

Quality control and public reporting in industrial minerals

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As with previous editions of the Joint Ore Reserves Committee (JORC) code the 2012 edition of JORC Code includes Table 1, which is provided for use by those preparing public reports on exploration results, mineral resources and ore reserves. There are some significant changes to the latest Table 1, not least of which is the 'if not, why not' requirement for comments on quality control of exploration samples by the competent person.

JORC 2012 Table 1

Table 1 is a checklist of assessment and reporting criteria in line with the principles governing the JORC code, namely transparency, materiality and competence. In the context of complying with these principles, "Comment on the relevant sections of Table 1 should be provided on an 'if not, why not' basis within the competent person's documentation and must be provided where required according to the specific requirements of clauses 19, 27 and 35 for significant projects in the public report," (JORC 2012, p26).

The phrase 'if not, why not' means that each item listed in the relevant section of Table 1 must be discussed and, if it is not discussed, then the competent person must explain why it has been omitted from the documentation. This ensures clarity for investors as to which items have been

considered, or have yet to be addressed or resolved.

As stated in JORC 2012 (p26), "The order and grouping of criteria in Table 1 reflects the normal systematic approach to exploration and evaluation. Criteria in Section 1 'sampling techniques and data' apply to all succeeding sections." The authors' intention is to address certain quality control aspects listed in Section 1 of Table 1 and to provide examples from graphite and vermiculite exploration projects related to:

- The nature of quality control procedures adopted (e.g., standards, blanks, duplicates, external laboratory checks) and whether acceptable levels of accuracy (i.e. lack of bias) and precision have been established; and
- the use of twinned holes.

Why QA/QC?

The 1997 Bre-X gold project scandal and consequent credibility gap in resource classifications resulted in an increased usage of Quality Assurance (QA) and Quality Control (QC) procedures in mineral exploration programmes. Publicly traded companies are now required by the Australian Securities Exchange (ASX), and other bourses, to release data that is accompanied by an outline of sampling and QA/QC procedures used during the collection and analysis of exploration samples. Many financial institutions now require an impartial audit

of geological and analytical data as part of the 'due diligence' process when raising funds for mining projects. Such audits usually include a detailed review of QA/QC procedures undertaken during exploration, including proof of accuracy and precision. A positive outcome of a QA/QC audit is the database's 'stamp of approval' and without this, all the effort put into geological modelling and resource classification is called into question. Poor QA/QC practice results in generating resource estimates 'in the dark'.

What is QA/QC?

According to the Canadian Institute of Mining, Metallurgy and Petroleum guide to Best Practice (CIM 2003, p8) QA are: "All of those planned or systematic actions necessary to provide adequate confidence in the data collection and estimation process." QC is the use of statistical tools to ensure that the systems are in statistical control. Quoting CIM Best Practice Guidelines (page 12), "QA/QC must be addressed during the collection, recording and storage of any of the data ultimately used in the MRMR estimation. This programme should be concerned with, but not limited to, data verification, drill sample recovery, sample size, sample preparation, analytical methods, the use of duplicates/blanks/standards, effects of multiple periods of data acquisition and consistency of interpretation in three dimensions. The results of

Table 1: Section 1 sampling techniques and data (excerpts from JORC 2012, p27)

Criteria	Explanation
Quality of assay data and laboratory tests	<ul style="list-style-type: none"> • The nature, quality and appropriateness of the assaying and laboratory procedures used and whether the technique is considered partial or total. • For geophysical tools, spectrometers, handheld XRF instruments, etc., the parameters used in determining the analysis including instrument make and model, reading times, calibrations factors applied and their derivation, etc. • Nature of quality control procedures adopted (e.g., standards, blanks, duplicates, external laboratory checks) and whether acceptable levels of accuracy (i.e., lack of bias) and precision have been established.
Verification of sampling and assaying	<ul style="list-style-type: none"> • The verification of significant intersections by either independent or alternative company personnel. • The use of twinned holes. • Documentation of primary data, data entry procedures, data verification, data storage (physical and electronic) protocols. • Discuss any adjustment to assay data.

