are tested regularly to ensure stability and homogeneity.

Neutron Activation Analysis Results (ppm)		Major Elements Fusion / XRF (%)	
Antimony	2660	Fe	nr
Arsenic	850	SiO2	nr
Barium	<150	Al2O3	nr
Bromine	<190	TiO2	nr
Cadmium	<300	MnO	nr
Cerium	<14	CaO	nr
Caesium	<0.5	P	nr
Chromium	<42	S	nr
Cobalt	280	MgO	nr
Europium	<2	K2O	nr
Gold ppb	20000	Na2O	nr
Hafnium	<1	LOI1000	nr
Iridium ppb	<100		
Iron %	20.7		
Lanthanum	697		
Lutetium	0.5		
Molybendum	57		
Nickel	<50		
Rubidium	<22		
Samarium	1.8		
Scandium	<0.2		
Selenium	60		
Sodium %	<5		
Tantalum	<0.5		
Tellurium	<67		
Terbium	<0.5		
Thorium	<0.7		
Tin	<230		
Tungsten	<23000		
Uranium	<11		
Ytterbium	<9		
Zinc	54000		
Zirconium	<450		
Calcium%	nr		
Potassium %	nr		
Silver	1800		
Mercury	nr		
Neodymium	nr		
Strontium	nr		

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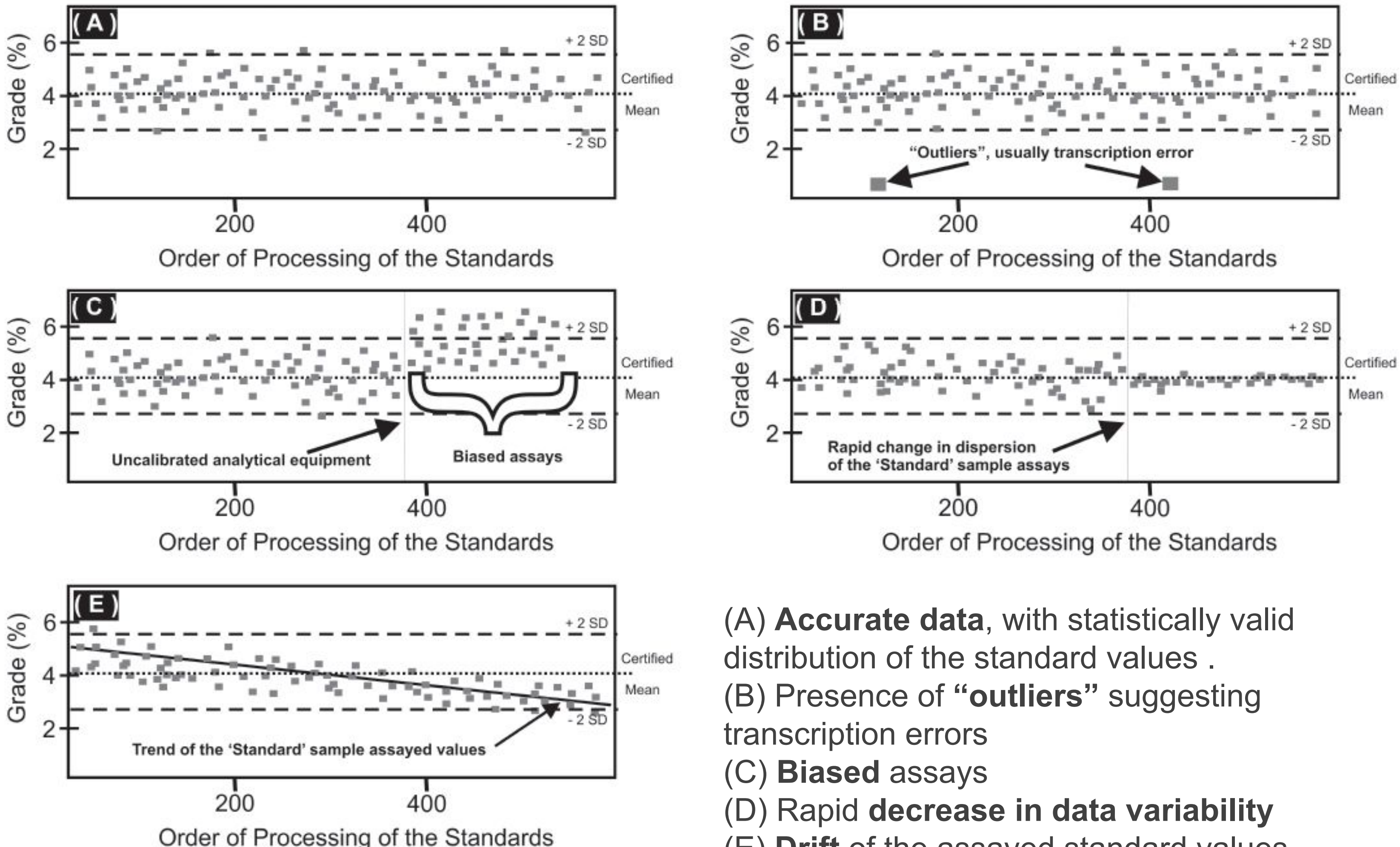
Phone : +61 8 9314 2566, Fax : +61 8 9314 3699
e-mail : pjh@geostats.com.au, srr@geostats.com.au
Website http://www.geostats.com.au

GBM304-13

Geostats Pty Ltd, Certified Base Metal Reference Material, Product Code :

Standards – what interpretations can be made?



