# Using Quality Control Data to Estimate Uncertainties in Resource Estimation

Dennis Arne

Principal Consultant – Geochemistry (Vancouver)

Matthew Cobb

Principal Consultant – Resources (Perth)

CIM Conference, Montreal, Canada, May 2, 2017

# Spot the Difference

- Huelandite = Lawsonite + Quartz + $H_2O$
  - 185+/-25$^{o}$C at 7kbar (Nitsch, 1968)
- Re-Os age of pyrite and arsenopyrite associated with gold mineralization at Bendigo, Australia
  - 438+/-6 Ma (Arne et al., 2001)
- NI43-101 published measured gold resource
  - 515,000 t @ 3.1 g/t for 51,000 oz using a 0.5 g/t cut-off

Why are there no uncertainties given for the resource estimate?

# Uncertainties in Resources

- Sampling errors
- Sub-sampling errors
- Analytical errors
- Systematic errors (bias)
- Bulk density errors
- Location errors
- Compositing errors
- Geostatistical estimation errors (kriging variance)
- Geological model errors

Fundamental sampling (random) error

These errors are cumulative!

# Outline

- Why do we do QAQC?
- How do we do QAQC?
- How to quantify accuracy and precision of assay data.
- What are acceptable results?
- Fundamental sampling errors and resource estimation.
- Conclusions

# Why do we do QAQC?

Short answer – because we have to

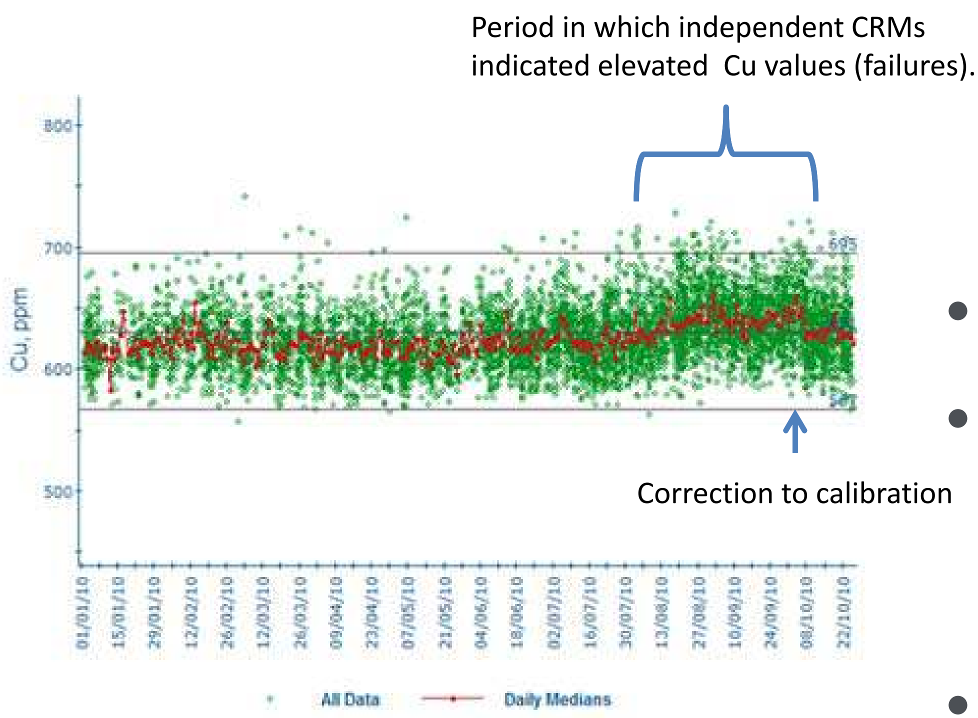
Official answer – to provide confidence in assay data

Best answer – to help minimise uncertainties in resource estimates

# How do we do QAQC?

- Certified or standard reference materials for accuracy
- Duplicates for precision (repeatability)
- Coarse blanks for cross contamination
- Check samples for systematic bias
- Note two levels of QA review – batch and project
- Apply to both assays and bulk densities