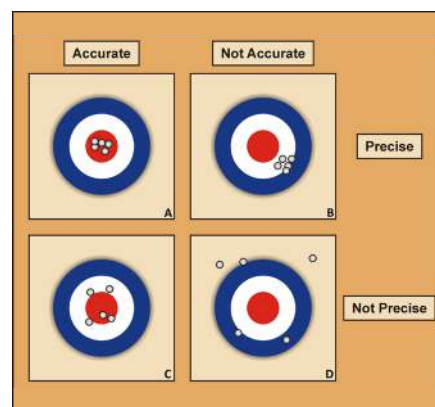


Figure 1. Dartboard example of accuracy, precision and bias.

the QA/QC programme form part of the database and must be recorded.”

As noted by Abzolov (2008) “QC procedures are necessary to monitor contamination, precision, accuracy and bias and typically involve using specially prepared standards of known grade and sample duplicates to achieve this”. Coombes (2008) corroborates this by stating that “A good QA/QC program is one that is active, ongoing and is reviewed throughout the data collection process, enabling corrective action to be taken at the drill rig, with the sampling procedures or at the laboratory.”

In summary, QA is put in place to prevent problems, while QC aims to detect them in the event that they occur.

Precision, accuracy and bias

JORC 2012, Table 1 (Section 1), mentions: “acceptable levels of accuracy (ie., lack of bias) and precision” and we need to define these terms, as errors in sample collection and analysis lead to mismatches between the population we are trying to represent and what is actually sampled. Thus, as illustrated in Figure 1, precision may be defined as the capability to be specific about a value and is measured by comparing repeat samples. Accuracy describes how close the repeat samples are to the true value, while bias measures a systematic difference between repeat samples and true value.

The classic analogy used to describe the differences between precision, accuracy and bias is throwing darts at a dartboard. If the arrows are clustered within the bull’s-eye, they show good accuracy and precision (Figure 1A) whereas if they are clustered away from the bull’s eye they show poor accuracy but good

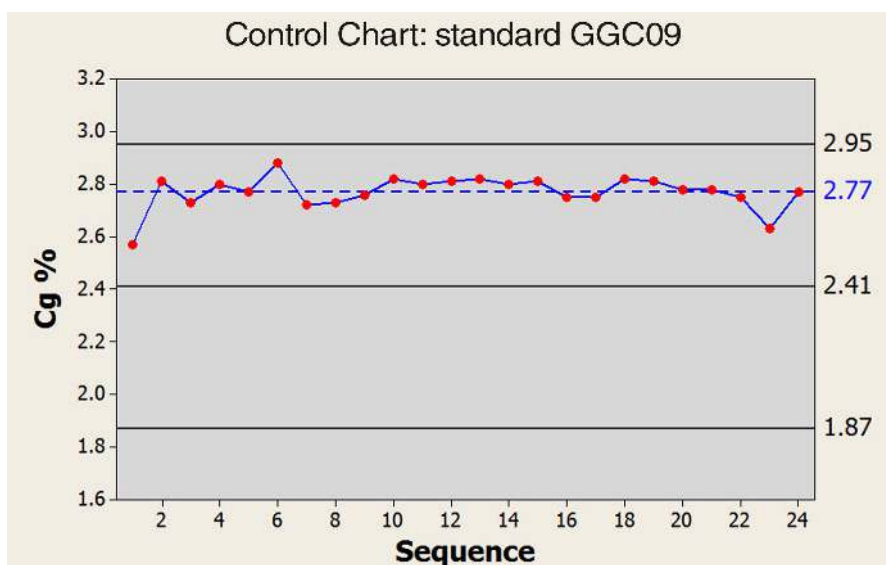


Figure 2: Graphite standard GGC09 submitted with RC and DD samples. Accepted value = 2.41 % graphitic carbon (Cg). Population mean = 2.77 %Cg.

Table 1. QA/QC Sample Insertion Rates suggested by Verly (2012)			
Sample Type	Sample sub-type	Insertion rate	
Duplicates	Field samples	2%	6%
	Coarse duplicates	2%	
	Pulp duplicates	2%	
CRMs	CRMs	6%	6%
Blanks	Coarse blanks	2%	4%
	Pulp blanks	2%	
Checks	Check (umpire) samples	4%	4%