(A) **Accurate data**, with statistically valid distribution of the standard values .
(B) Presence of **"outliers"** suggesting transcription errors
(C) **Biased** assays
(D) Rapid **decrease in data variability**
(E) **Drift** of the assayed standard values

Be careful of analysing averages – they can hide all manner of errors

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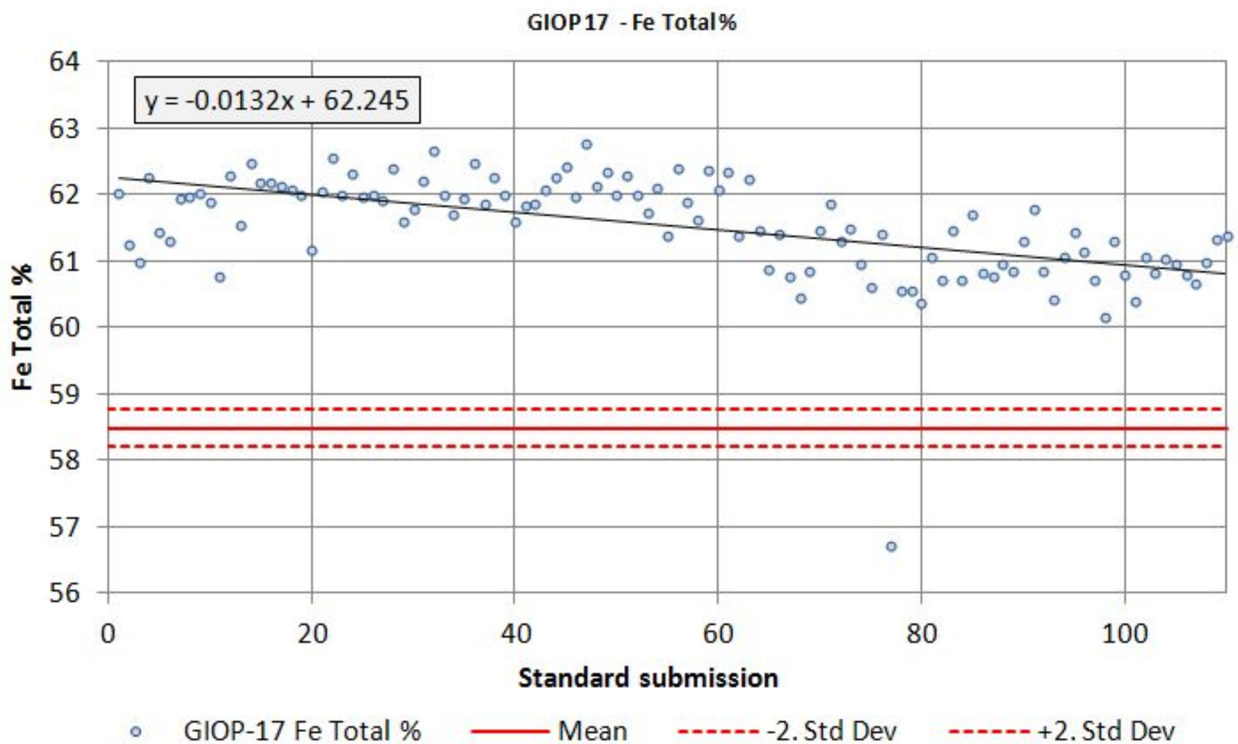
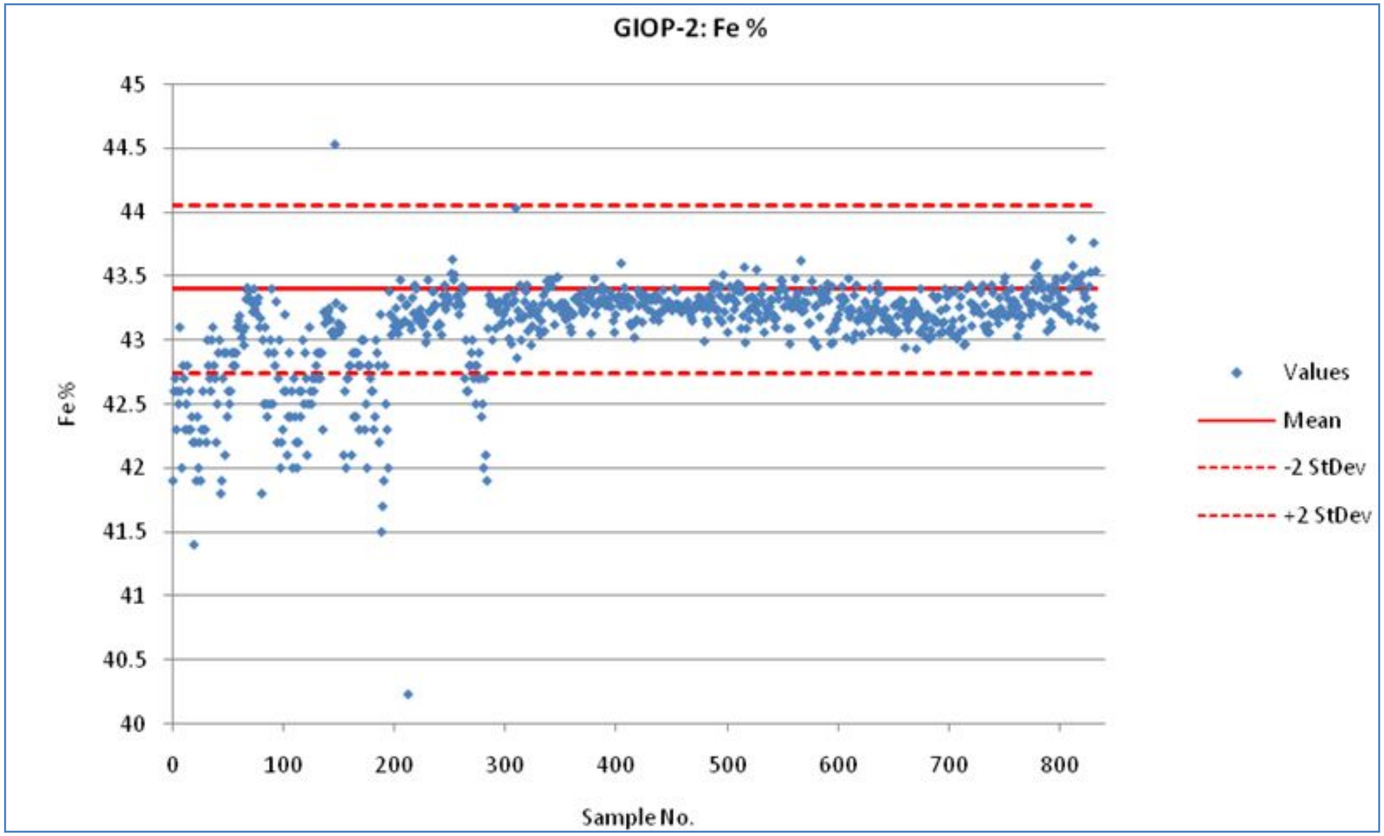
When it goes wrong:

- Standards had not been routinely analysed, despite being submitted.
- **Poor precision and poor accuracy.**
- There is no point submitting QAQC samples unless someone is going to bother to analyse them – this is a less obvious statement than many people think!



Be careful of analysing averages – they can hide all manner of errors

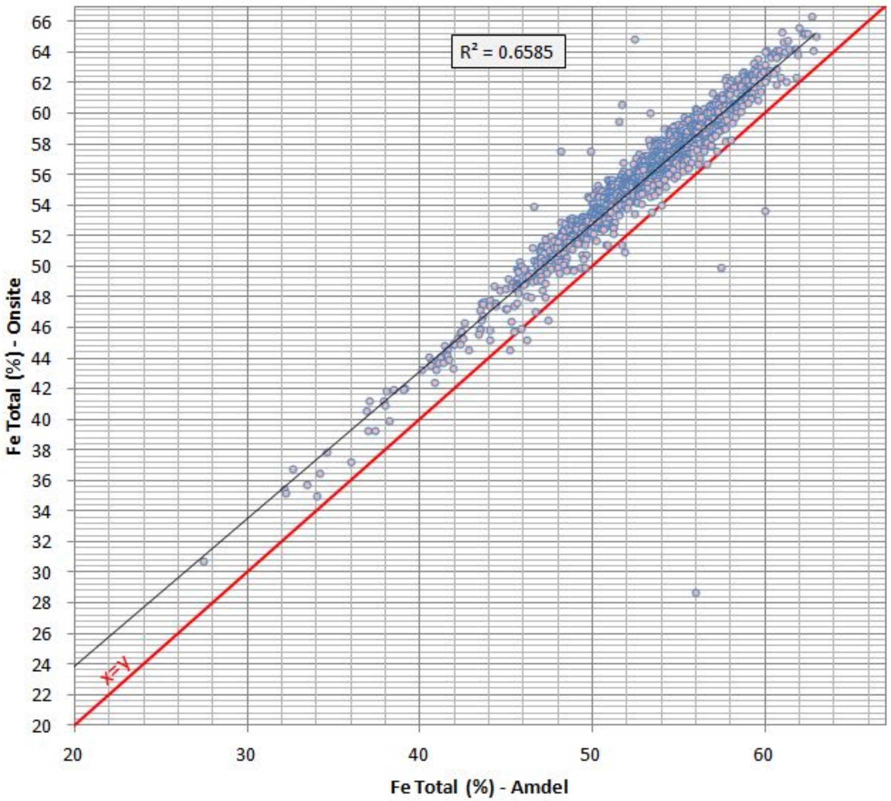
Observation of improvements



Laboratory QAQC

Duplicates

•Bias at an onsite lab (iron ore XRF).
•Not detected for several weeks – no checks were being performed.
• High data frequency around the cut-off grade (57% to 58% Fe Total) – result in correct allocation of marginal versus on-spec' ore.
•Fortunately analysis was still being undertaken by an accredited lab