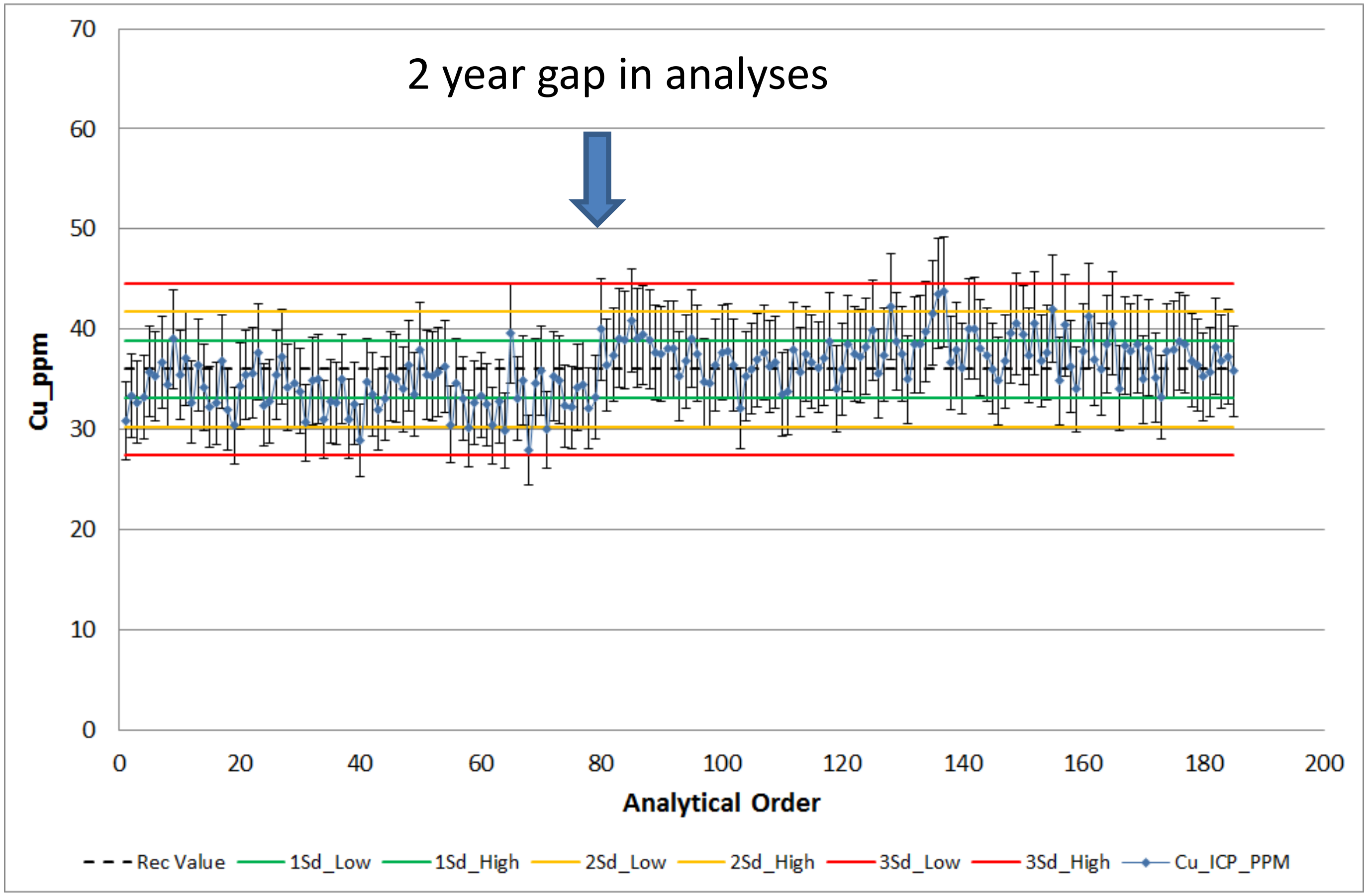
# Accuracy




CRM = certified reference material

- There are no “absolute” determinations in geochemistry – everything is a relative measurement.
- All laboratories have bias.
- Submission of blind CRMs required to independently monitor this bias.
- Biases will propagate through resources estimates unless corrected.

# Bias Shift




- Precision of any individual CRM analysis can be displayed.
- Note change in bias before and after break in analyses.