Table 2: Summary Statistics for the African Graphite and Vermiculite Projects										
	Graphite RC & DD twins		Graphite Original & duplicate RC		Graphite Original & duplicate DD		Vermiculite Original & duplicate DD		Vermiculite Original & umpire DD	
	% Cg RC	% Cg DD	%Cg O	%Cg D	%Cg O	%Cg D	+0.71mm O	+0.71mm D	+0.71mm O	+0.71mm U
Number	79	79	22	22	24	24	143	143	46	46
Minimum	0.8	1.0	0.1	0.1	0.2	0.2	2.2	2.2	3.0	2.5
Maximum	24.9	26.3	6.8	6.8	3.9	3.8	62.6	63.7	50.5	55.7
Mean	5.2	4.9	2.9	2.8	2.2	2.2	24.7	23.3	25.4	19.5
Median	3.4	3.4	2.8	2.8	2.0	2.1	22.3	20.8	22.9	16.2
Std Dev	5.3	5.0	1.7	1.7	1.0	0.9	11.8	11.7	11.0	11.3
Variance	27.6	24.9	2.8	2.9	0.9	0.9	138.8	136.4	121.1	128.0
Coeff Var	1.0	1.0	0.6	0.6	0.4	0.4	0.5	0.5	0.4	0.6
Percentiles										
10	1.6	1.5	0.8	0.6	0.7	0.7	10.0	10.1	13.9	8.0
30	2.3	2.1	1.7	1.5	1.6	1.6	17.9	15.6	17.1	12.7
50	3.4	3.4	2.8	2.8	2.0	2.1	22.3	20.8	22.9	16.2
70	4.5	4.3	3.6	3.4	2.6	2.7	29.6	27.1	29.7	24.0
90	13.9	11.9	5.0	4.8	3.6	3.3	41.2	38.6	41.2	32.5
99	23.1	23.9	6.4	6.4	3.9	3.7	50.0	52.9	49.4	51.0

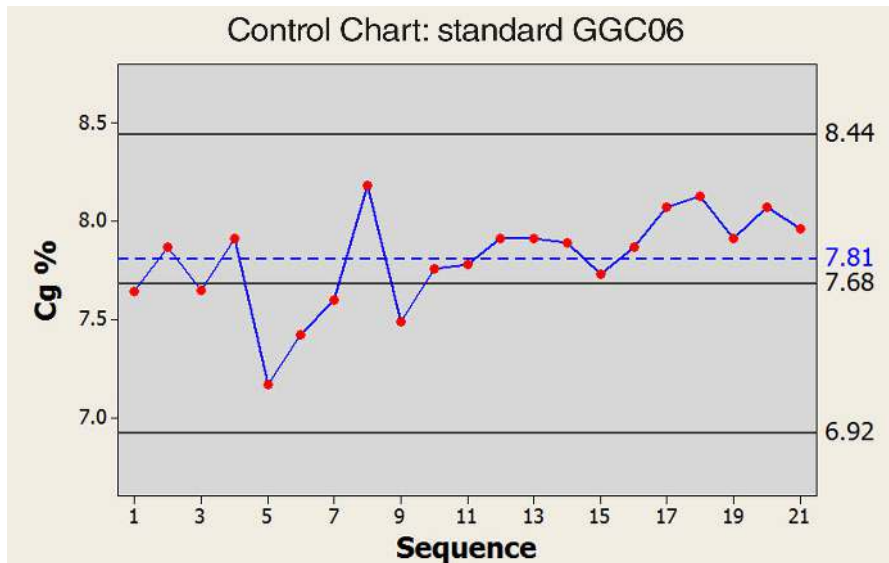


Figure 3: Graphite standard GGC06 submitted with RC and DD samples. Accepted value = 7.68 % Cg. Population mean = 7.81 %Cg.

precision and high bias (Figure 1B). In reality, samples invariably incur a degree of imprecision and inaccuracy and by using proper sampling practices it can be ensured that the errors are as small as possible. Sampling errors occur at each stage of the sampling process and the reader is referred to, i) Pierre Gy's Seven Sampling Errors and, ii) to the concept of the Fundamental Sampling Error which is the "error that remains when the sampling operation is perfect," (Pitard, 1993; Coombes, 2008).

Standards, blanks, duplicates and external laboratory checks

Standards or Certified Reference Materials (CRM) are samples of known or accepted value that are submitted to assess the accuracy of a laboratory. A systematic difference from the expected CRM result indicates a bias within or between assay batches. Standard samples may be purchased commercially or may be prepared internally and it is recommended to submit standards that span the practical range of likely assay values (e.g., % Cg) or market performance tests (e.g., bentonite fluid loss). Abzolov (2008) recommends insertion of 3-5% of the standard/s in each sample batch to identify bias, whereas Verly (2012) suggests 6% (Table 1).