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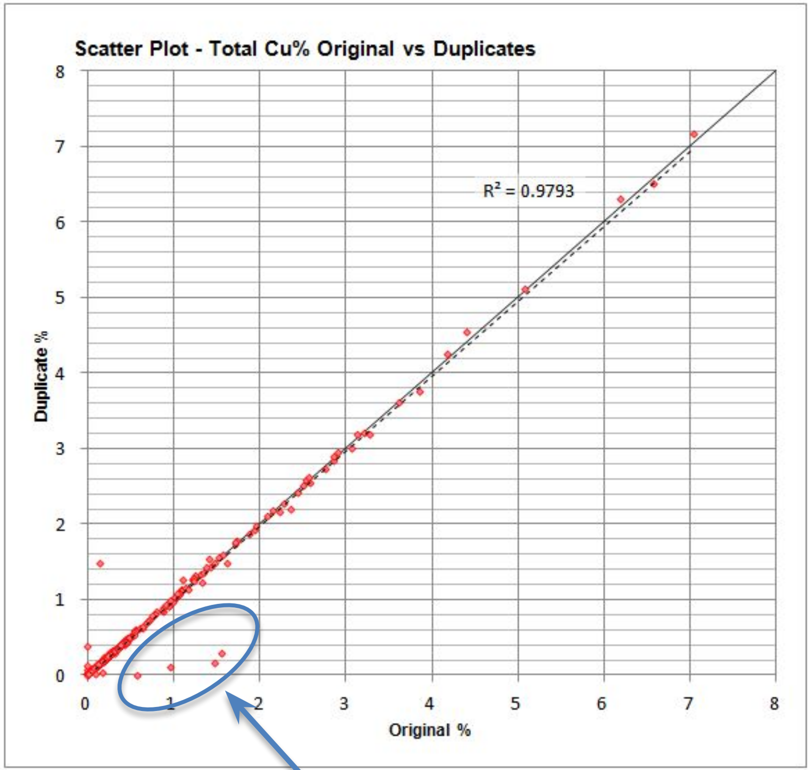
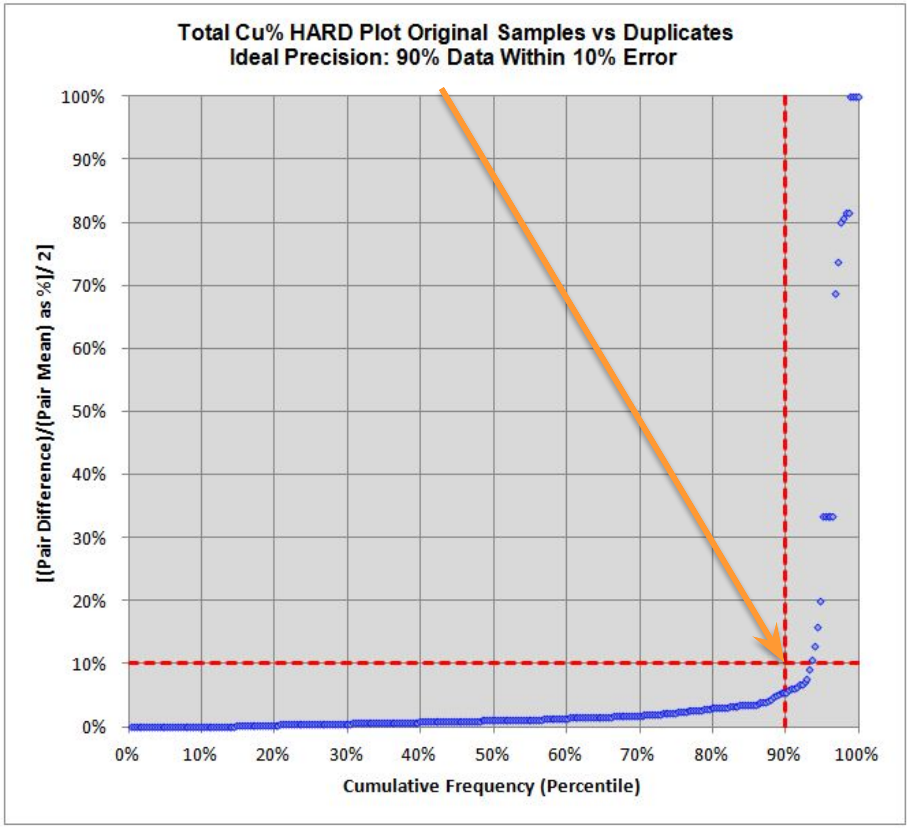
Laboratory QAQC

Duplicates Analysis



Transcription errors?



Duplicates Analysis

- There are **numerous ways to calculate the difference or relative error** between duplicate samples (be clear about what formula you use).
- **Coefficient of variation (CoV)** - the standard deviation (σ) divided by the mean (μ) is a useful statistic.
- Each of the following is proportional to the CoV – so offer no more information than the CoV itself (comes down to presentation).

Measurement	Conceptual Formula	Single Duplicate Pair Formula	Average Formula for Several Duplicate Pairs	Relationship with CV
Coefficient of Variation (CV)	$CV = \frac{\sigma}{\mu}$	$CV = \frac{2}{\sqrt{2}} \frac{\lvert x_1 - x_2 \rvert}{(x_1 + x_2)}$	$\overline{CV} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{2}{\sqrt{2}}\frac{\lvert x_{1i} - x_{2i}\rvert}{(x_{1i} + x_{2i})}\right)^2}$	CV
Relative Precision (RP)	$RP = \frac{2\sigma}{\mu}$	$RP = \frac{4}{\sqrt{2}} \frac{\lvert x_1 - x_2 \rvert}{(x_1 + x_2)}$	$\overline{RP} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{4}{\sqrt{2}}\frac{\lvert x_{1i} - x_{2i}\rvert}{(x_{1i} + x_{2i})}\right)^2}$	$2 \times CV$
Relative Variance (RV)	$RV = \frac{\sigma^2}{\mu^2}$	$RV = 2\frac{(x_1 - x_2)^2}{(x_1 + x_2)^2}$	$\overline{RV} = \frac{1}{n}\sum_{i=1}^{n}\left(2\frac{(x_{1i} - x_{2i})^2}{(x_{1i} + x_{2i})^2}\right)$	CV^2
Absolute Relative Difference (ARD)	$ARD = \frac{\lvert x_1 - x_2 \rvert}{\mu}$	$ARD = 2\frac{\lvert x_1 - x_2 \rvert}{(x_1 + x_2)}$	$\overline{ARD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(2\frac{\lvert x_{1i} - x_{2i}\rvert}{(x_{1i} + x_{2i})}\right)^2}$	$\sqrt{2} \times CV$
Half Absolute Relative Difference ($HARD$)	$HARD = \frac{1}{2}\frac{\lvert x_1 - x_2 \rvert}{\mu}$	$HARD = \frac{\lvert x_1 - x_2 \rvert}{(x_1 + x_2)}$	$\overline{HARD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{\lvert x_{1i} - x_{2i}\rvert}{(x_{1i} + x_{2i})}\right)^2}$	$\frac{\sqrt{2}}{2} \times CV$