# Precision

- Many approaches have been proposed:
  - Thompson-Howarth approach (unbiased estimate)
  - Calculation of relative precision (biased estimate)
  - Geostatistical methods (variography)
  - Application of sampling theory
- No agreement in the terminology used means it’s difficult to compare data precision from one project to the next.
- Growing consensus to use the coefficient of variation (CV) as the fundamental estimate of relative precision.
  - Published ranges to benchmark against are available

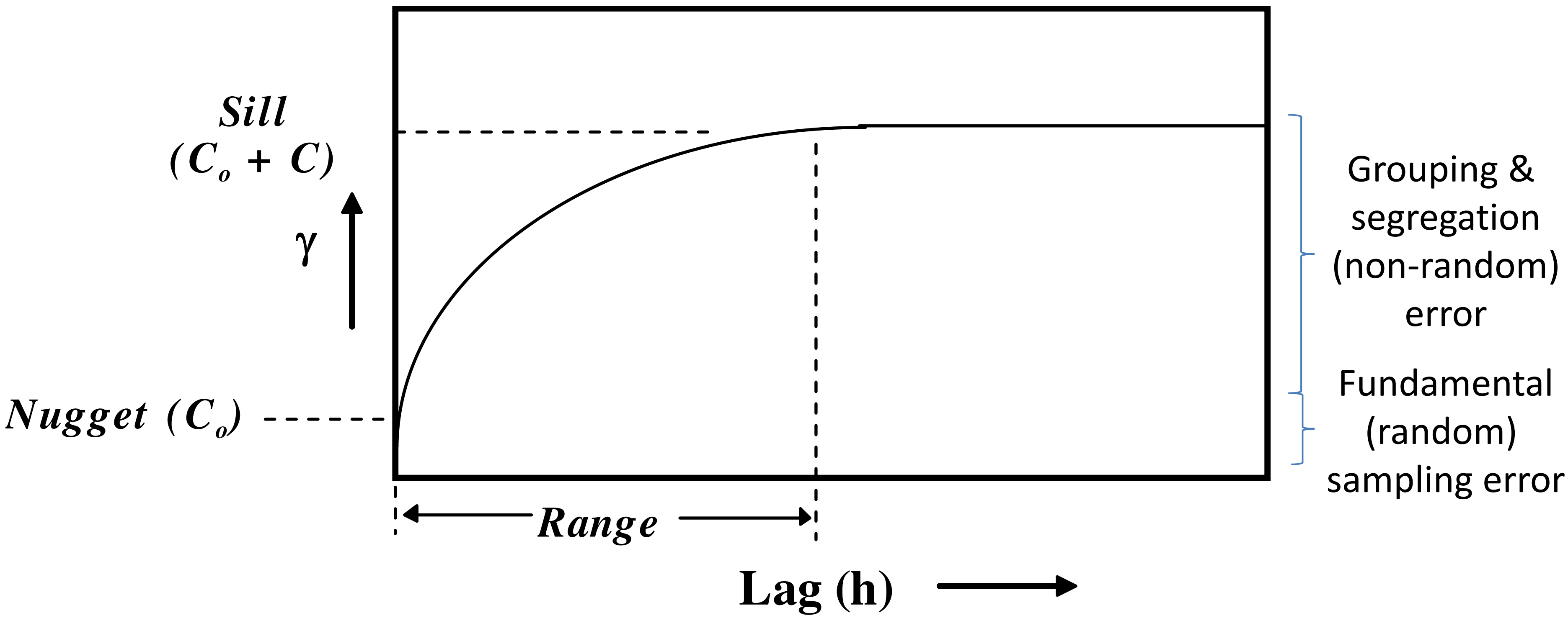
Coefficient of variation (CV) = relative standard deviation (RSD)

# Relative Precision

Table 1. List of Common Measures of Relative Error Calculated from Duplicate Pairs of Measurements and Used in a Variety of Geological Applications

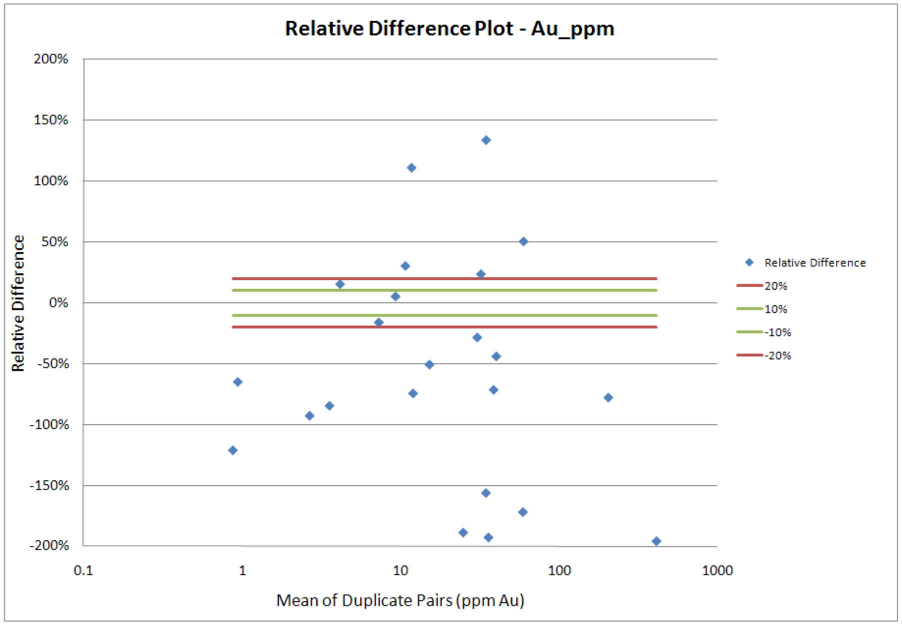
| Measurement | Conceptual Formula | Single Duplicate Pair Formula | Average Formula for Several Duplicate Pairs | Relationship with $CV$ |
|---|---|---|---|---|
| Coefficient of Variation ($CV$) | $CV = \frac{\sigma}{\mu}$ | $CV = \frac{2}{\sqrt{2}} \frac{\lvert x_1 - x_2 \rvert}{(x_1 + x_2)}$ | $\overline{CV}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