Blanks are barren samples with an expected low grade (value) relative to the mineralisation being evaluated and are submitted to check for contamination during sample preparation or assaying of major and trace elements. Although blanks are commonly used during exploration for precious metals, base metals and some industrial minerals such as graphite (Cg), phosphates (P₂O₅) and potash (K₂O, MgO, NaCl), they are less likely to be used for other industrial minerals where market performance is generally more important than elemental analysis. Blanks are effectively another type of CRM, albeit with very low values of the element/s in question. Verly (2012) suggests an insertion rate of 4% blanks (Table 1).

Duplicates are samples collected, prepared and assayed in an identical manner to an original sample, to provide a measure of the total error of sampling. There are several types of duplicates possible: field duplicates are collected at the drill rig or trench, while laboratory duplicates may be produced by taking a second split after crushing, before the pulverising stage, or a third split of pulp after pulverising (e.g., 90% passing 75m).

Residues of samples may be collected at all stages of the sampling protocol. Experience suggests that so-called duplicate core samples are often not true duplicates, due to the common practice of using an 'original' 1/2 core and a 'duplicate' 1/4 core. Clearly the 1/4 core duplicate is not a duplicate as it is half the volume of the original and, furthermore, it is spatially different from the original 1/2 core. It is preferable to prepare core duplicates after the initial coarse crushing stage. Abzolov (2008) suggests that, for reliable control of sample precision, approximately 5-10% of field duplicates and 3-5% of pulp duplicates should be tested.

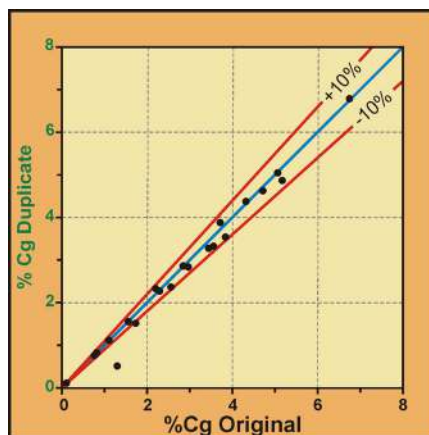


Figure 4: Scatterplot comparing % Cg in original and duplicate RC samples. Correlation coefficient = 0.99

External laboratory checks generally rely on pairs of pulverised exploration samples (also known as umpire samples) to define inter-laboratory precision and bias. It is suggested that at least 5% of samples be tested by an umpire lab.

Twinned holes

Twinned holes are specifically referred to in JORC 2012 Table 1 for the verification of sampling and assaying, and are traditionally drilled for verification of historic data or confirmation of drillhole data during geological 'due diligence' studies.

"Twinned holes are typically drilled less than 5 metres apart and are best compared according to geological units, individual samples or equal-length composites. Repeatability of analytical results and bias must be statistically quantified. Compositing of short and or variable length samples into composites of a larger size converts samples into common length data, necessary for geostatistical evaluation. In addition, grouping samples to larger composites (by geological boundary) helps to minimise the noise exhibited by individual samples," (Abzolov, 2009).

Describing populations

Geological sample populations can be described statistically e.g., mean, standard deviation, variance, percentiles (refer to Table 2) or graphically e.g. control charts, histograms, scatterplots and quantile-quantile (QQ) plots (Figures 2 to 13). A brief description of some commonly used geostatistical measures and graphical methods is shown below:

- The *mean* is the sum of the sample values divided by the number of samples.
- The *median* is the middle value when the samples are sorted in order of ascending grade.
- The *mode* is the most typical value and is typically taken as the peak in a histogram. If a histogram has two peaks the population is described as *bimodal*.
- A *percentile* describes the value below which a certain percentage of the population falls.