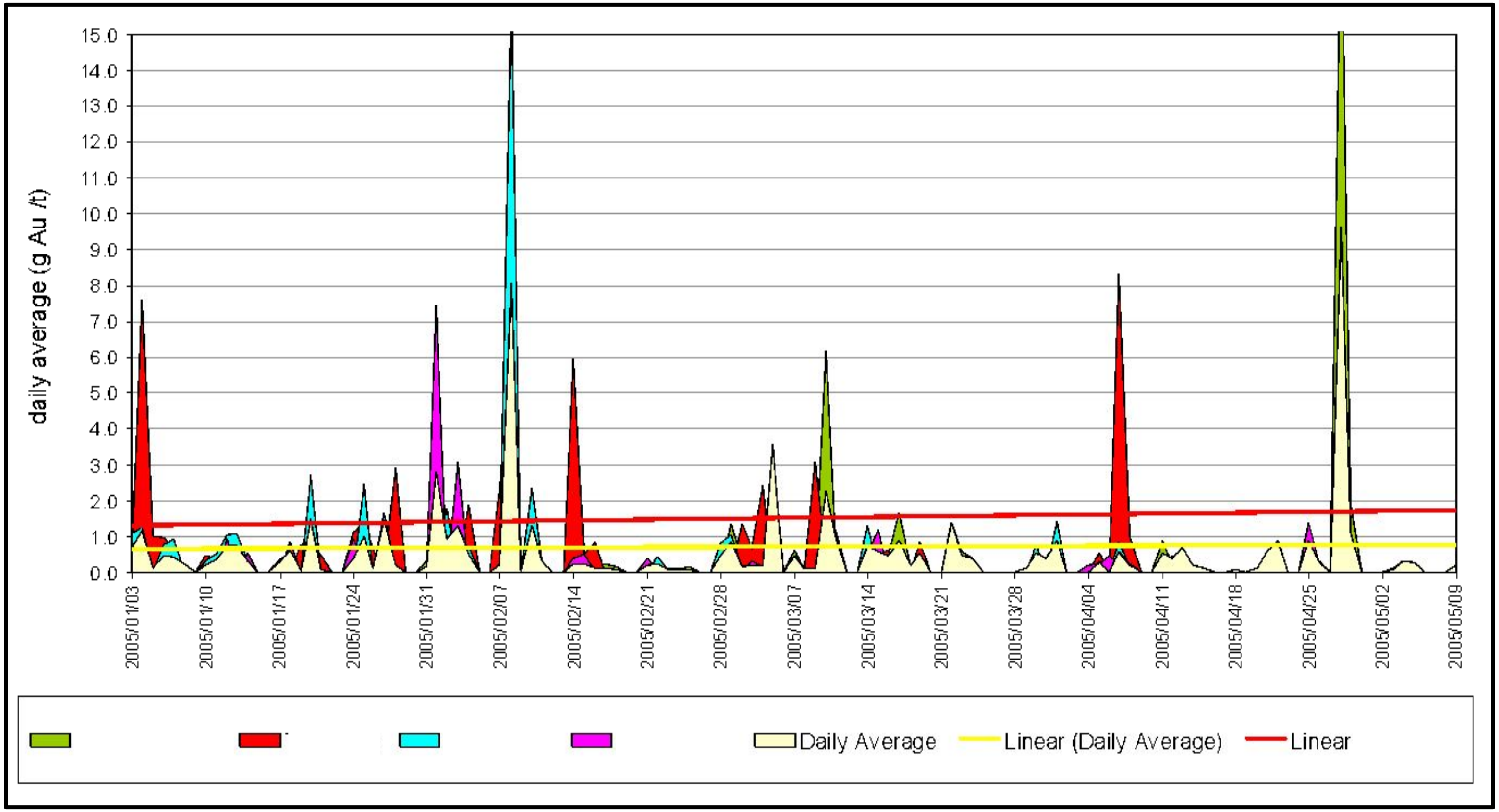
Laboratory QAQC

Blanks

- Sourcing blanks can be difficult for some projects – matching the colour with out matching the grade can be hard (especially in iron ore)!

- Blanks provide a measure of sample contamination throughout the preparation process.

- Coarse gold example – sample preparation contamination (jaw crusher). 15g/t Au is not a blank!!