Stanley, C.R. and Lawie, D., 2007, Average relative error in geochemical determinations: Clarification, calculation and a plea for consistency. Exploration & Mining Geology, vol. 16, pp. 267-275.




The nugget, or random variance, can be estimated from core duplicates (lag ➡ 0) through regression analysis of duplicate paired analyses.

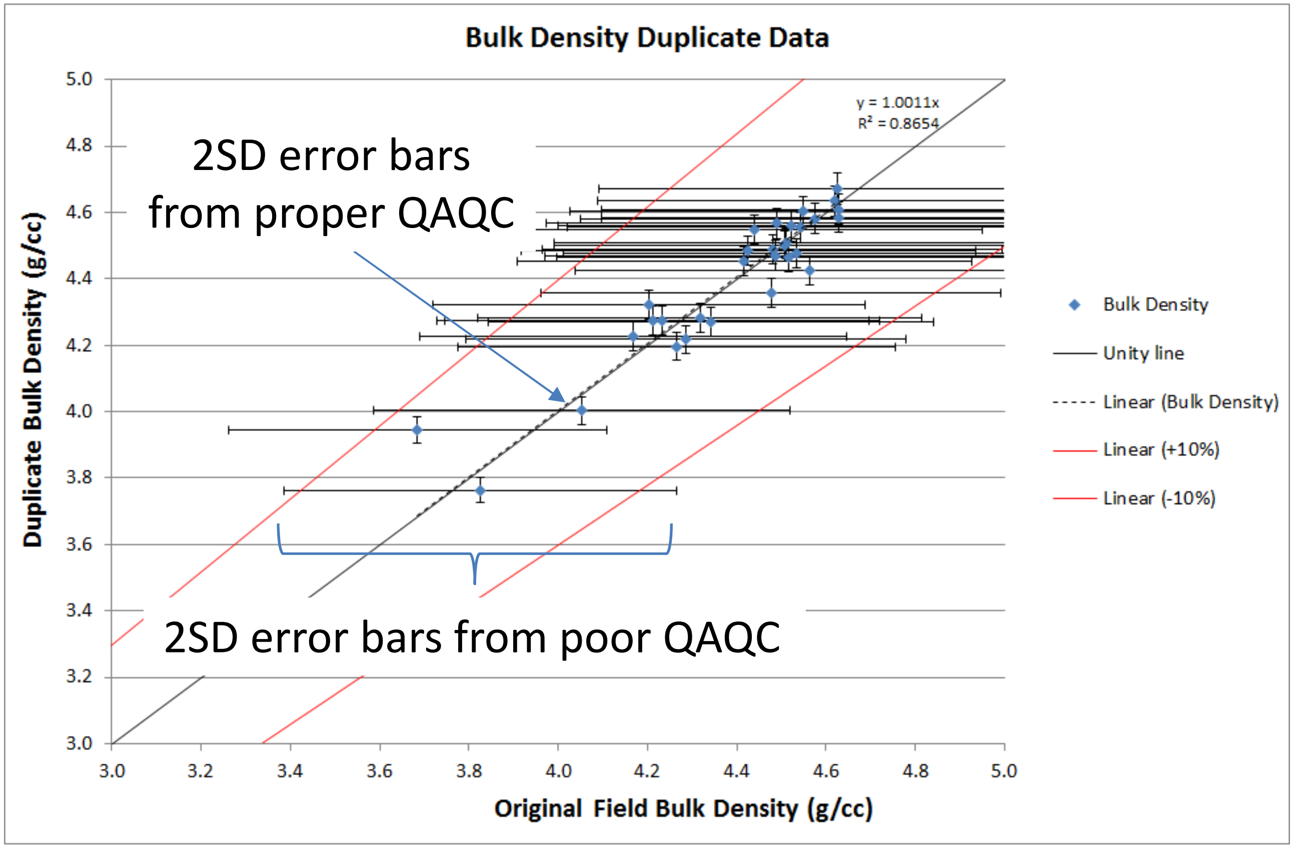
# Nuggetty Gold




Data from George NI43-101 Technical report dated 2010

- ¼ core duplicate analyses compared to original ½ core samples.
- Analyzed by 30 g fire assay.
- Unable to reproduce original assays !!!!
- Data also show a bias toward higher grades in original ½ core samples.

# Bulk Density




Poor precisions in field bulk density data carry through to tonnage estimates.

# Maximizing Precision

- Sampling theory dictates that precision is improved by:
  - Increasing sample mass
  - Decreasing particle size
  - Increasing grade
- All approaches involve increasing the number of target particles within a sample aliquot.
- Precision is <u>not</u> improved by more sample points.

Example using particulate gold in a certified reference material:

Mean Au = 16.4 ppb; **CV = 327%**; n = 78

Mean Au = 11.6 ppb; **CV = 315%**; n = 185

Certified Au value = 8 ppb

# What We Often Say

"The QAQC protocols meet current industry best practice."

"Paired field duplicate data suggest that the gold grades are difficult to reproduce by fire assay….However this trend is not uncommon in gold deposits with highly variable grades."

"In the opinion (of the QP), the data are sufficiently reliable for the purposes of resource estimation."