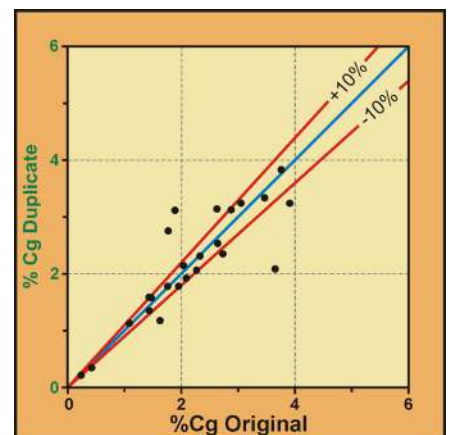


Figure 5: Scatterplot comparing % Cg in original DD (1/2 core) and duplicate DD (1/4 core) samples. Correlation coefficient 0.85

- The *variance* is the typical difference between each sample and the mean value.
- *Standard deviation* is the square root of the variance.
- *Coefficient of variation* is the variability relative to the mean value.
- *Control charts* have values plotted relative to time or sequence, so that the value measured is plotted on the Y axis and time (or sequence number) is plotted on the X axis.
- *Histograms* are useful plots for understanding and measuring population distributions.
- *Scatterplots* (X-Y plots) are useful for comparing two sets of data, for example assays of duplicate samples from Lab A against Lab B.
- *QQ plots* are another type of scatterplot in which respective percentile values are plotted against each other, which is analogous to a scatterplot of two histograms.

As the aim of this review is to focus on graphical methods used to describe sample populations, some graphical examples are presented below to illustrate the value of QC graphs in industrial mineral exploration programmes. The graphite and vermiculite data presented are from projects located in Africa.

Graphite standard samples

Two sets of standard graphite samples, namely GGC06 and GGC09, were selected to span the anticipated range of graphitic carbon. A comparison of control charts for the two standards submitted with reverse circulation (RC) and diamond drilling (DD) samples suggests a consistent response in the assaying mechanism (Figures 2 and 3). Whilst the graphitic carbon (% Cg) averages tend to be higher than the expected standard value, the assay values of the standards are within the two-standard deviation limits of control, suggesting the slight positive bias is within reason for the expectations of the standard. It was concluded from the standards that the graphite assay values are acceptable.

Graphite duplicate samples

For the project under consideration, there is no

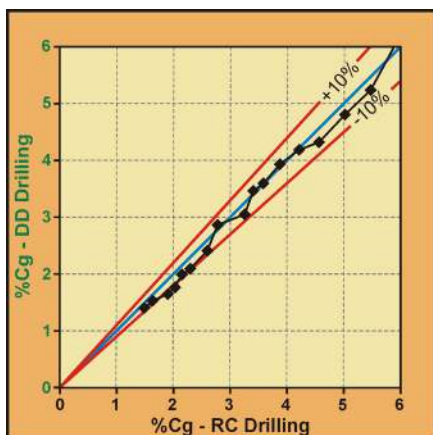


Figure 8: QQ plot comparing % graphitic carbon in twinned RC and DD holes.

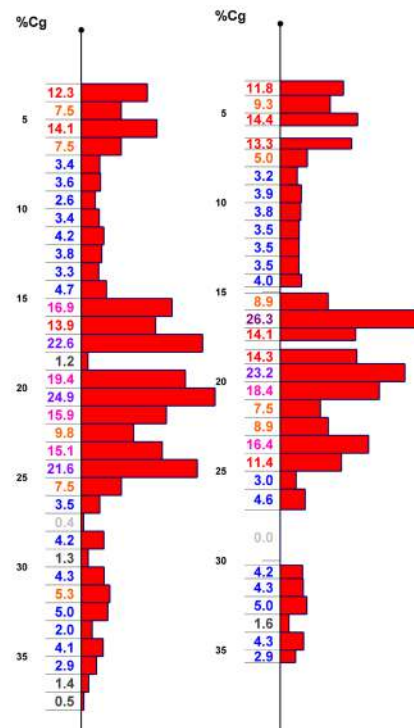


Figure 6: Comparison of twinned RC (left borehole) and DD (right borehole). % Cg assay results for samples collected at 1m intervals. Logged barren intervals in DD hole were not sampled.

significant discrepancy in graphitic carbon analyses between the duplicate and original samples for both RC and DD drilling when plotted on scatterplots (Figures 4 and 5). The RC field duplicates are well within a 10% tolerance, suggesting both good accuracy and precision from the laboratory sample preparation process for RC samples. Although 25% of the DD drilling duplicates lie outside this nominal 10% tolerance, the overall trend is around the one-to-one line, suggesting good accuracy.