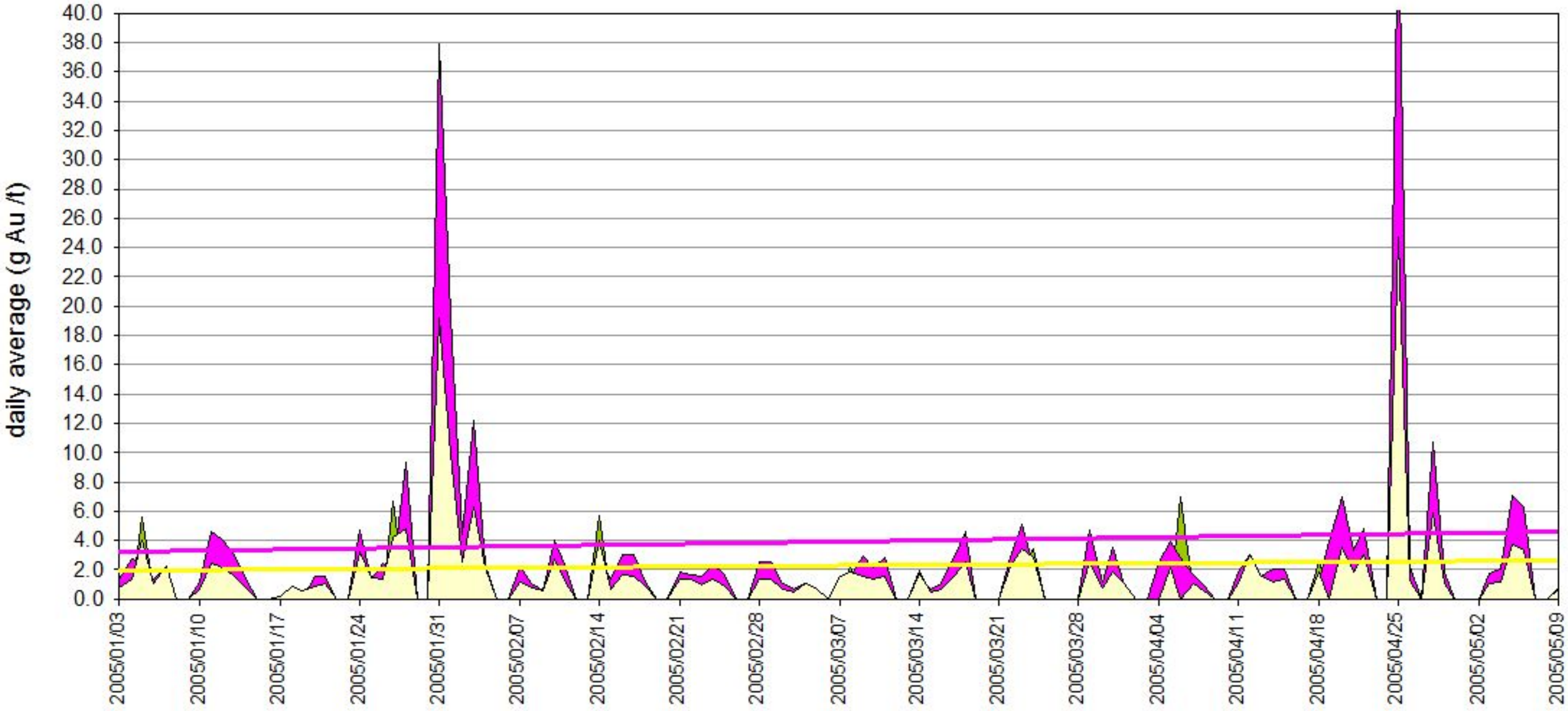


Laboratory QAQC

Blanks

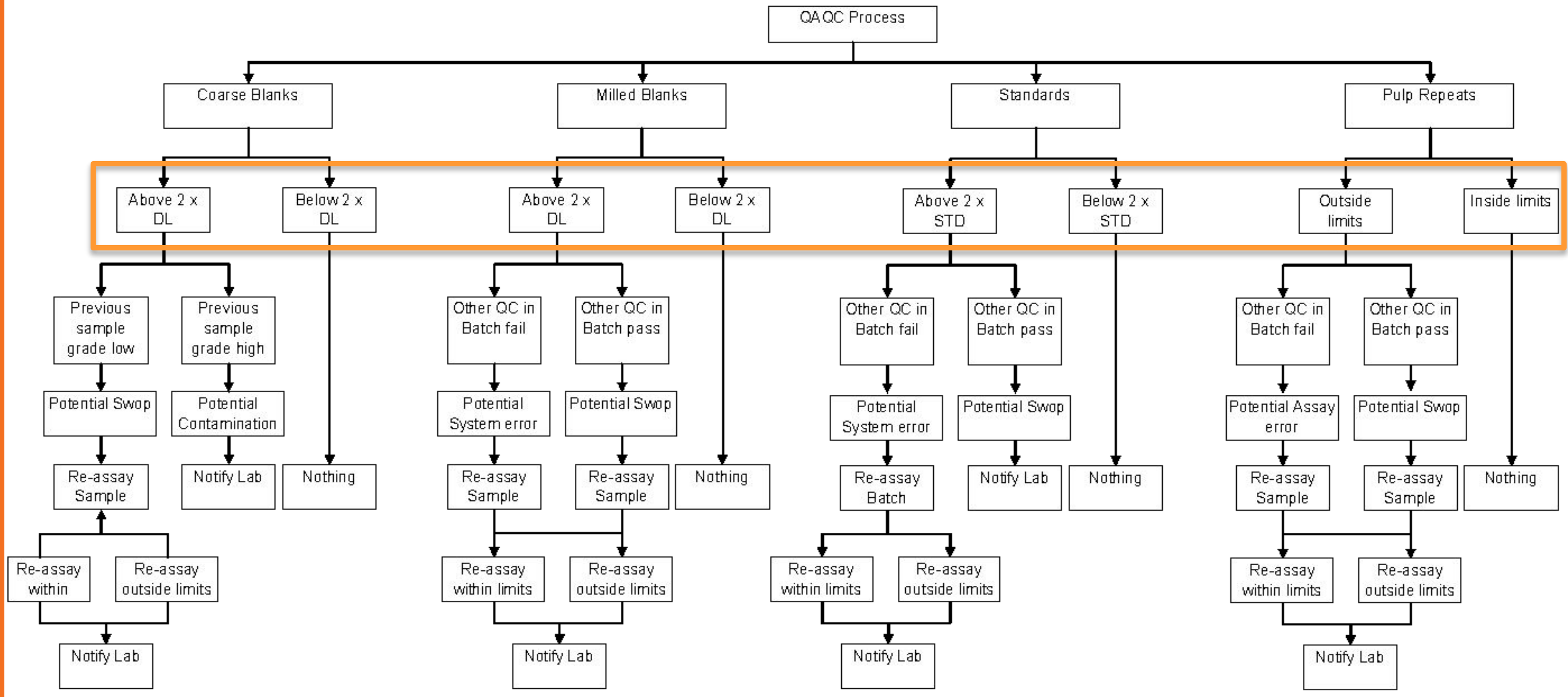
- The problem: crushing and pulverising equipment was not adequately clean between samples. Gold particles can easily be held up in the equipment (cracks, corners, grease).

- All blanks in this case have high background gold grades.