# What are acceptable levels of accuracy and precision?

Increasing assay data accuracy, precision and relevance

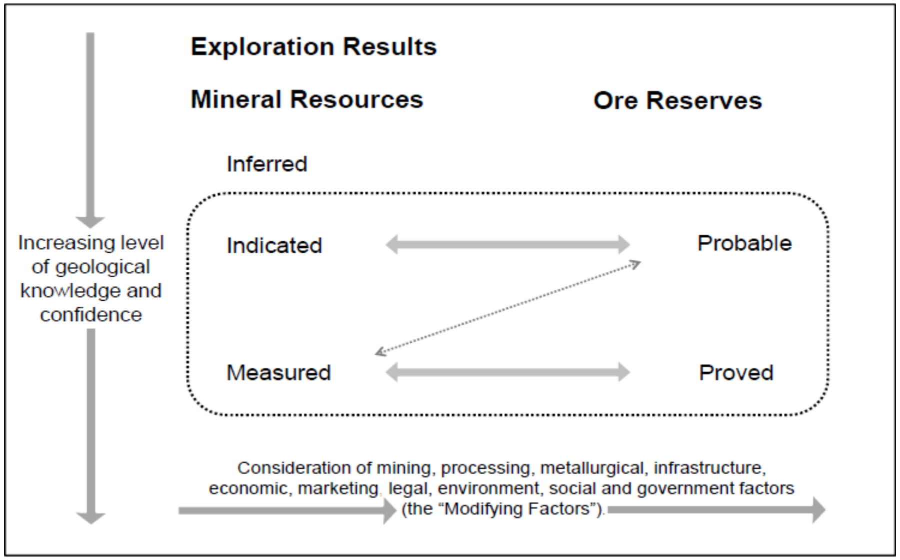
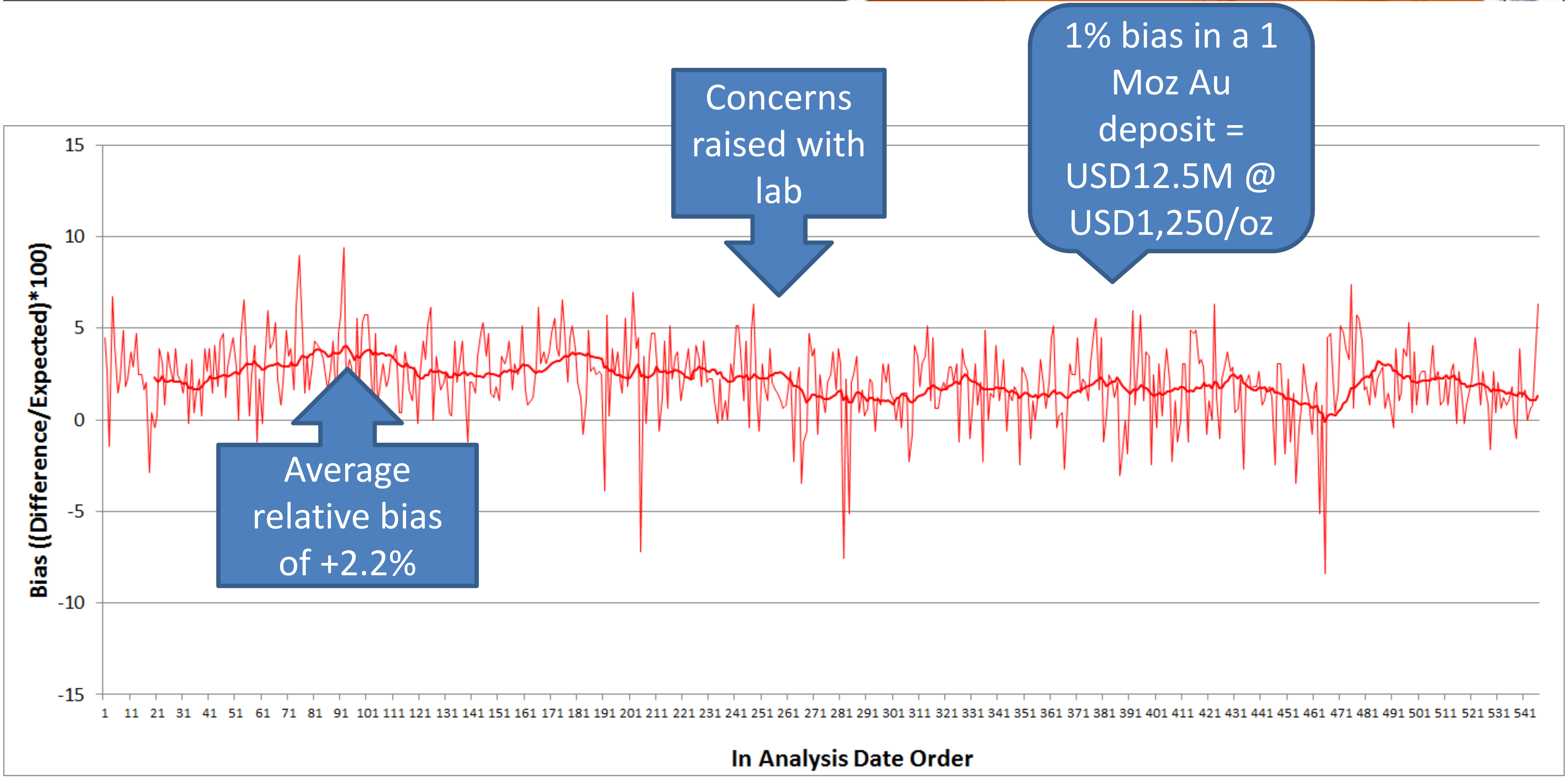



Figure 1 from JORC 2012

# Systematic Error




How much bias is acceptable at the various stages of resource estimation?

# Base/Industrial Metals

| Deposit Type | Best Practice | Acceptable Practice | Sample type |
|---|---|---|---|
| CID Iron Ore | 1 % | 3 % | Field duplicates |
| Cu-Mo porphyry Cu | 5 % | 10 % | Crusher duplicates |
| | 3 % | 10 % | Pulp duplicates |
| Cu-Mo porphyry Mo | 10 % | 15 % | Crusher duplicates |
| | 5 % | 10 % | Pulp duplicates |
| IOCG Cu | 10 % | 15 % | Crusher duplicates |
| | 5 % | 10 % | Pulp duplicates |
| Magmatic Ni | 10 % | 15% | Crusher duplicates |
| | 5 % | 10 % | Pulp duplicates |
| VMS Cu | 5 % | 10 % | Crusher duplicates |
| | 2% | 5 % | Pulp duplicates |
| Mineral sands | 5 % | 10 % | Field duplicates |