As illustrated in Figure 5, the lower precision response in the DD duplicates (as reflected by the wider scatter between duplicates and original values)

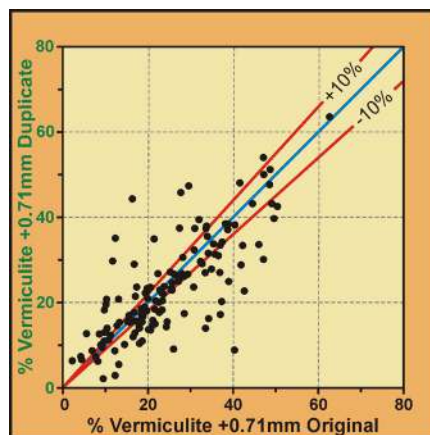


Figure 9: Scatterplot between original and duplicate vermiculite core samples. Correlation coefficient = 0.77

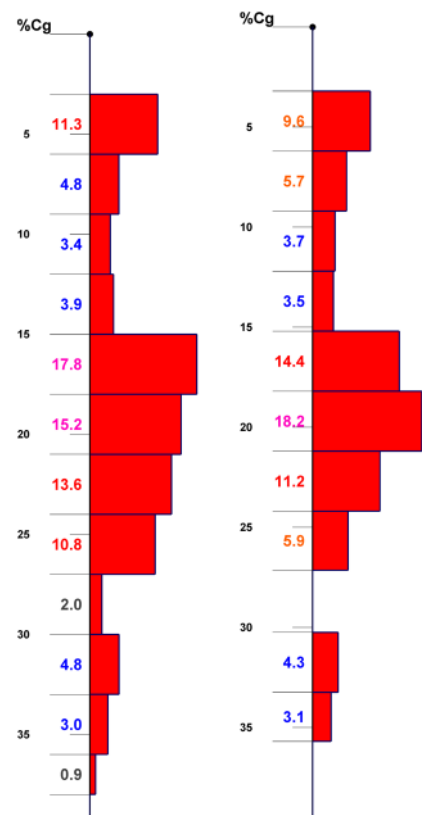


Figure 7: Comparison of RC and DD twinned assay results composited to 3 metres lengths.

may be because the original and duplicate data samples are not true duplicates, which should be an identical volume extracted simultaneously with the original sample. In this case the original sample is based on 1/2 core, whilst the duplicate is based on a 1/4 core (half of the remaining 1/2 core) of the same sample intersection, but not the identical volume and not of the identical source. The DD duplicate analysis therefore does not reflect a measure of the DD sampling process, but rather it reflects short scale variability, assuming identical geological units are included in the comparison. It was concluded that the duplicates suggest no reason to doubt the veracity of the sampling process.

Graphite twinned holes

Three pairs of twinned holes were drilled to compare % Cg in RC vs DD samples. A visual comparison of mineralised intersections in the twinned RC and DD holes suggests an overall similar representation of the mineralisation (see Figures 6 and 7 for an example of one pair) especially when the 1 metre samples are composited to 3 metre lengths to reduce noise. The similarity in assay results is evidenced in a QQ plot comparing the grade percentiles from the two data sets (Figure 8). On the basis of the similarity between the RC and DD twinned drilling results, it was concluded that RC and DD data could be combined for resource estimation purposes (% Cg only, not flake size or quality) since there is no significant bias between the twinned drillholes.

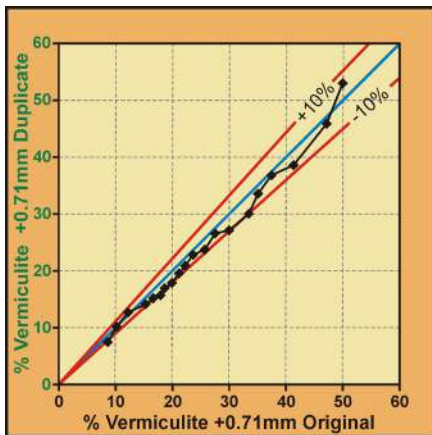


Figure 10: QQ scatterplot between original and duplicate vermiculite core samples; same data as in Figure 9.

Vermiculite duplicate samples

A comparison between 143 duplicate DD samples of vermiculite content shows a wide scatter between the original and duplicate samples (Figure 9). Although 65% of the DD drilling duplicates lie outside of the nominal 10% tolerance, the overall trend in both the scatterplot and the QQ plot is around the one-to-one line suggesting no significant bias, but poor precision. This is borne out by the average vermiculite content for each population being very similar (24.7% and 23.3% averages for the originals and duplicates, respectively).