Laboratory QAQC

Decisions Points

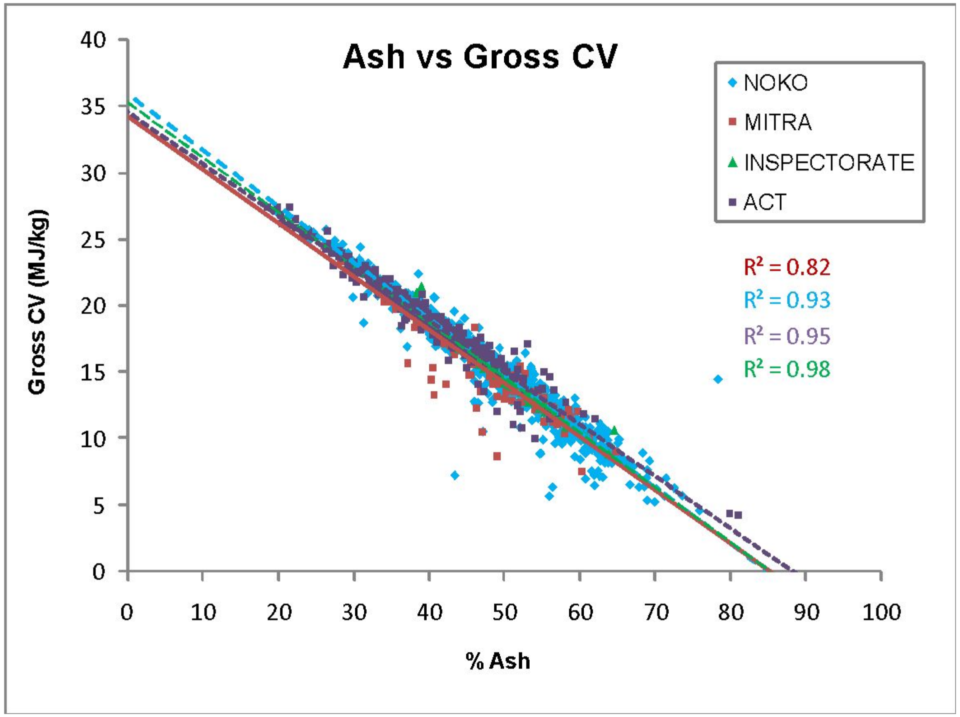


Coal QAQC:

Data Collection – common problems:

- **Geophysical logs and Lithologically and Structural Logging**
  - Not all holes have geophysical logs
  - Depth correction of lithologically logged seams with the geophysical log is not done
  - Cored holes are logged and sampled without the lithological log so there is sample contamination and the lithological logging may not be reliable
  - Digital format of geophysical logs may not be available for cross checking and verification– scale adjustment in a different software package
  - Holes are vertically drilled so a teliviewer is the only way of gaining reliable and useful structural information – perception that it is expensive with most clients
- **Diamond Core drilling and sampling**
  - Core is not wrapped immediately and sealed to prevent moisture loss before sampling - Exposure in hot arid climates dries the coal and can significantly change the coal qualtiy for ROM calculations
  - Core loss it high because the core barrel is too small and the pressure on it too great – (inexperienced drillers!)
  - Core that has been stored for a long time will weather and deteriorate – therefore duplicates are not stored as they will produce unrepresentative results if sampled and analysed in the future
  - Typically a percentage of the holes are cored – 25% so the distribution of quality data may not be representative in variable depositsCoal Analysis
- **Coal Analysis – has it been analysed and sampled appropriately for the resource declared?**
  - i.e. – coking tests – are there enough to declare a coking coal resource – if it is declaring coking coal does the resource defined have the quality and quantity of data that can prove the continuity of coking coal?
  - Wash testing – similar assumptions, have the main seams been characterised with the distribution and quality of the data?
  - Has more than one laboratory been used and is at least one laboratory accredited – typically round robin approach used for coal
- **Coal Analysis – Proximate, must do basis and analysis checks?**
  - Air Dry Basis: inherent moisture + ash + volatiles + fixed carbon = 100
  - As Received Basis (ROM) total moisture + ash + volatiles + fixed carbon = 100
  - Calorific Value – what basis and what units BTU, Kcal/Kg, MJ/Kg etc
- **Coal Analysis – Deleterious elements are not analysed early stage**
  - Sulphur and Phosphorous, (Chlorine), must be appropriate for process – i.e. Metallurgical coal or thermal – how critical are boiler specs?
- **Analysis – Washability Testing (more and more applicable as poorer coal deposits are developed)**
  - Wash testing on different size fractions can produce significantly different curves – used as part of the economic criteria for a resource
  - Can we make assumptions from adjacent properties and our own knowledge at the early stage of a project – this becomes more problematic as new areas are developed – i.e. Pakistan, Mozambique