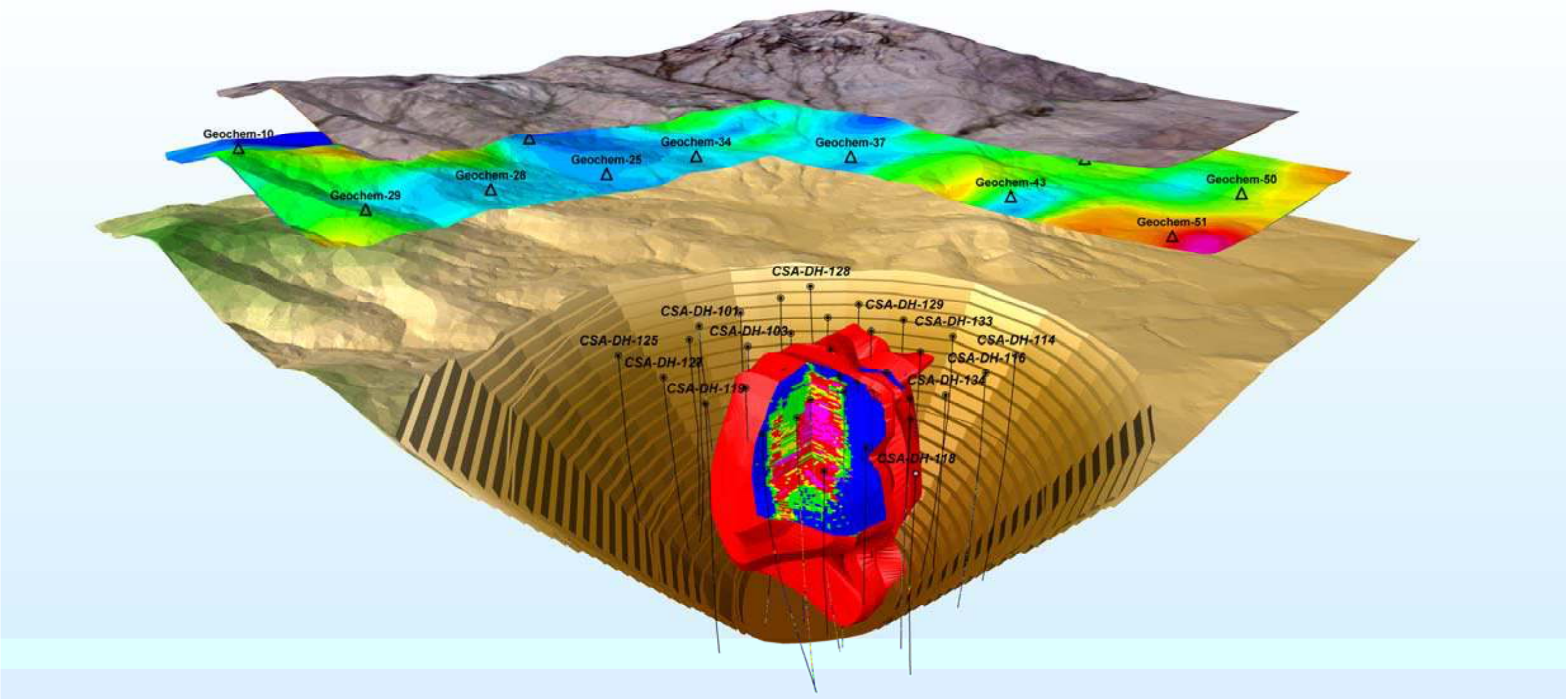
Average CV values modified from Absalov (2008, 2011).

# Precious Metals

| Deposit Type | Best Practice | Acceptable Practice | Sample type |
|---|---|---|---|
| Coarse/medium Au | 30 % | 40 % | Core duplicates |
| | 20 % | 30 % | Crusher duplicates |
| | 10 % | 20 % | Pulp duplicates |
| Cu-Mo porphyry Au | 10 % | 15 % | Crusher duplicates |
| | 5 % | 10 % | Pulp duplicates |
| IOCG Au | 15 % | 25 % | Crusher duplicates |
| | 10 % | 15 % | Pulp duplicates |
| Magmatic PGM | 20 % | 30% | Core duplicates |
| | 10 % | 20 % | Crusher duplicates |
| | 5 % | 10 % | Pulp duplicates |
| VMS Cu-Zn Au | 10% | 20 % | Crusher duplicates |
| | 5 % | 10 % | Pulp duplicates |

Average CV values modified from Absalov (2008, 2011).