This may very well be due to the original and duplicate data samples not being true duplicates (these should be an identical volume extracted simultaneously to the original samples). Given the highly variable vermiculite flake size (in places pegmatic), it more likely reflects the short scale variability or potential nugget effect for the intersections, assuming identical geological units are included in the comparison. The analysis of the duplicates highlights the variability in local sample values and supports the need for systematic sampling and ensuring appropriate sample size.

Vermiculite external laboratory (umpire) samples

A comparison between 46 samples from an external laboratory and the original samples show an overall difference in mean grade (19.5% and 25.4% vermiculite from the umpire and original samples

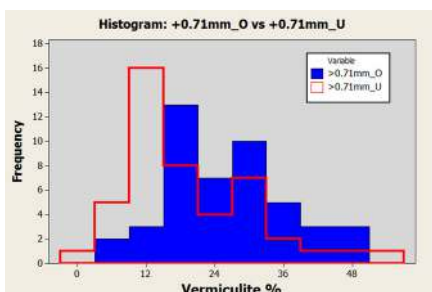


Figure 12: Histograms illustrating population distributions of original and umpire vermiculite samples; same data as in Figure 11.

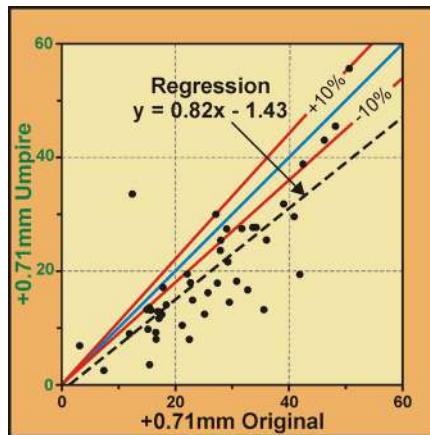


Figure 11: Scatterplot between vermiculite original and umpire samples. Correlation coefficient = 0.8.

respectively, see Table 2). A scatterplot between the check samples and corresponding original laboratory shows a significant positive bias towards the original lab (Figure 11). This bias between the sample data sets is also evident on comparative histograms (Figure 12) and a QQ plot (Figure 13). Further investigation into the bias highlighted differences in analytical procedures, with the original lab reporting vermiculite inclusive of some entrained impurities and un-exfoliated material, whereas the umpire laboratory process produced a more refined product and hence lower recoveries as is evidenced in the statistical plots. Such umpire data may be used to adjust the original data by means of regression, which is the process of fitting a line to data and applying the best-fit equation, for example $y = 0.82x + 1.43$ (Figure 11).

Conclusions

- There are some significant changes to Table 1 of JORC 2012, not least of which is the 'if not, why not' requirement for comments on QA/QC, amongst others, by the competent person.
- Publicly-traded companies are required by the ASX (and other bourses) to release data that is accompanied by an outline of sampling and QA/QC procedures used during the collection and analysis of geological exploration samples.
- QA is put in place to prevent problems, while QC aims to detect them in the event that they occur.
- QC is the use of statistical tools to monitor contamination, accuracy, precision and bias.
- A good QA/QC programme is one that is active and is reviewed throughout the data collection process, enabling corrective action to be taken.
- QC sample populations can be readily described and interpreted using graphical techniques, in addition to classical statistical methods.
- The use of standard, blank, duplicate and check samples according to modern best-practice QC procedures adds value to industrial mineral exploration programmes, whether or not the explorer is required to do so in terms of reporting codes.

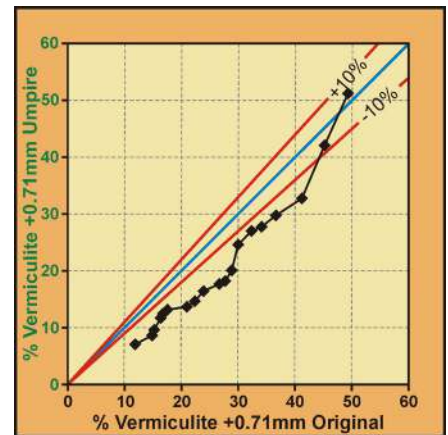


Figure 13: QQ scatterplot between original and umpire samples; same data as in Figure 11.

More than compliance with any particular code, having good control of the data quality feeds into good decision making. It is the explorer's responsibility to maintain professional standards, including the data quality that forms the basis for all subsequent decision making.

Acknowledgements

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