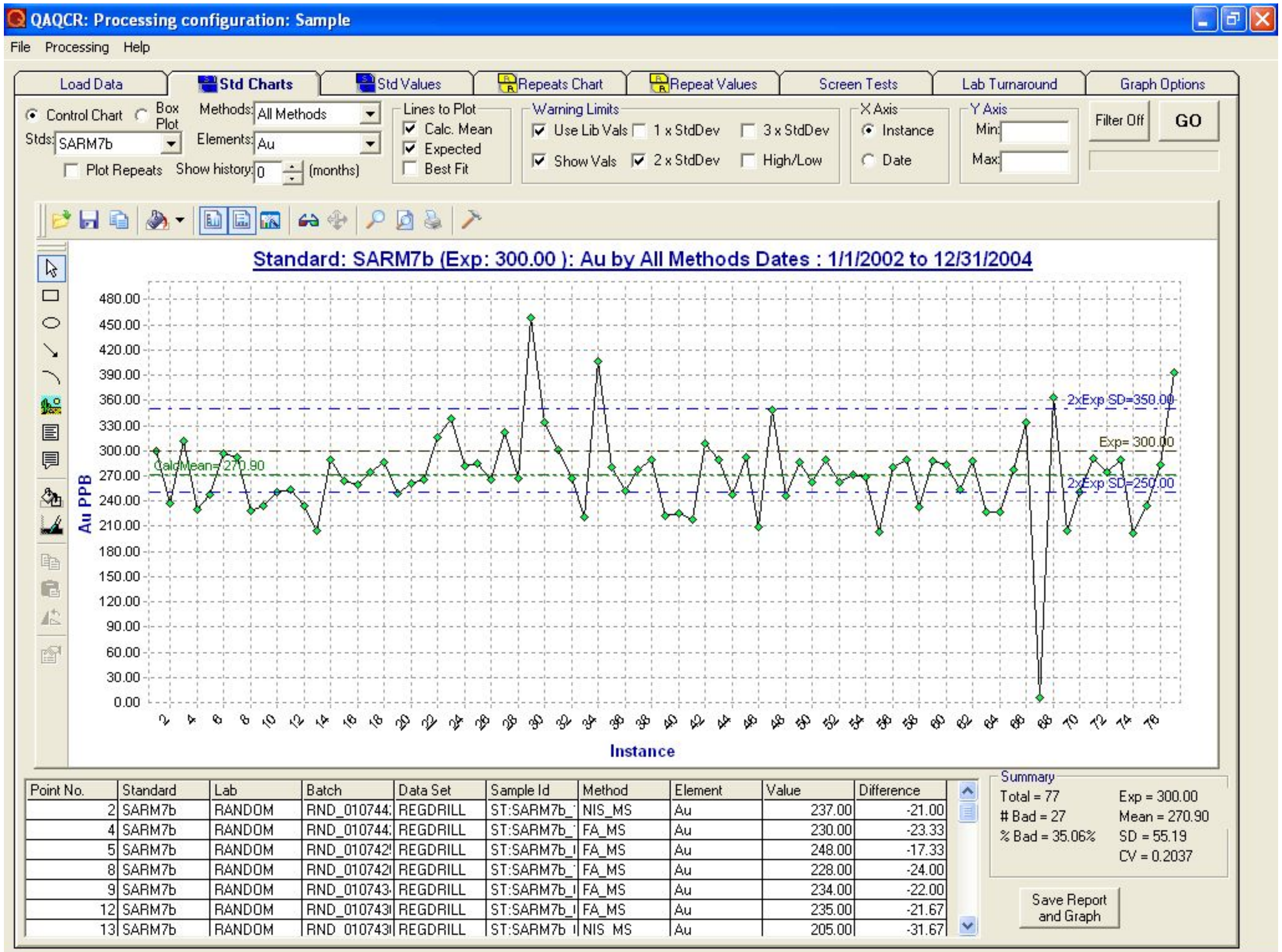
Laboratory Data – Graphically investigating procedures and bias



- Regression analysis plotted shows the relative coal quality between laboratories
    - Calorific Value vs Ash
    - Ash vs Volatiles
    - Ash vs Relative Density
- Suppressed volatiles typically indicates proximity to intrusions
- High volatiles and high ash indicate a high iron content
- Statistical comparisons between laboratories and seams are used to analyse bias

"dot-the-dot assay grade geological models are not acceptable"

QAQC Databases



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Are samples stored and delivered in an appropriate and orderly manner?

Good, orderly

A QAQC disaster in the making!

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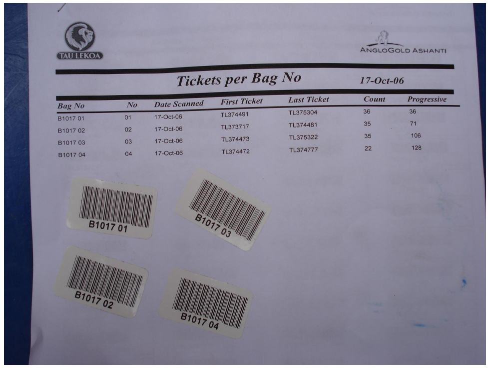
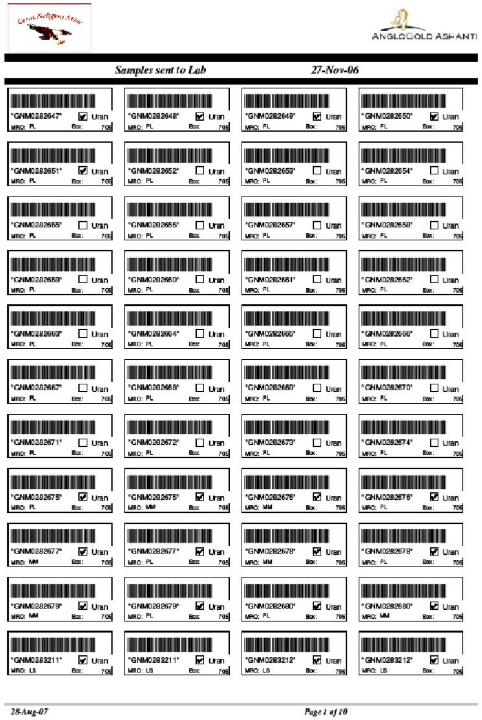
Auditing Laboratories and Preparation Facilities – What to Look out for!

- Are samples identifiable, labelled, etc?
- Are the sample transferred to and from the oven safely (no risk of injury, dropping the pans or confusion)
- Does stacking allow for complete drying?
- Is the temperature correct?

Auditing Laboratories and Preparation Facilities – What to Look out for!

- The **Good**, **Bad** and the **Ugly**





Crushing and Pulverising

- **Blanks should detect any contamination**

Cleaning apparatus is critical

Crushing and Pulverising

Summary

- **Critical component**
- **Often overlooked**
- **QAQC needs to be monitored on a continual basis in all aspects**
- **Errors can be significant and have a large effect on Mineral Resource classification**

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