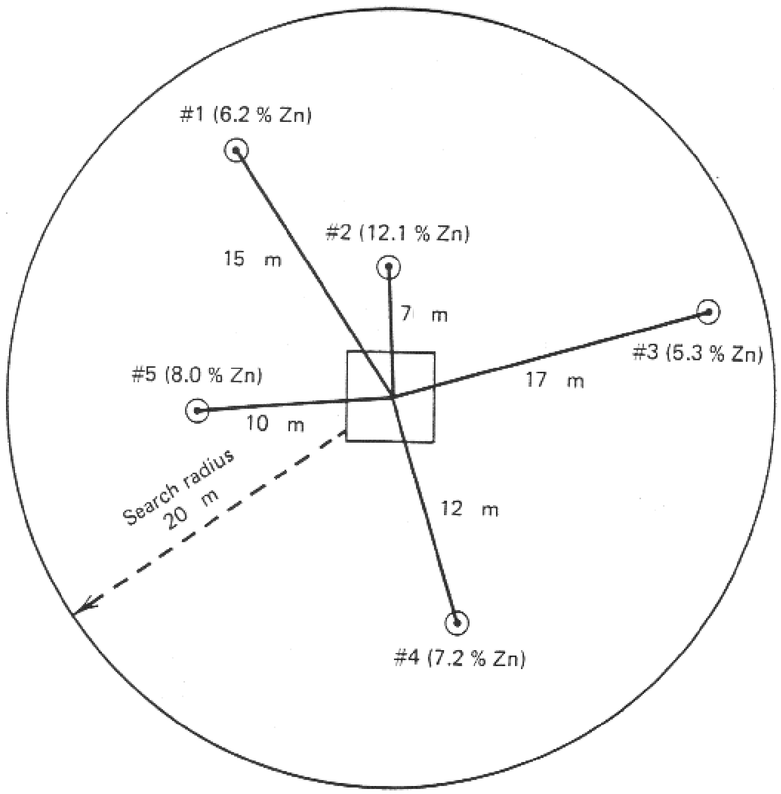
# How do errors estimated from QAQC data affect uncertainties in resource estimates?




(Image from L. McGarry, CSA Global)

# Inverse Distance Weighting

(Example modified from Peters, 1992)




$$G_b = \frac{\frac{6.2}{15} + \frac{12.1}{7} + \frac{5.3}{17} + \frac{7.2}{12} + \frac{8.0}{10}}{\frac{1}{15^2} + \frac{1}{7^2} + \frac{1}{17^2} + \frac{1}{12^2} + \frac{1}{10^2}}$$

- Samples are weighted based on distance from the centre.
- The higher the power, the lower the influence of distal samples ($ID^2$ most common).
- Classical treatments do not include the fundamental sampling errors associated with sampling, sub-sampling and analysis.

# Base Metal Example

| % Zn Grade | Precision (2SD) | Distance (m) | Weighting | Weighted Grade (%) | Weighted Variance |
|---|---|---|---|---|---|
| 6.2 | 1.24 | 15 | 0.098 | 0.61 | 0.038 |
| 12.1 | 2.42 | 7 | 0.451 | 5.46 | 0.660 |
| 5.3 | 1.06 | 17 | 0.076 | 0.41 | 0.021 |
| 7.2 | 1.44 | 12 | 0.153 | 1.11 | 0.080 |
| 8 | 1.60 | 10 | 0.221 | 1.77 | 0.141 |
| | | | **1.000** | **9.34** | **0.94** |

- Precision uncertainties assuming a CV of 10% can be calculated for the weighted grade as a relative variance.
- Final estimate for block is therefore 9.34 +/- 1.94% Zn at 2SD.

# Bulk Density Example

| Bulk Density | Precision (2SD) | Distance (m) | Weighting | Weighted BD (%) | Weighted Variance |
|---|---|---|---|---|---|
| 4.2 | 0.1176 | 15 | 0.098 | 0.41 | 0.000 |
| 4.6 | 0.1288 | 7 | 0.451 | 2.07 | 0.002 |
| 4.1 | 0.1148 | 17 | 0.076 | 0.31 | 0.000 |
| 4.4 | 0.1232 | 12 | 0.153 | 0.68 | 0.001 |
| 4.5 | 0.126 | 10 | 0.221 | 0.99 | 0.001 |
| | | | **1.000** | **4.47** | **0.004** |

- Precision uncertainties from CV (1.4%) calculated from standards can also be used for weighted bulk density.
- Final estimate at 2SD for block is therefore 4.47 +/- 0.13g/cc

# Conclusions

- A well thought out QAQC program will provide the basis for benchmarking data quality, allow correction of bias and reduces uncertainties in resource estimates.
- Set corporate quality objectives that evolve with the project; sampling & analytical protocols should be designed to meet these objectives.
- Errors are additive – they will accumulate through the work flow, beginning with sampling.
- Adding more imprecise data to a grade estimate does not reduce the fundamental sampling error.
- Quantifying uncertainties on grade and tonnage estimates will help de-risk projects.